A SYSTEM

OF

NATURAL PHILOSOPHY,

DESIGNED FOR

THE USE OF SCHOOLS AND ACADEMIES,

ON THE BASIS OF

THE BOOK OF SCIENCE BY MR. J. M. MOFFAT.

COMPRISING

MECHANICS,	PYRONOMICS,
HYDROSTATICS,	OPTICS,
HYDRAULICS,	ELECTRICITY,
PNEUMATICS,	GALVANISM,
ACOUSTICS,	MAGNETISM.

WITH EMENDATIONS, NOTES, QUESTIONS FOR EXAMINATION, LISTS OF WORKS FOR REFERENCE, SOME ADDITIONAL ILLUSTRATIONS, AND AN INDEX.

BY WALTER R. JOHNSON, A.M.

Professor of Chemistry in the Pennsylvania College, Philadelphia, and late Professor of Mechanics and Natural Philosophy in the Franklin Institute of the State of Pennsylvania, &c. &c.

ILLUSTRATED BY

MORE THAN TWO HUNDRED ENGRAVINGS.

EIGHTH EDITION.

PHILADELPHIA:

PUBLISHED BY E. C. BIDDLE.

1842.

PRINTED BY T. K. & P. G. COLLINS, PHILA.

CONTENTS.

PREFACE.
INTRODUCTION, 9.

MECHANICS.

Preliminary Observations, 17—Mobility, 18—Elasticity, 23—Velocity of Motion, 25—Different Kinds of Motion, 27—Parallelogram of Forces, 31—Gravitation, 36—Accelerated Motion, 47—Curvilinear Motion, 53—Oscillation of the Pendulum, 59—Centre of Gravity, 65—Mechanic Powers, 72—Lever, 74—Wheel and Axle, 83—Machine of Oblique Action, 87—Pulley, 89—Inclined Plane, 91—Wedge, 93—Screw, 94—Compound Machinery, 98—Friction, 108—Rigidity of Cordage, 111—Strength of Materials, 112—Moving Powers, 113—Works on Mechanics, 121.

HYDROSTATICS.

Preliminary Remarks, 122—Properties of Liquids, 123—Hydrostatic Pressure, 129—Specific Gravity, 147—Capillary Attraction, 162—Works on Hydrostatics, 165—HYDRAULICS, 166—Hydraulic Machines, 172—Works on Hydraulics, 179.

PNEUMATICS.

General Observations, 179—Common Properties of aerial Fluids, 181—Different Kinds of Airs, 183—Elasticity of Air, 185—Weight of Air, 196—Pneumatic Instruments and Experiments, 199—AEROSTATICS, 218—Air-balloon, 221—Parachute, 223—Paper-kite, 226—Diving-bell, 227—Torpedo, 230—Works on Pneumatics, 230.

ACOUSTICS

Cause of Sound, 231—Sonorous Vibrations, 233—Velocity of Sound, 238—Musical Sounds, 242—Musical Scale, 246—Musical Instruments, 254—Human Voice, 262—Reflection of Sound, 266—Echoes, 267—Ventriloquism, 273—Works on Acoustics, 276.

PYRONOMICS.

Causes of Heat and Cold, 277—Sources of Heat, 280—Effects of Heat, 288—Instruments for measuring Temperature, 292—Latent Heat, 303—Ebullition, 309—Steam-engine, 313—Propagation of Heat, 320—Caloric Engine, 323—Works on Heat, 332.

OPTICS.

Observations on Light and Vision, 333—CATOPTRICS, 347—Effects of Plain Mirrors, 348—Atmospheric Reflection, 351—Convex Mirrors, 354—Concave Mirrors, 358—DIOPTRICS, 362—Optical Lenses, 368—Organs of Vision, 373—Theory of Vision, 375—CHROMATICS, 384—Chromatic Refraction, 387—Rainbow, 395—Varieties of optical Instruments, 407—Spectacles, 407—Microscopes, 411—Telescopes, 412—Double Refraction and Polarization of Light, 413—Works on Optics, 417

ELECTRICITY.

Miscellaneous Observations, 418—Theory of Electricity, 421—Conductors and Non-conductors, 425—Induction, 427—Electrical Instruments and Experiments, 429—Electro-galvanism—Electro-magnetism, 451—Terrestrial Magnetism, 459—Variation of the Compass, 461—Works on Electricity, 462—Index, 463.

PREFACE.

The extensive adoption in the United States of that system of education which regards *useful knowledge* as indispensable to a *useful life*, necessarily calls for the preparation of treatises adapted to the requisitions of those who are to *impart* as well as to the wants of those who are to receive such knowledge. Not only are elementary works demanded, but they must occasionally be remodelled with a view to the advancement of the sciences to which they relate. To adhere pertinaciously to the text books of the last century would be to do equal injustice to the state of education and to the progress of human knowledge. To suppose that the labours of the learned have, within the last *quarter* of a century, resulted in no modifications of elementary laws, as enunciated at the *beginning* of that period, would be to contradict the plainest evidence of daily observation. The physical sciences have, within this period, enjoyed a most vigorous growth. Not content with the bare discovery of a law and the enunciation of it as among the maxims hereafter to be received as *truth*, the views of men of science have become habitually directed to the harmonizing of the known and received laws, into more general and comprehensive expressions of nature's vast designs. By this course of proceeding, the mind is not only enabled to embrace wider ranges of thought, and more rational speculative views in *each department* or branch of science, but in several instances to include under one department the facts and phenomena previously regarded as constituting several distinct sciences. Thus while the inductive labours of Galvani and Volta laid the foundation, as *they* (and as all the world) supposed, for a *new science*, the recent researches of philosophers have wellnigh resolved not only *that*, but two or three other sciences into one general principle of action, variously manifested according to the circumstances of each particular case. While this process of enlarging and clearing the views of men in regard to general truths in science has been advancing, there has been a constant and zealous vigilance displayed in reference to the practical applications of knowledge to the great physical and social purposes of man. These purposes can be fully subserved, only by keeping the public mind apprized of all the important steps taken in the advancement of those sciences which are susceptible of a practical application. Natural Philosophy, Chemistry, and several branches of Natural History, are, of all departments of human knowledge, those which have most engaged the attention of modern philosophers; and it is with a view to the present state and the useful employment of these sciences, that the publishers of the Scientific Class Book have sought to furnish the schools and academies, no less than the private students of the United States, with an appropriate and eligible manual.

In selecting for the basis of such a manual the text of Mr. Moffatt, it was with the full understanding that in order to be adapted to the purposes of instruction here it must be somewhat varied from its English dress. Some inaccuracies in the statement of facts and principles were easily perceived; some grave errors in regard to persons, places, and things, especially in this country, were at once discovered, a number of important discoveries and inventions due to the citizens of the United States were wholly overlooked; several long notes in Latin not likely to interest the young reader had been introduced; the allusions to local objects and occurrences which pervaded the work seemed to require more oral explanation than the student in any other place than *London* was likely to receive; the puerile cuts which headed the chapters in the English editions, and which have conveyed to many persons the idea that the compilation was intended for very young children, were conceived to be less useful than some additional figures illustrating the topics treated in the work. In the above-mentioned particulars, the work was thought to require *emendation.*

But as the several treatises appeared *in the main* to have been compiled with a view to the best authorities, as well as in a style sufficiently simple and perspicuous to warrant an attempt to adapt it to the purposes here intended, the publishers were induced to believe that they could not offer to teachers and students a more acceptable addition to the means of instruction than the work now presented for their consideration.

The general practice of introducing into class-books questions for examination is so well established as to need little comment. Yet not every kind of questions can render a text-book more valuable than it would be without them. It has been the aim of the editor so to execute this part of his duty, as to lead the student into habits of reflection on the true nature and bearings of the subject before him, not to confine his attention while answering the queries merely to certain words of the text ;—to excite the industry of the pupil, rather than increase the labour of the teacher ;—to enable the student to rise from his task with clearer conceptions of things, than he enjoyed before attempting to answer these questions, not to deceive either himself, his teacher, or others, by a show of knowledge which he does not possess. In some cases hints and suggestions are conveyed by the same means, and the application of certain terms not contained in the body of the work, will be easily understood from the manner in which they are introduced into the questions. The answers will occasionally be inferences and deductions, generally easy to be made, from the facts and principles contained in the text. In these cases the mind will, it is conceived, find a more pleasing and profitable exercise than in the mere repetition of statements found on the page to which these questions refer.

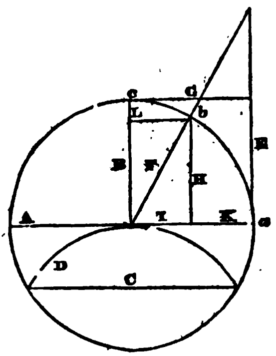
At the end of every important division of the subject is presented a list of such works as may be found useful to those who desire to prosecute particular inquiries relating to the part immediately preceding. A few works in foreign languages are included in the number, and as the French language in particular is now so extensively *read* at least among teachers, it is believed that references to them will by no means prove useless. The index will, it is hoped, prove entirely adequate to the purpose which it is designed to subserve.

In conclusion it may be observed that, whatever merit may be claimed for other treatises on the same departments of science, it is confidently anticipated that this will be found to embrace as full and satisfactory a view of the subject which it proposes to treat, as any similar compilation, which has hitherto been dedicated to the service of American youth. In this hope the publishers respectfully submit it to the consideration of the reader.

☞ The publisher has deemed it advisable to adopt a new title for this book, setting forth more clearly the particular branches of science of which it treats, and this change is rendered expedient by the further consideration that there is another work of a totally different character published in this country, called the Scientific Class Book.

INTRODUCTION.

1. Among the several distinctions which have been made in human knowledge, those of most importance to be noticed in the commencement of the present work, regard the discrimination between the mathematical and the physical sciences. The latter are so far dependent on the former, that some knowledge of mathematics is absolutely necessary, previously to entering to any extent on the study of physical or natural philosophy. A general acquaintance with at least the elementary branches of mathematics, as arithmetic, geometry, and trigonometry, may be expected to have been acquired by all tolerably well educated persons, as usually forming a part of a common school education. Physical science, or natural philosophy, constitutes the exclusive object of the present volume, in order to the perusal of which, with profit and advantage, it will be requisite that the reader should not be ignorant of the names and general properties of geometrical lines and figures. The following diagram and explanatory observations are therefore introduced, as they may be useful to those who are but slightly acquainted with mathematics, and may sometimes save the better informed student the trouble of referring to other books for information, respecting the signification of particular terms.



A a Circle.
A *a* its Diameter.
B the Radius.
C a Chord.
D an Arc.
E a Tangent.
F a Secant.
G a Co-tangent.
H the Sine of Arc *a b*.
I the Co-sine.
K the Versed Sine.
L the Sine of complemental Arc *b c*.

2. Every circle is supposed to be divided into 360 degrees, and the line which bounds the circle, and on which therefore these degrees may be marked, is called its circumference. Any lines equidistant from each other throughout their whole extent

Describe the several parts of the diagram represented in the margin.
Into how many degrees is a circle supposed to be divided?
What are parallel lines?

are termed parallel lines. Two lines not parallel but in the same plane must, if sufficiently produced, meet in a point, which is called an angle. Angles are principally distinguished by the relative inclinations of the lines by which they are formed. When one line meets or crosses another perpendicularly, the angles they form are called right angles; and any angle smaller than a right angle, is styled an acute angle, and any greater an obtuse angle. But angles are more precisely measured by reference to the number of degrees contained in an arc of a circle joining the two lines by which an angle is formed. Thus a right angle must be included within an arc of a circle equal to a quadrant, or the fourth part of 360 degrees, namely, 90 degrees; and an acute angle included within an arc only half the extent of a quadrant will, of course, be an angle of 45 degrees.

3. A space or flat surface, inclosed by three lines, is the most simple of all definite figures, and is called a triangle. Among the varieties of these figures are the rectangular triangle, so named because it has one right angle; the equilateral triangle, which has three sides of equal extent; the isosceles triangle, which has only two equal sides; and the scalene triangle, all the sides of which are of different lengths. Any space inclosed by four lines is called a quadrilateral, or four-sided figure. Among such are included the square, having four equal sides and right angles; the rectangle, or oblong square, having only the opposite sides equal; the lozenge, which has equal sides and unequal angles; and the trapezium, which has only two of its sides parallel. When the sides of a quadrilateral figure are parallel, it is termed a parallelogram. A line joining two opposite or alternate angles, is called a diagonal. Any figure having several angles, and consequently several sides, is named a polygon.

4. Solid figures include the tetraedron, or four-sided solid, which is the most simple figure of the kind, as no solid can have less than four sides; and when the number of sides is greater, the figure is called either a hexaedron, an octaedron, an icosaedron, or a polyedron, according to the number of its sides.

5. Among polyedrons may be distinguished the prism, formed

What constitutes an angle?
By what names are different angles distinguished?
How are they accurately measured?
How many degrees of a circle are contained in a right angle?
What is the most simple definite figure?
What is a rectangular triangle? an equilateral triangle? an isosceles triangle? a scalene triangle?
What is a four-sided figure called?
Describe some of the figures that come under this denomination.
What is a diagonal?
What is a polygon?
What is the most simple of solid figures?
How many sides has a hexagon?
How many an octagon? an icosaedron and a polyedron?
Of what form is a prism?

of parallelograms only, or of parallelograms and two polygons of any number of sides. Among the prisms may be specified the parallelopiped, formed of six parallelograms only; and among the parallelopipeds may be noticed the cube, having six square sides. The pyramid is a polyedron, formed by a polygon of any kind as its base, and as many triangular planes as the polygon has sides: the point where all the triangular planes unite is called the summit of the pyramid. The most simple solid of this kind is the tetraedron, or four-sided pyramid, including the base.

6. The terms sphere, cylinder, and cone, designate solid figures, having either entirely or partially curved surfaces; and the expressions spheriod, cylindroid, and conoid, are used to denote solid figures, more or less resembling a sphere, a cylinder, or a cone, respectively.

Natural Philosophy is the science which explains the causes of the various properties of bodies in general, as shown by the changes which they undergo in any particular circumstances, or the changes which they may occasion in other bodies, under certain circumstances. The province of natural philosophy does not extend to the explanation of the doctrine of final causes, or the immediate and positive reasons why particular effects take place, or why certain bodies possess the peculiar properties with which they are endowed; but it enables us to appreciate the consequences of any body being placed in a given situation, or to foretel what will be result of any body acting on another in a certain manner.

7. Thus, we know nothing of the absolute cause of gravity or weight, which is that property of bodies in consequence of which they fall towards the surface of the earth, if raised in the air by any force and then dropped; but natural philosophy, while it leaves us in ignorance of the final cause of gravity, enables us to determine a vast variety of curious circumstances with respect to falling bodies. Thus, it is found that a heavy body, as for instance a marble or a musket-ball, dropped from a high tower, would fall faster as it approached near to the ground than it would in passing through the former part of its descent; and the rate at which a body falls through a given space has been ascer-

How is the parallelopiped formed?

How many sides has a cube?

How is a pyramid formed?

Where is the *summit* of a pyramid?

What is the most simple solid of this kind?

What kind of figures are designated by the terms sphere, cylinder, and cone?

How are those figures denominated that more or less resemble these figures?

What is Natural Philosophy?

What are some of the doctrines beyond the explanation of Natural Philosophy.

What is there in the subject of *gravity* which is inexplicable by natural philosophy, and what does this science enable us to determine respecting it?

tained by experiment, and can be calculated with the utmost exactness. So as to the final cause of electric and magnetic attraction various opinions have been advanced, and it is still involved in obscurity; but we know by experience that a magnet attracts iron with considerable force, and that a thin bar of magnetic iron, accurately poised on its centre, will, when left free, point towards the north with one end, and towards the south with the other; and on the latter property depends the action of the mariner's compass, by means of which the sailor, crossing the pathless sea, is able to ascertain in what direction his vessel is steering; and to this little instrument, which was unknown to the ancients, we are in a great degree indebted for the important discoveries of modern navigators.

8. Whether light and heat are owing to matter or motion has been left among the questions which philosophy has hitherto been unable satisfactorily to decide; but the effect of light on bodies, whether opaque, transparent, or semi-transparent, the velocity with which it passes through space, and the manner in which it is modified by optical glasses of various forms, are among the numerous interesting and surprising properties of light, which natural philosophy has laid open to our investigation, and which we are enabled to verify and illustrate by means of mathematical calculation; and the phenomena of heat and cold, with which we are so intimately familiar, from the sensations they occasion, are equally hidden as to their final cause, and equally wonderful and curious as to their effects, the latter of which alone afford an ample field for the experiments and deductions of the philosophical inquirer.

9. Astronomy presents a boundless field for research, and notwithstanding it has been explored with signal success in modern times, yet the most important discoveries that have been made only serve most distinctly to evince that the wisest and most successful investigators of the phenomena of the science have merely entered on the confines of knowledge, and enabled us to form some imperfect estimate of those boundless regions which display an inexhaustible field for future speculation and inquiry. It has indeed been ascertained that the sun and the planetary and other bodies which constitute the solar system, are influenced by the same moving power as that which causes the fall of an acorn to the ground, when detached from the oak on which it was pro-

What has experience taught respecting magnetic and electric attraction?

What question respecting the nature of light and heat has been hitherto undecided by philosophy?

What are some of the properties of light which natural philosophy has laid open to our investigation, and how are these to be verified?

In regard to heat, what points are known and what unknown?

What conclusions have been drawn from the most successful investigations in astronomical science?

What has been ascertained to be the moving power that influences the bodies of the solar system?

duced; and that the attractive force which retains the moon in her orbit, and causes her reaction on the fluid parts of the terrestrial globe we inhabit, producing the tides, may be estimated with accuracy, and subjected to mathematical calculation. But there are numberless topics of inquiry—with regard to the constitution of the sun, the nature of comets, and the causes of their peculiar motions, the kind of medium which occupies the space beyond the atmospheres of the earth and planets, and the relations that may exist between our solar system and the numberless other systems, the existence of which may be inferred from the appearance of the starry heavens—which may for an indefinite period serve to exercise the talents of men of genius and learning, but concerning which we can hardly hope to attain any knowledge approaching to certainty, till discoveries and inventions in other sciences provide us with means for investigating the works of nature, as much superior to those which we at present possess, as our instruments of research surpass those employed by the ancients.

10. "The proper business of philosophical inquiry," says Leslie, "is to study carefully the appearances that successively emerge, and trace their mutual relations. All our knowledge of external objects being derived through the medium of the senses, there are only two ways of investigating physical facts—by *observation* or *experiment*. Observation is confined to the close investigation and attentive examination of the phenomena which arise in the course of nature; but experiment consists in a sort of artificial selection and combination of circumstances, for the purpose of searching minutely after the different results.

11. "The range of observation is limited by the position of the spectator, who can seldom expect to follow nature through her winding and intricate paths. Those observations are of the most value which include the relations of time and space, and derive greater nicety from their comprising a multiplied recurrence of the same events. Hence Astronomy has attained a much higher degree of perfection than the other physical sciences.

12. "Experiment is a more efficient mean than observation for exploring the secrets of nature. It requires no constant fatigue of watching, but comes in a great measure under the control of the inquirer, who may often at will either hasten or delay the expected event. Though the peculiar boast of modern times, yet the method

What is the effect of this force upon the moon, and indirectly upon the earth? How are these effects to be estimated?

What subjects of inquiry in astronomical science, are supposed to lie beyond our present means of investigation?

What does Leslie affirm to be the proper business of philosophical inquiry?

What are the only two methods of investigating physical facts, and what is the province of each?

What circumstance limits the range of observation?

What observations are of most value?

Which is the more efficient means of exploring the secrets of nature?

of proceeding by experiment was not wholly unknown to the ancients, who seem to have concealed their notions of it under the veil of allegory. *Proteus* signified the mutable and changing forms of material objects; and the inquisitive philosopher was counselled by the poets to watch that slippery dæmon when slumbering on the shore, to bind him, and compel the reluctant captive to reveal his secrets.* This gives a lively picture of the cautious and intrepid advances of the skilful experimenter. He tries to confine the working of nature—he endeavours to distinguish the several principles of action—he seeks to concentrate the predominant agent—and labours to exclude as much as possible every disturbing influence. By all these united precautions, a conclusion is obtained nearly unmixed, and not confused, as in the ordinary train of circumstances, by a variety of intermingled effects. The operation of each distinct cause is hence severally developed."†

13. The object of Natural Philosophy may be stated to be the study of the general properties of unorganized bodies, or inert substances in the state of *solids*, *liquids*, *airs*, or *gases*, and those which have been termed *incoercible* or *ethereal fluids*. It is also within the province of the physical sciences to examine the mechanical action which bodies, in their different states, may exercise on each other, and the different circumstances connected with their movements.

14. The various effects of the motions and operations of bodies depending on their general properties have hence been made the foundation of several distinct sciences or branches of knowledge, which have been usually classed with reference to the several forms of matter called solids, liquids, and airs, or to certain kinds of phenomena, supposed to depend respectively on the presence and action of some imponderable modification of matter or ethereal fluid, to which have been referred thermometrical, optical, electrical, and magnetic phenomena. Hence a treatise on Natural Philosophy may be conveniently arranged under the different departments of (1.) MECHANICS, or the doctrine of equilibrium and motion as respects solids, including Statics and Phoronomics or Dynamics; (2.) HYDROSTATICS, including Hydrodynamics or Hydraulics, relating to the equilibrium and motion of liquids; (3.) PNEUMATICS, including Aerostatics, and Aerodynamics, or the effect of forces on air and other gaseous fluids; (4.) ACOUSTICS, or the theory of sound, comprehending observations on musical and vocal sounds; (5.) PYRONOMICS, or the investigation of the causes and effects of heat, or more generally of change of temperature;

What is the object of Natural Philosophy?
How have its divisions been formed?
What are the different departments under which a treatise on Natural Philosophy may be properly arranged?
Of what does each of these departments treat?

---

* V. Virgil. Georgic. lib. iv.
† Introduction to Elements of Natural Philosophy.

(6.) PHOTONOMICS or OPTICS, including the theory of light and vision; (7.) ELECTRO-MAGNETISM, which treats of the causes of electric and magnetic attraction and repulsion.

15. The idea of *absolute* or *indefinite space* is obtained by abstraction, or conceiving in imagination the absence of all bodies, or of all the properties of matter. Every part of this space, or rather of this imaginary void or vacuum, which can be conceived to be included in any way between limits, is called *relative space*. The term *body* is used to designate limited extension, to which are attached any of the properties of matter. That which distinguishes in general a simply extended body from a void space or vacuum, is the property of impenetrability, that is, the quality in consequence of which a body occupies a certain space, and excludes from it all other bodies.

16. We acquire a knowledge of the properties of matter through our senses, either by immediate observation, or by experimental inquiry with the aid of instruments. The senses of sight and feeling afford us abundance of information concerning the properties of bodies around us, but our knowledge may be vastly extended when we assist the former by means of optical glasses, which open new worlds to our view, or when by means of delicate instruments we measure degrees of temperature, electricity, or magnetic power.

17. Solid bodies are those which, like stone or wood, present a sensible resistance when touched, pressed, or handled. They may be cut into various forms, and preserve without difficulty the figures which are given to them, or which they possess naturally. Sand, powders, and similar substances consist of small particles not united together; yet though, collectively, masses of sand present but little resistance to pressure, the individual minute particles have all the characteristics of solid matter, and though readily dispersed by force, they may be assembled in heaps more or less considerable.

18. Liquid substances are those which, like water, manifest immediately to the touch but a very feeble resistance, but quite sufficient to indicate their presence, even when in a state of repose. They cannot be grasped between the fingers like solid bodies, nor can they be collected in heaps, or made to take any particular figure, except that of the vessel in which they may be included.

19. Aeriform fluids are in general invisible bodies, which like the air surrounding us cannot be felt, and afford no evidence of their presence to the sense of touch when in repose. But their existence is ascertained with abundant certainty when they are in motion: thus no one can doubt the materiality of atmospheric air after

How do you obtain an idea of *absolute* or *infinite* space?
What is relative space?
What is meant by the term *body*?
What is the property of impenetrability?
By what means do we acquire a knowledge of the properties of matter?
What are *solid* bodies? liquid substances? aeriform fluids?

experiencing the violent exertion necessary in walking against a high wind. Aëriform bodies may be confined in vessels, whence they exclude liquids or other bodies, demonstrating their impenetrability, though they readily become compressible to a great extent, but there are limits beyond which it is impossible to reduce them.

20. Incoercible or imponderable fluids do not manifest their existence by the exhibition of impenetrability or weight, which have usually been regarded as essential properties of matter; and they must, therefore, be considered as hypothetically admitted, in order to account for certain phenomena, which appear to depend on the presence and action of one or more ethereal media.—That light is such an imponderable fluid, emanating from the sun, was one of the generally received doctrines of the Newtonian Philosophy; the caloric or matter of heat of the French chemists was supposed to be a fluid of a similar nature; and men of science who have written concerning magnetism and electricity have vaguely employed the terms magnetic fluid and electric fluid to designate the unknown causes of the phenomena they describe.[1]

21. At present it is perhaps the more prevalent opinion of philosophic inquirers that there exists at least one kind of ethereal, imponderable medium, the different modifications and modes of action of which give rise to the various phenomena of light, heat, and electro-magnetic attraction and repulsion. Thus it may be supposed that as sound is conveyed to our ears by the vibrations of the air, so light affects our eyes through the immensely more rapid vibrations of the electro-luminous ether. The existence of such a medium, manifesting neither weight nor impenetrability capable of being appreciated by the most delicate instruments, may be fairly inferred from the movements which take place in bodies under certain circumstances when all the ponderable and coercible kinds of matter have been carefully excluded, and these movements therefore must be ascribed to the presence of an ethereal influence, which can penetrate glass and other dense substances which are impervious to the rarest gases or most attenuated and subtile vapours with the existence of which we are acquainted.

22. But such speculations, if not rather curious than useful, would, if extended, be incompatible with the plan and objects of the present work. Therefore, though it would have been improper to have omitted all mention of them, they must be dismissed for the present, with the preceding short notice; especially as opportunities for resuming them will occur in some of the ensuing treatises.

[1] How is their existence ascertained, and how is their impenetrability demonstrated?

How do the *incoercible* or *imponderable* fluids differ from these?

What have hitherto been considered imponderable fluids?

What is the present more prevalent opinion respecting the imponderable medium?

MECHANICS

1. There is perhaps no department of Natural Philosophy of such extensive importance as Mechanics, since its principles are founded on those properties of matter which are among the most obvious and essential,—namely, Mobility and Weight; and the effects produced by the operation of these properties are so distinct and certain, that they can be subjected to mathematical calculation. Hence Dr. Wallis has described Mechanics, with some degree of propriety, as the "Geometry of Motion."

2. The designation of this branch of knowledge, like most other scientific terms, is derived from a Greek word,* signifying a *Machine;* and Mechanics may be considered as the Philosophy of Machinery, or the Theory of Moving Powers. Many writers have treated of this science under two heads, regarding those principles which relate to the gravity or weight and to the equilibrium of bodies, or the powers which preserve bodies in the state of rest, as the subject of the doctrine of Statics;† and the principles relating to the causes of movement, or the forces producing motion, acting by means of solids, as forming the subject of the doctrine of Dynamics.‡ But, as the respective states of bodies at rest, and bodies in motion, may be most correctly considered as the consequences of different modes of action of the same causes, they may be instructively illustrated by showing their relations to each other, for which reason it will be proper to treat of them in conjunction, rather than separately.

3. From this statement of the nature and objects of Mechanics, it will at once appear that we have by no means overrated the importance of an acquaintance with this science to the Student of Natural Philosophy. For all motions are more or less subject to the laws of Mechanics, and without a knowledge of those laws, it is impossible to appreciate the effects, or calculate the consequences, of those motions of the celestial bodies which occasion the phenomena of Astronomy; or of those properties of fluids, whether liquid or gaseous, on which depend the principles of Pneumatics, Hydrostatics, and Hydraulics; or indeed of any circumstances affecting the ponderable forms of matter. And those sciences which relate to Heat, Light, Electro-magnetism,

Upon what properties of matter are the principles of mechanics founded?

What definition is given of mechanics?

Under what heads has this science generally been treated?

How extensive is the application of mechanical principles to other departments of science?

---

* Μηχανη.

† From the Greek verb Στaω, to stand, or be fixed; or from Στασις, the act of standing.

‡ From the Greek word Δυναμις, power or force.

Vital Power, either in Animals or Vegetables, or any other phenomena which appear to be independent of the force of gravitation, yet derive most important aid from Mechanics; for it is chiefly by means of mechanical instruments that the influence of heat, light, electricity, magnetism, or the effects of vitality, as in the motion of the blood in animals, or of the sap or other fluids in vegetables, can be estimated. Mechanics may, therefore, be considered as the basis or groundwork of the other Physical Sciences, or branches of Natural Philosophy.

4. Previously to entering on the consideration of the Theory of Mechanical Powers, it will be necessary to show the nature and effects of Mobility, or the capacity for motion, and of Weight, or the gravitation of bodies,—as these are the general properties of matter on which, as already stated, the phenomena of Mechanics depend.

Mobility.

5. Every individual body, or portion of matter, must take up a certain space. This may be considered as the absolute place of the body, in reference to its situation simply and singly; or as its relative place, or situation with respect to other bodies. The relative situation of a body may be changed either by its own motion, or by the motion of the bodies around it. A body may exhibit the appearance of actual motion, or absolute change of place, while it remains at rest, its change of place being only relative. Thus, the Moon, when a train of thin fleecy clouds is passing over its face, if we attentively fix our eyes on it, seems to move, and the clouds to stand still, though this is only an apparent motion of the Moon, in a direction contrary to that in which the clouds are really moving. And if we hold a common eyeglass, or any transparent substance, a few inches before the eyes, and move it backwards and forwards, looking through it at any object, as an inkstand or knife, which remains unmoved, it will, as in the former case, exhibit an apparent motion, arising from the actual movement of the glass.

6. Mobility is the capacity of a body for change of place by its own motion, it therefore infers the capability of real or actual motion, and not of relative motion only. Yet this change of place may sometimes be most readily estimated by the consequent relative motion which accompanies it. Thus, a person sailing in a boat on a smooth stream, or going swiftly in a coach along an even road, would hardly perceive the motion of the vehicle except by the change of scene, and trees or buildings on the banks of the stream, or by the road-side, would seem to move in an opposite direction from that of the real motion of the boat or carriage. Every tolerably well-informed person now admits

What is meant by the *absolute* place of a body?
What by the *relative*?
What is *mobility*?

that the earth moves, and the sun stands still; but the motion of the former is not perceptible, and the apparent daily motion of the latter, being so obvious to our senses, was, till within the last three centuries, considered as a real motion, the existence of which could not even be questioned with impunity.

7. Without some active cause motion can neither commence nor cease; since a body in the state of rest would always remain unmoved, if never subjected to the influence of a moving force, and on the contrary, a body when set in motion would go on t move for ever, if it met with no opposition to its progress. I may seem inconsistent with this doctrine, that any body set ii motion, within the range of our observation, will continue to move without a fresh impulse for a time, but at length will slacken its speed, and finally resume the state of rest. Thus, a cannon-ball will pass a certain distance when discharged from the mouth of a cannon, but if it does not strike a solid body, still it will ultimately fall to the ground; and a marble or a cricket-ball thrown forwards with the hand, if it meet no obstacle, will reach only a certain distance, proportioned to the force used in throwing it.

8. In both these and all similar cases, the termination of the motion of the moving body is owing chiefly to two causes. The first of these is gravitation towards the earth's centre, common to all bodies, and which constantly tends to keep them at rest, pressing on the surface of the earth with a degree of force proportioned to their weight and bulk; or, if, as in the case of the cannon-ball, they pass through the air, the force of gravitation then tends to draw them continually nearer to the earth, till at length they fall and rest upon it. But the second and more obvious cause of the decay of motion is the resistance of the medium through which the moving body takes its course; and thus, a body moving through the air, like the cannon-ball, gradually becomes less and less able to pass forward till its moving force is destroyed. It will be readily perceived, that the resistance of the medium to the body which passes through it, must depend much on its density or consistence; thus, a ball driven by a certain force would pass further through the air than through water, and further through the latter than through a denser fluid, as brine or syrup, or through solids, as sand or clay.

9. Another circumstance which will affect the motion of a body, with relation to the medium through which it travels, must be taken into the account, and this is the form of the moving body. A small body will meet with less resistance than a large one of the same weight; and a body which presents an extensive

State some familiar examples, and show how real and apparent motion may best be distinguished.

How is a body at rest to be put in motion, and when in motion, how brought to rest?

What other circumstances go to retard or accelerate the motion of bodies?

surface to the medium through which it moves, will be retarded in its passage much more than one with a small surface. A sheet of paper stretched out to its full extent, and suffered to fall a few feet, and then folded up into a small compass, and again suffered to fall from the same height, will afford an exemplification of the resistance of the atmosphere to falling bodies; and an illustration of a different kind, but to the same purpose, may be drawn from the advantage which sharp-edged and pointed instruments have over blunt ones in penetrating hard or tough substances. A body moving in contact with a solid substance, as when it is rolled or dragged along the ground, is also affected by friction. This obstacle to motion is proportioned to the roughness or smoothness of the surface over which the body passes: thus, a marble thrown with any given force will run much further along an even pavement, than along an equally level gravel walk; and still further along smooth ice. Here again the form of the moving body has much influence on the velocity and extent of motion; for the fewer the points of contact between the surface and that which passes over it, the more freely will motion take place.*

10. All bodies subject to our control are exposed to the operation of gravity, in various degrees, and from this cause, independent of the resistance of the medium which they traverse, or of the effect of friction, their motions cannot be indefinitely continued, but must decline and terminate in a given time, according to the circumstances in which they are placed. But though perpetual motion cannot be exhibited by any methods which human skill or industry can contrive, yet we have continually before us the display of bodies which have been moving with undiminished velocity for ages past, and which no power but that which governs all nature can prevent from moving in the same manner for innumerable ages to come. The bodies to which we refer, as will probably be anticipated, are those whose motions are the objects of the science of Astronomy; and though that subject will not come under our immediate discussion, yet the general nature of the forces which occasion the revolution of the celestial bodies will be explained, and the causes of their uniform and uninterrupted motion will be illustrated.

11. That state of bodies just described, in which motion or the cessation of motion can take place only in consequence of an extraneous cause, has been termed Inertia, which signifies inac-

What are some of the examples which illustrate this point?

What other cause is there, independent of these, which operates upon all bodies, limiting their motion and precluding the possibility of perpetual motion by human skill?

What is *inertia?*

---

* This statement is to be understood as limited by the greater or less difficulty with which the surface can be abraded.

tivity, equally opposed to motion when at rest, and to rest when in motion; so that if a given force is required to make a body move with a certain velocity, the same force will be required to destroy its motion. When a garden roller is being drawn along a level surface, the exertion necessary to stop it suddenly, at any given point, would be precisely the same as would be required to move it backward, if it were at rest, and of course the same that was applied to set it in motion at first.

12. Any force applied to produce motion may be called Power or impulse, which may be either continued, as in the case of pressure, or intermitting, as in the case of impact or percussion. Whatever opposes motion so as to retard the moving body, destroy its motion, or drive it in a contrary direction, may be termed Resistance, and its effect, reaction or counteraction. It is one of the laws of motion that action and reaction are always equal and contrary. Thus, in pressing down the empty scale of a balance, while the other scale held a five pound weight, it is obvious that the force exerted must be equal to five pounds; but if one scale had been loaded with fifteen pounds, and the other with only ten, the equilibrium might still be preserved by pressing on the latter with a force equal to five pounds only. And if a man, sitting in a boat on a canal, draws towards him, by means of a rope, another boat of equal weight, they will meet at a point half-way from the places whence they began to move. Suppose, however, the second boat to be so laden as to be twice the weight of the first, it must move the slower of the two, and consequently the point of meeting would be nearer the second boat than the first. If a body in motion strikes another body of equal mass at rest, the two bodies will move together, but with only half the original velocity of the first, the other half having been expended in overcoming the inertia of the second body. Corresponding effects will take place, whatever difference there may be between the masses of the two bodies; for if the second body should be double the mass of the first body, the common velocity after the impact of the two bodies would be one-third that of the first; and if the mass of the first body be to that of the second, as 5 to 7, the common mass after impact will be 12; and as the second will deduct from the motion of the first in proportion to its mass, the motion lost by the first body will be seven-twelfths, and the motion retained would be five-twelfths.

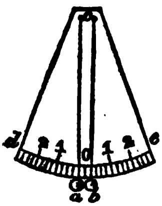
13. If two bodies are both in motion in the same direction, and one overtake and impinge on the other, suppose the masses of the two bodies to be the same, and the velocity of the first to be 7, and that of the second to be 5, their common velocity after impact will be 6, or half the sum of the two velocities. But if the masses are unequal, the mass of each must be multiplied sepa-

What is *power?*
What resistance?
What is one of the laws of motion?
Give some of the illustrations.

rately by its velocity, and the products added together, and their sum divided by the sum of the two masses will give the common velocity. When two bodies are moving in opposite directions, with the same velocity, and having equal masses, action and reaction being equal, both motions will be destroyed. Suppose, however, the masses to be alike, and the velocity of the first body to be 10, and that of the other to be 6, the first body will lose 6 parts of its velocity, which will be requisite to neutralize or destroy the opposite velocity of the second body, and the remaining 4 parts of the velocity of the first body being divided between the two, they will move together in the direction taken by the first body with a common velocity equal to 2.

14. When the masses, as well as the velocities, are unequal, the common velocity of two bodies after impact may be found by multiplying the numbers denoting the masses by those expressing the velocities respectively, subtracting the less product from the greater, and dividing the remainder by the sum of the numbers denoting the masses: the quotient will then show the velocity with which the bodies will move together, in the direction of the body having the greatest quantity of motion.

15. An experimental illustration of the equality of action and reaction in the collision of bodies may be thus exhibited:



Suppose *a* and *b* to be two inelastic balls,* suspended together at *c*, by threads of equal lengths, so that they may be in contact when at rest; and let *d e* be a graduated arc, over which the balls may oscillate freely; then, if the ball *b* be moved a certain number of degrees towards *e*, and let fall so that it may impinge on the ball *a*, both together will move towards *d*, through a number of degrees proportioned to their common velocity.

Since it appears from the foregoing observations to be an established principle of Mechanics, that the force or impetus of a body in motion is to be estimated by its mass and velocity, it must be concluded that a body, the mass of which is very inconsiderable, may be made to act with the same force as another body the mass

How do you find the common velocity of two equal bodies which impinge against each other? state separately the cases where one of them is at rest before impact, when they move in the same and when in opposite directions.

How do you find the common velocity after impact when the masses as well as velocity differ?

Describe the experiments which demonstrate the equality of action and reaction.

* No substance in nature is wholly destitute of elasticity, but soft clay, which is among the least elastic of solid bodies, may be used to make the balls for the above experiment.

of which is much greater, provided the smaller body has a velocity communicated to it greater than the velocity of the larger body in the same proportion that the mass of the latter surpasses that of the former. Thus, a pincushion weighing half an ounce might produce as great an effect as a cannon-ball weighing thirty-six pounds, provided the pincushion had 1152 times the velocity of the cannon-ball; for 1152 half ounces being equal to 36 pounds, it must be obvious that the velocity of the pincushion would be just so much greater than the velocity of the cannon-ball, as the mass of the latter would be greater than that of the former.

16. Hence as the momentum or effect of moving force is to be estimated by the velocity of the motion and the weight or mass of the moving body taken together, it may be perceived how it happens that a small mass may produce an extraordinary effect when moving with great velocity. Thus, a tallow candle fired from a gun will pierce a deal board. On the other hand a great effect may be produced by a small velocity if the moving mass is extremely great. As for instance, a heavily laden ship of great burden, afloat near a pier wall, may approach it with a velocity so small as to be scarcely observable, yet its force will be sufficient to crush a small boat.

17. When two bodies meet in consequence of moving from opposite directions, each body will sustain a shock as great as if one body at rest had been struck by the other with a force equal to the sum of both their forces. Suppose two persons of equal weight walking in opposite directions, one at the rate of two miles an hour, and the other at the rate of four miles, if they should suddenly come in contact, each would receive a shock as great as if he had been standing still, and another had run against him moving at the rate of six miles an hour. In the ancient tournaments when mailed knights met in full career, prodigious must have been the shock when the collision was direct, and both would often be overthrown with a force proportioned to their joint weights and velocities. So when two vessels under sail run foul of each other, suppose one of them eight hundred tons burden, and the other twelve hundred tons, their velocities or rates of sailing being equal, each would sustain a shock equal to that which a vessel would receive if at anchor, and struck by another vessel of two thousand tons burden, sailing at the same rate with the vessels in question. Yet though the shock would be the same, the consequences would be most disastrous to the smaller vessel, the other being protected in a greater degree from injury by its superior strength and bulk.

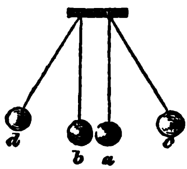
18. Elasticity being a common property of matter, and many substances employed for a variety of purposes, as several kinds of wood and metal, possessing that property in a high degree, its

What remarkable examples can be cited of the effect of momentum on bodies at rest?

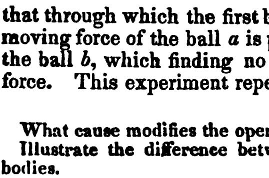
What practical illustrations can be given of the effect of bodies encountering each other when moving in opposite directions?

influence in modifying the operation of moving forces must not be neglected.

The different effects exhibited by bodies almost inelastic and those which are highly elastic may be illustrated by the simple experiment of dropping a ball of soft clay or wax from any given height on a solid pavement, and then letting fall from the same height a ball of box-wood or ivory of equal weight with the clay. The first ball will give way to the pressure of the pavement, and become dented or flattened on the side on which it rests, while the latter ball will rebound from the pavement with a force proportioned to the height from which it fell. This resiliency or rebound, in an ivory ball, is partly occasioned by its giving way to the pressure of the pavement, but unlike the clay it recovers its shape almost instantaneously, its surface thus acting as a spring against the pavement. That a hard substance like ivory is compressed by striking against a similar substance, may be shown by making a small dot with ink on the surface of one ball, and then bringing it gently in contact with another ball at that point, when a small mark will also appear on the latter ball; but if the balls, one being marked as before, be brought into contact with considerable force, as by pressure or collision, a much larger mark will be found on the latter ball than before; proving that, though both have recovered their shape, they must have undergone compression.



19. Let two ivory balls of equal weight, *a b*, be suspended by threads, as in the annexed figure, if the former be then drawn aside to *c*, and suffered to fall against the latter, it will drive it to *d*, or a distance equal to that through which the first ball fell; but it will itself rest at *a*, having given up all its own moving power to the second ball.



If six ivory balls of equal weight be hung by threads of the same length, and the ball *a* be drawn out from the perpendicular, and then let fall against the second, that and the other four, *c d e f*, will continue stationary; but the last ball *b* will fly off to B, being the same distance as that through which the first ball fell. Here the motion or rather the moving force of the ball *a* is propagated through the whole train to the ball *b*, which finding no resistance is acted on by the whole force. This experiment repeated with any number of balls would

What cause modifies the operation of moving forces?
Illustrate the difference between the effects of elastic and inelastic bodies.
What is the nature and cause of *resiliency?*
How may its existence in *ivory* be made sensible?
Describe the experiments which illustrate the law of collision in elastic bodies.

give the same result. It is proper to observe that in stating the effect of the collision of the balls in these experiments, they are supposed to be perfectly elastic bodies; such however do not exist among the substances with which we are acquainted; the phenomena exhibited by ivory balls would therefore be nearly, but not exactly, such as are stated.

20. The effect of elasticity in modifying the propagation of motion is curiously displayed in those exhibitions of human strength, which have occasionally taken place, and of which remarkable instances are related by some authors. Vopiscus, the Roman historian, mentions a circumstance of this kind, in his Life of Firmus, who, in the reign of Aurelian endeavoured to make himself emperor in Egypt, and who has therefore been reckoned one of the Thirty Tyrants. He was a native of Seleucia, in Syria, who espoused the cause of the famous Zenobia, Queen of Palmyra; and having been taken prisoner, he was executed by order of the emperor Aurelian. The historian says of Firmus, that he was able to bear an anvil on his breast, while others were hammering on it: he lying along, with his body in a curved position. And Beckmann, in his History of Inventions, notices the extraordinary feats of John Charles von Eckeberg, a German, who travelled over Europe about the beginning of the last century. After mentioning other feats, he adds, "But what excited the greatest astonishment was, that he suffered large stones to be broken on his breast with a hammer, or a smith to forge iron on an anvil placed upon it."* A part of the mysterious effect produced in these cases is to be accounted for by the position of the exhibiter, which may be thus described. He must place himself with his shoulders resting on one chair, and his feet upon another, both chairs being fixed so as to yield firm support; and thus his backbone, thighs, and legs would form an arch, of which the chairs would be the abutments. The anvil also must be so large as by its inertia and elasticity, nearly to counterbalance the force of the hammer; and thus the strokes would be scarcely or not at all felt; besides which the elasticity of the man's body, as well as his position, would contribute to his security against the effect of the blows.

Velocity of Moving Bodies.

21. Communication of motion, however rapid, must take up some portion of time; for as there can be no such thing as instantaneous motion, much less can motion be propagated instantaneously from one body to another. Hence motions performed with

What property of matter is assumed in stating these experiments, and how is it to be applied?

What remarkable example of the effect of elasticity does the human body afford?

What explanation can be given of the exploits of Firmus and Eckeberg?

* Hist. of Invent., Eng. Trans. 1797. Vol. iii. p. 206.

great velocity sometimes produce peculiar effects, as may be shown by the following experiments.

EXPERIMENT I.

22. A long hollow stalk or reed, suspended horizontally by two loops of single hairs, may, by a sharp quick stroke at a point nearly in the centre, between the hairs, be cut through, without breaking either of them. The hairs in this case would have been ruptured, if they had partaken of the force applied to the stalk; but the division of the latter being effected before the impulse could be propagated to the hairs, they must consequently remain unbroken.

EXPERIMENT II.

23. A smart blow, with a slight wand, or hollow reed, on the edge of a beer-glass, would break the wand, without injuring the glass.

EXPERIMENT III.

24. A shilling, or any small piece of money, being laid upon a card placed over the mouth of a tumbler glass, and resting upon the rim of the glass, the card may be withdrawn with such speed and dexterity that the piece of money will not be removed laterally, but will drop into the glass.

EXPERIMENT IV.

25. A bullet discharged from a pistol, striking the panel of a door half open, will pass through the board, without moving the door; for the velocity of the bullet will be so great that the aperture is completed in a space of time too limited to admit of the momentum of the moving body being communicated to the substance against which it is impelled.

26. It is an effect of the principle just illustrated, that the iron head of a hammer may be driven down on its wooden handle, by striking the opposite end of the handle against any hard substance with force and speed. In this very simple operation, more easily conceived than described, the motion is propagated so suddenly through the wood that it is over before it can reach the iron head, which therefore, by its own weight, sinks lower on the handle at every blow, which drives the latter up.

27. The velocity of motion is measured by time and space taken conjointly or relatively. Thus, a body moving through a given space, in a certain time, and supposed to pass through every part of that space at a uniform rate, is said to move with a velocity denoted by the ratio of the time to the space; and there-

State the four experiments which exemplify the peculiar effects of rapidly communicated motions.

How do you explain the operation of driving a handle into the eye of a hammer?

How is velocity of motion measured?

How are the relative velocities of different bodies estimated?

fore a uniformly moving body will describe equal spaces in equal times, and different bodies relative spaces in relative times. Hence a horse that will trot eight miles in an hour, would trot sixteen miles in two hours, and twenty-four miles in three hours, if he could traverse the distance with unabated speed. If in this case the three distances mentioned be considered as three distinct journeys, it will readily be perceived that the horse must have passed through the same distance, in each of the two hours of the second journey, and each of the three hours of the third journey, as in the single hour of the first; and this is what is meant by the statement that equal spaces are passed over in equal times; so that when the distance travelled is doubled or tripled, the time will be doubled or tripled also; and if the distance is reduced to one-half or one-fourth, the time will be reduced in the same proportion. The relative velocities of different bodies must be estimated in a similar manner. A man walking three miles in an hour would require double the time to perform a journey of eighteen miles, that would be taken up by another man running six miles an hour; and a horse galloping twelve miles an hour would complete the journey in one-fourth of the time of the first man, and one-half the time of the second man. The minute-hand of a common clock or watch has twelve times the velocity of the hour-hand, since the former passes through a whole circle, while the latter is passing through the twelfth part of it.

27. The velocity of a uniformly moving body may be discovered by dividing the space passed through by the time consumed: thus, the velocity of a steam-boat, going eighteen miles in two hours, will be found to be nine miles an hour. The velocity being known, the distance passed over in a given time may be discovered, by the contrary operation of multiplying the velocity by the time: thus, the steam-boat, with a velocity of nine miles an hour, will of course run twice nine miles in two hours, and forty-eight times nine miles in forty-eight hours.

Different Kinds of Motion.

28. Motion may be uniform or variable with respect to its rate or relative velocity. The nature of uniform motion has been just pointed out: and that of variable motion will be subsequently investigated. But motion may be different in one case from what it is in others, when considered with regard to the manner in which a body moves: as whether in a straight line, in a circle, or in any other curve. The line described by a body, in passing from one point to another, is called its direction, or line of motion. The direction of a moving body may be either a right line, across a level surface, or plane; a curved line, passing over a similar plane; or a curved line, the different parts of which are not on one plane.

What is the method of discovering the velocity of a uniformly moving body? of computing its distance passed over?

What distinctions of motion are founded on its *direction?*

29. Curvilinear motion is of a more complicated nature than motion in a straight line, the circumstances relating to it therefore cannot be properly explained without a previous investigation of rectilinear motion.

Sir Isaac Newton, in his great work entitled "Principia Philosophiæ Naturalis," "Principles of Natural Philosophy," has laid down three general positions, styled *Laws of Motion*, which have been considered as the foundation of mechanical science. These laws are the following:

I.

"Every body must continue in its state of rest, or of uniform motion in a straight line, unless it is compelled to alter its state of rest or motion, by some force or forces impressed upon it."

II.

"Every change of motion must be proportioned to the impressed force or forces, and must be in the direction of that force."

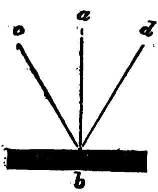
III.

"Action and reaction are always equal and contrary to each other."

30. Both the first and the last of these laws or positions, relating to moving bodies, have been already discussed, and their consequences pointed out: they may therefore be admitted as propositions not requiring further demonstration.

The second law of motion is of the highest importance, as it relates to compound motion, and the direction of a body acted on by two forces in different but not contrary directions. The effect of forces thus applied will be most readily understood after a short explanation of the nature of reflected motion, which affords a familiar example of action and reaction, the subject of the third of the preceding laws.

31. If a cricket-ball, or any similarly shaped elastic body, be dropped perpendicularly on a smooth pavement, it will rebound to a certain point in the same straight line in which it descended; but if it be impelled obliquely against the pavement, it will not rise in a perpendicular line, but in a line having the same degree of obliquity as that in which it struck the pavement.

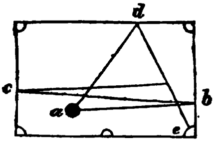


Thus, if the ball were dropped from *a*, to the pavement at *b*, its upward course would be in the same line, *b a;* but if it be thrown in the line *c b*, it will rebound in the line *b d*. In this case the angle formed by the line *c b*, with the line *a b*, is called the "angle of incidence," and that formed by the line *d b*, with the line *a b*, "the angle of reflection;" and it is to be observed that these angles will always be precisely equal. For it signifies not whether the obliquity of the line of incidence be great or small, since the line of reflection will in every

What three *laws of motion* were laid down by Newton? Which of these is of the greatest importance, and why?

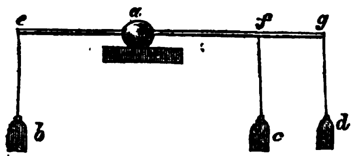
How is the principle of compound and reflected motion illustrated in the motions of cricket and billiard balls?

case have the same obliquity, and consequently form a similar angle with the surface from which the body rebounds.



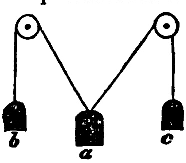
32. Suppose the parallelogram in the margin to represent a billiard-table, if a ball standing on it be impelled in the direction *a b*, it will strike against the end cushion and return in the line *b c*, and either of those lines would form a similar and very acute angle with a line drawn between them parallel to the sides of the table; but if the ball were driven from *a* against the side cushion at *d*, it would return in the corresponding line *d e*.

33. Equal weights, or equal forces of any kind, acting on a body, in a similar manner, but in opposite directions, will keep it in a state of rest or equilibrium, like the scales of a common balance, each loaded with a weight of one pound. But when the arms of a balance are of unequal lengths, as in the steelyard, a small weight fixed at the end of the longest arm will counterpoise a much greater weight at the end of the short arm.



34. Let *a* represent a globe of lead resting on a level surface, and having an iron rod passing exactly through its centre, the extremities of which *e* and *f* are equidistant from the ball; if threads of equal lengths be fixed at those points with hooks at the lower ends for the suspension of weights, the globe and rod will be kept in equilibrium so long as the weights *b* and *c* are equal; but if a longer rod be passed through the ball projecting further from it towards *g* than towards *e*, a smaller weight *d* will then counterbalance the weight *b*, and the relative number of ounces or pounds contained in these weights will always bear certain proportions to the number of inches or feet in the respective parts of the rod *e f*, and *e g*.

Here the equilibrium is maintained by equal forces acting in opposite directions; and the illustration of this simple principle is deserving of attention, as it leads to the consideration of the case of equilibrium maintained by the application of three forces.

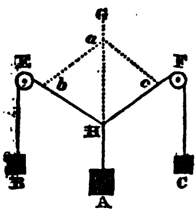


35. In the annexed figure the weight *a* being attached to the centre of a cord passing over two small wheels, and the weights *b* and *c* to either end of the cord, the equilibrium will be maintained only while the central weight counterbalances those at the ends, in order to which, exclusive of the effect of

How may the equilibrium of a body be preserved, and how is this subject exemplified?

How may an equilibrium be maintained by the application of three forces to a flexible cord?

friction, the weight *a* must be less than the sum of the two equal weights *b* and *c* taken together. For if the weight *a* be equal to the sum of *b* and *c*, there can be an equilibrium only when the two ends of the cord which sustain it become perfectly parallel to each other and to the parts which support *b* and *c*. This case is familiarly illustrated by the manner often adopted of suspending lamps from ceilings by means of a weight, to which the two ends of a chain or cord are attached, which having passed over two pullies at the ceiling very near each other, comes down through a hole in the centre of the weight, and receives the lamp at the middle part of the chain. By this means free motion is allowed to the lamp to ascend and descend through a convenient distance, and the equilibrium is maintained in all positions. If the weight *a* be greater than the sum of *b* and *c* the cord will obviously sink in the centre, and the weight *b* and *c* be drawn up to the wheels; and weight added on either side will drag down the cord on the side of the additional load and raise the central and opposite side-weight.



36. Suppose a cord, as in the marginal figure, stretched over the wheels E F, attached to an upright board, and having fixed to its extremities the weights B C. From any part of the cord, between the wheels, as at H, let a weight A be suspended, it will then draw down the cord so as to form an angle, E H F, and the weights will remain in equilibrium. It is obvious that in this case the weight A, acting in the direction H A, will counterbalance the weights B and C, acting in the direction H E and H F, and their joint forces must be equivalent to a force equal to A, acting in the direction H G. To ascertain the relative effect of the weights thus operating, it will be necessary to complete the figure, by drawing on the board the dotted line H G, in the direction of the cord A H; and lines under the cords H E and H F. Then on the line H G mark the point *a*, and H *a* must be supposed to represent as many inches as the number of ounces contained in the weight A. From *a* draw the dotted line *a b*, parallel to H F, and the dotted line *a c*, parallel to H E; then if the diagram were in the proportion just described, the line H *b* would contain as many inches as there were ounces in the weight B; and the line H *c* as many inches as the number of ounces in the weight C. A moment's reflection will show that the relative weights and lengths might consist of any denominations of weight and longitudinal measure; so that feet and pounds, or any greater or smaller denominations might have been substituted for inches and ounces; only in every case the same denomination of longi-

What familiar illustration can be given of an equilibrium of this sort?

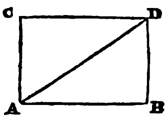
Describe the apparatus for exemplifying the parallelogram of forces.

tudinal measure must be applied to all the lines, and the same denomination of weight to all the gravitating forces.*

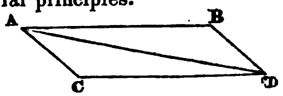
37. The case just considered affords an experimental illustration of what is called the parallelogram of forces, a principle of the utmost importance in mechanics, since it enables us to estimate the joint operation of moving powers, as well as their relative effect or influence.

In the preceding diagram, the parallelogram of forces is represented by the lines *a b*, *b H*, *H c*, and *c a*, and the line *H a*, joining the opposite angles, which is called the diagonal. The sides of the parallelogram, *a b*, and *a c*, will represent the quantity and direction of the two forces acting together, and the diagonal *H a* will denote the equivalent or counterbalancing force. This last force is styled the resultant, and the two forces opposed to it are its components.

38. In the preceding examples, the object has been to show the effect of opposing forces in producing equilibrium; but precisely the same method may be taken to explain the operation of forces applied in different directions, when their effect is to produce motion, instead of restraining it.



If a body A be impelled at the same time by two forces, which would separately cause it to describe the lines A B and A C of the parallelogram A B D C, the body will, by their joint action, describe in the same time the diagonal A D. For if the body had been previously moving with the velocity, and in the direction A B, and had been acted on at A by the force A C, it would have described A D in the same time. So that, whether the forces begin to act simultaneously or successively, their effects may be calculated on similar principles.



39. When the angle at which the different forces meet is very acute, they act with greater power on the moving body; thus, as the angle C A B, made by the directions of the composing forces, decreases, the effect arising from their joint impression will be increased;

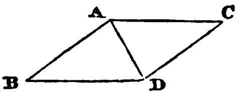
Whence does this principle derive its importance in mechanics? How is the parallelogram of forces applied to explain the laws of motion?

Under what circumstances will the effects of two forces co-operate in producing motion in the same direction? How may they destroy each other's effects?

---

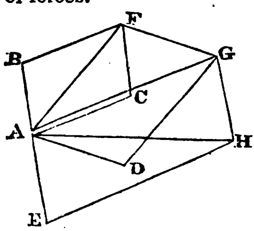
* On this subject, see a description, in the Journal of the Franklin Institute, vol. 3. p. 354, of the tricardo, showing under what circumstances three forces may produce a stable, and in what cases an unstable, equilibrium.—Ed.

and hence the diagonal A D, which expresses that effect, will likewise be increased. Therefore, when the angle C A B vanishes, or in other words, when the sides A C and A B coincide with the diagonal, the joint forces will have their full effect; but this would no longer be a case of the composition of forces, but of the junction or union of two forces.



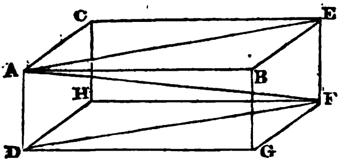
40. When the angle B A C, made by the directions of the two forces, is very obtuse, their effect is diminished, and the diagonal, representing the resultant of the forces, is consequently contracted. It will be obvious, therefore, that when the sides A B and A C meet without forming any angle, the forces will act in opposite directions; and provided they were equal forces they would destroy each other, no motion taking place; but if one force be superior to the other, the body will move on, not in a diagonal line, but in the direction of the greater force.

41. The combined effect of three or more forces acting on a body in different directions, may be discovered by means of the parallelogram of forces; and a single force may be thus assigned which will be the resultant of those forces. This may be done by obtaining first the diagonal representing the resultant of the combination of two forces, and considering that diagonal as the side of a parallelogram, of which a line representing a third force will form one of the other sides, and the parallelogram being completed, the diagonal will be the resultant of the first three forces; and the operation may be extended in the same manner, so as to discover the ultimate resultant of any given number of forces.



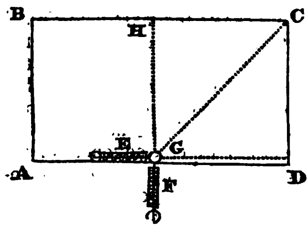
Let the point A be impelled by forces in the directions A B, A C, A D, and A E; then, to find out the resultant of these combined forces, complete the parallelogram C A B F, and the diagonal A F will exhibit the result of the forces, A B and A C. Complete the parallelogram D A F G, and its diagonal A G will denote the result of the three forces A B, A C, and A D. In the same manner, complete the parallelogram E A G H, and the diagonal A H will represent the force compounded of all the four forces, A B, A C, A D, and A E. But the construction may be simplified by merely drawing the lines B F, equal and parallel to A C; F G, corresponding with A D; and G H, bearing the same relation to A E; then, the line joining A and H, which as before will express the resulting force.

How may the combined effect of several forces be determined? Construct and explain the diagram relating to this subject.



42. It may be demonstrated by means of the parallelogram of forces, that from three forces acting in the directions A B, A C, and A D, in the proportions of the length, breadth and depth of a parallelopiped,* will result a motion in the diagonal A F of that parallelopiped; for A B and A C compose A E, and A E and A D compose A F; which last is the resultant of the moving forces in the directions of the three sides of the parallelopiped.

43. The effect of the composition of forces, when a body impelled in different directions takes its course in a diagonal line between the two impelling forces, may be thus experimentally exemplified:



On a billiard-table, A B C D, place a ball at G, equally distant from the side B C, and the end C D, then let two spring guns, capable of communicating equal impulses, be placed so that when the ball is impelled by E, it will move along the side A D, and that when the ball is impelled by F only, it will move in the line G H: then if the ball be struck by both the guns at the same instant, it will be found to move in the diagonal line G C, in the same time in which it would have moved from G to D, impelled by the gun E alone; or from G to H, if acted on only by the gun F. From the observations which have been already made on the relations between the extent of the lines described by moving bodies, and the amount of the forces by which they are impelled, it will be apparent that this experiment may be so modified as to show what would be the direction of the ball, when the impelling forces, or the angles at which they acted, were variously adjusted.

44. The operation of the principle called the composition of forces may be perceived in numerous cases of frequent occurrence. Indeed there are no motions with which we are acquainted that can be considered, strictly speaking, as instances of simple motion; for the effects of gravitation and the diurnal motion of the earth are alone sufficient to occasion some degree of complexity

What will be the direction and amount of a motion produced by three forces proportionate to the length, breadth, and depth of a parallelopiped?
What experimental illustration exemplifies the composition of forces?
How extensive is the application of this principle?

* See Introduction, 5.

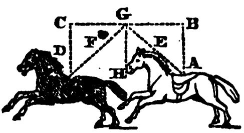
in all motions taking place on the earth's surface. Simple motion therefore is only relative.

45. Suppose two persons to be seated on the opposite sides of an omnibus, or any other oblong carriage, and to pass a ball forwards and backwards, from one to the other, in a level line. Now, if the carriage were four feet wide, and the ball were passed across that space in precisely the same time that the carriage would be going four feet along an even road, the real motion of the ball through the air would be in a zigzag line.

46. A stone dropped on the deck, from the mast-head of a ship under sail, would be affected by the motion of the vessel, as well as by the force of gravitation, and would therefore fall, not in a perpendicular, but in a diagonal line.

Let A represent the mast, C the stone, D the deck, and the line C E will be the distance that the mast-head will have moved, while the stone would have fallen, by the force of gravity alone, from C to the point under it on the deck; the mast being fixed is carried forward by the ship, and therefore the foot of the mast will have moved equally with the head, and will have reached the point vertically beneath E when the stone touches the deck; the stone will also be found at the foot of the mast, having taken a diagonal direction, in consequence of its being impelled at the same time by the ship's motion and by its own weight. For, if it had not been affected by the former as well as the latter, it would have fallen where the foot of the mast was when it began to fall, and not at the actual foot of the mast.

47. Any one who has witnessed the common feats of equestrian exhibiters at a circus, or elsewhere, may have seen a man leap from the back of a horse over a garter or handkerchief stretched horizontally across the track in which the horse was galloping, round the border of a circular area, and the horse passing under



the garter, the man comes down again on the saddle, after finishing his leap. To do this, it is only necessary for the rider to spring upright from the saddle, on which he was previously standing, and suffer himself to sink by his own weight on the saddle again; for as his body would partake of the motion of the horse, that force would be sufficient to carry him forwards, and his motion in rising, by an impulse which would carry him from A to B if the horse were standing still,

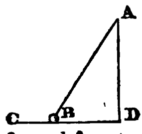
What is the real motion communicated to a body thrown from one side of a carriage to another when in motion?

Illustrate this principle in the falling of a body from the mast-head of a vessel under way?

What enables an equestrian performer, after leaping upward from a horse in motion, to alight again on the saddle?

would be nearly in the line E, while he would descend in the corresponding line F, through the joint effect of the force derived from the horse, and his own weight, the latter of which alone would occasion him to sink in the direction C D, or G H.

48. As it has been observed that all motions are really of a compound nature, resulting in a greater or less degree from combined forces, it may sometimes be requisite to ascertain the separate effects of acting forces; or to determine what portion of any given force acts in some direction different from that in which motion takes place. The operation requisite for this purpose is called the resolution of forces, the object not being as before, to discover the resultant from the combining forces, but to discover one or both of those forces from the resultant.



If a compound force, acting upon a body, produces motion in the direction A B, and it is required to find the part of that force which affects this body in any other direction, as D C; by drawing A D perpendicular to the direction D C, will be found the proportion which the absolute force bears to that part, which acting alone would produce motion in the proposed direction.

49. A boat may be moved across a river by the current passing in a direction parallel to its banks. To effect this the boat must have a rope fastened to it, the other end of which is connected with another rope extended directly across the stream, a noose or ring being fixed to the first or boat-rope, through which the stretched rope is passed in such a manner that the ring may slide freely in either direction. Then the rudder of the boat being properly turned to receive the impulse of the current, it will pass across the river, for the ropes will prevent it from being carried down the stream, while it glides with ease transversely as the ring of the boat-rope slides from one extremity to the other of the extended rope. Part of the force of the current in this case is destroyed, and the remainder is made to produce a motion in a direction different from that in which the water is flowing. The velocity of the current and that of the boat being ascertained, it would be easy to calculate what proportion of the moving force acted on the boat.

50. When the impulse of air or water is employed as a moving power, either can seldom act directly and with full force, some portion being lost, and the effect consequently diminished. A ship sailing with a side wind has the sails set obliquely with respect

By what operation may the separate effects of acting forces be ascertained?

What is the precise object to be discovered in this case? construct and explain the diagram.

How is the resolution of forces applied in the rope ferry? How might we calculate what proportion of the moving force acted on the boat?

What examples are afforded in which the impulse of air and of water produces a resolution of forces? What becomes of the ineffective part of the force in these instances?

to the course pursued; so the vanes of a windmill, and the float-boards of an undershot water-wheel are moved in general by a force applied in a slanting direction. Indeed the motion of a windmill would be prevented, by setting the surface of the sails perpendicular to the direction of the wind. In these and many other cases, only part of a moving force is brought into action, the other part being dissipated and lost, because it cannot be made to act in the required direction.

Gravitation.

51. Among the causes of motion, or moving forces, there are some, the effects of which are simple and uniform, producing movement in a single direction or straight line, and for a given time, proportioned to the degree of impulse. Others act in more than one direction, but with combined effect, so as still to produce uniform motion. Nature, however, presents to our notice motions which are not uniform, the velocity of the moving body varying in different parts of its course, so that the velocity or rate of motion may gradually increase to a certain point, and be suddenly terminated; or first increase, and then decrease till it ceases altogether. Motion with a perpetually increasing velocity is called accelerated motion. The phenomena of simple and compound rectilineal motions have been already described; but those of accelerated motion, which come next to be considered, cannot be fully understood without a previous acquaintance with the laws of gravitation, with which they are intimately connected. So general indeed is the effect of the property of gravity or weight on all bodies, within the reach of our observation, that its influence is perpetually interfering with our operations and experiments; and hence references have necessarily been made to it in the preceding pages, as in explaining the cause of the decay of motion, and elsewhere; but it will be requisite here to take a more extensive view of the nature and effects of this important principle.

52. Gravitation or Gravity has been noticed in the Introduction, under the appellation of gravitative attraction, as distinguished from cohesive attraction, capillary attraction, magnetic attraction, and other forces which tend to bring bodies into contact. Most of these forces or kinds of attraction are perceived only under particular circumstances; as cohesive attraction, which seems to act on solid and liquid substances alone, and not on gases; and capillary attraction, which only takes place between certain fluids and solids. But the attraction of gravitation differs from other attractive forces in being a common property of all bodies, since every thing to which we can attach the idea of materiality is affected more or less by gravitation.

53. It is by no means inconsistent with this statement that some

What is the distinctive character of variable motion? What is accelerated motion?

How is gravitation distinguished from other species of attraction? How extensive is its influence over material things?

bodies, possessing all the characteristics of solid matter, capable of being seen and felt, yet in certain circumstances, instead of exhibiting the common effect of gravity, in falling towards the earth or pressing on it, display the contrary phenomenon of ascending from it. Thus, smoke will be seen, in some states of the atmosphere, rising in a column to a considerable height. Even solid masses of no small bulk and weight may be made to ascend to a great height, as by means of an air-balloon. But all these and similar phenomena are in fact so many instances of the effect of gravitation; for the ascending bodies are driven upward solely by the force of the medium through which they pass; since the particles of smoke, or the balloon with its car and contents, cannot advance upward in the most minute degree without displacing, or thrusting downward, portions of the atmosphere equal to their own bulk. Hence it will be perceived that aërostatical bodies do not ascend because they possess absolute levity, but simply because, bulk for bulk, they are lighter than the air. A cork or a piece of deal, for the same reason, will float on water, and if pressed down in it will rise again to the surface, by the effect of relative levity.

54. All substances, then, gravitate towards the earth; that is, they have weight, which occasions them to fall to the earth when dropped from a height above it; to rest upon it with a certain degree of pressure, according to circumstances; or if rendered buoyant, to rise in the atmosphere surrounding the earth, till they reach a part of it where it is less dense than near the surface, so that a portion of it, precisely equal to their bulk, would exactly counterpoise them, and there of course they could neither rise nor fall, without an alteration of their own weight taking place. In the case of an air-balloon, the aëronauts have the means for lessening its buoyancy whenever they may find it convenient, by opening a valve, and letting out a part of the gas, or light air, to which it owes its ascending force; thus they can, at any time, render the weight of the whole apparatus much greater than that of an equal bulk of atmospheric air, and then it must fall to the ground. Smoke only remains suspended till its particles unite, and thus becoming heavier than the air, they descend in the form of small flakes of soot, covering with a dingy coat or incrustation all buildings, after a time, in large and populous places.

55. Let us suppose for a moment that while a mass of smoke and an air-balloon were hovering in the air near together, and at

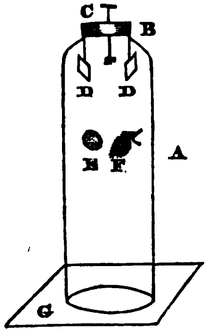
How is the universal prevalence of gravitation to be reconciled with the appearance of light substances rising from the surface of the earth? What is the true explanation of these phenomena?

What expedient enables the aëronaut to descend from a higher to a lower level in the air?

In what manner is smoke finally deposited from the air?

What would be the effect on suddenly removing the air from beneath a mass of smoke and an air-balloon hovering near each other?

precisely the same height, it were possible to withdraw from under them the support of the atmosphere, it will be immediately perceived that they must fall; but probably the young reader will be surprised to learn, that they would not only fall, but likewise that they would both fall through the same space in the same time; so that if their common height had been five hundred feet, the smoke would have reached the surface of the earth at the same instant with the balloon, though the latter might in weight far exceed the other body. It must not be imagined that the circumstance just stated is a mere philosophical conjecture, or that it cannot be confirmed by the test of experiment; for, though it is impossible to annihilate the atmosphere, or effectually remove it from beneath an air-balloon, or any other body suspended in it, yet on a small scale appearances precisely similar to those just described may be easily exhibited.



56. Let A represent a tall bell-glass, open at the bottom, and having the top closed, so as to be air-tight, by a brass cap or cover, B, through which passes the wire C, fitting close, but capable of being turned without admitting the air. The lower end of the wire must be made to support a small stage, the two sides of which, D D, will fall and separate, when the wire is turned in a transverse direction. Then, the stage being fixed, a gold coin and a feather, E and F, or any two small bodies differing greatly in their comparative weight, may be laid on the stage, and the bell-glass, or as it is called, receiver, being placed on the plate, G, of an air-pump, must be exhausted of the air it contained. This being done, if the two bodies E and F are made to fall by turning the wire, it will invariably be found that they will both strike the plate of the air-pump beneath them at the same point of time.

57. The influence of gravitation is not only extended to all bodies on or near the surface of the earth, but likewise, as we have the utmost reason to believe, to all bodies in the universe. This is not the proper place to describe the nature and operation of those forces which regulate the orbits of the moon, the planets, and the comets belonging to the solar system; but it may be here observed that Sir Isaac Newton discovered gravity to be the cause of all the motions of the heavenly bodies; and that the laws of gravitation displayed in the monthly revolution of the Moon round the Earth, the annual circuit of the Earth round the Sun, and the

In what manner can we prove, experimentally, that light and heavy bodies would fall with equal velocity if the air were suddenly annihilated?

How extensively is gravitation applicable to the works of nature?

What discovery did Sir Isaac Newton make on this subject?

corresponding motions of the other planets and their satellites are capable of the strictest mathematical demonstration.

58. Gravitative attraction acts upon all bodies, with forces proportioned to their masses. Thus suppose two bodies so situated as to be wholly exempt from the influence of any attraction except that resulting from their gravitation towards each other, they will then approach with velocities corresponding with their respective forces. If the larger of the two bodies be double the size of the smaller, the former will act with twice the force of the latter; and therefore while the small body will move two feet in consequence of the double power of the larger one, the larger will move but one foot drawn by the single power of the smaller. If the larger body be four times the size of the other it will exert four times as much attractive force, or make the smaller body move with four times as great velocity as it would if the masses of the bodies were equal.

59. Hence it may be regarded as a general law of gravitation, that while the distance between two bodies remains unaltered, they will attract and be attracted by each other, in proportion to their respective masses; and therefore any increase or decrease of the mass must occasion a corresponding increase or decrease of the amount of attractive force, as measured by the velocity.

60. Since gravitative attraction is a common property of all bodies, it may naturally be inquired why all bodies not fastened to the earth's surface do not, by their mutual attraction, come in contact; or by what means the force which they derive from gravitation is prevented from appearing in their relations to each other. A little reflection will show that the cause of this seeming inactivity of bodies at rest is the overpowering influence of the earth's attraction. If a small particle of matter were placed at the surface of a solid sphere or globe of gold, one foot in diameter, its gravitation to the earth would be more than ten millions of times greater than its gravitation to the gold. For the diameter of the earth is nearly forty millions of feet, and the density of gold is nearly four times the medium density of the earth; therefore in a second, the particle would approach the gold less than the ten millioneth part of sixteen feet, a space utterly imperceptible. It is also owing to the immense difference in the mass of the earth and that of any one body on its surface, that the attractive influence of bodies falling towards the earth produces an effect in drawing the earth upwards so insignificant as to be infinitely beyond the reach of our observation.

61. Though we cannot institute direct investigations of the

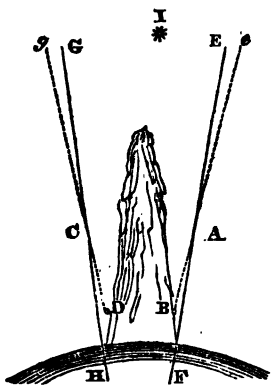
In what proportion does gravitation affect different bodies?

What would be the relative velocities of two unequal bodies actuated solely by each others gravitative attraction? State the general law on this subject.

Why do not all unconfined bodies rush together by their mutual attraction?

Why do not falling bodies draw up the earth instead of descending to its surface?

comparative effect of gravitation, by making experiments on detached masses whose magnitude bears any considerable proportion to that of the earth, yet it may be shown that partially isolated portions of the earth's surface exhibit a sensible degree of gravitative attraction, when small bodies are brought near them. A mountain two miles in height and of an hemispherical figure, rising in a level country, would cause a plummet suspended beside it to deviate one minute of a degree from the perpendicular direction which gravitation towards the earth would otherwise produce. Observations of this nature have been actually made on more than one occasion. The French Academicians, Bouguer, De la Condamine, and others, when employed in measuring a degree of the meridian, in Peru, towards the middle of the last century, having placed their observatories on the north and south sides of the vast mountain of Chimborazo, found that the plummets of their quadrants were deflected towards the mountain. The manner in which these philosophers ascertained the amount of the deflection of their plummets may be thus concisely explained.



Their object being to determine the zenith distance of a star, I, it was necessary to regulate the position of a telescope by means of a quadrant, the plummet of which, instead of hanging in the vertical lines A F, and C H, on the opposite sides of the mountain, were found to take the positions A B, and C D, and thus the star seemed to have the zenith distances *e* I, and *g* I, instead of E I, and G I, which it ought to have had: hence it is obvious that the plummet was drawn aside, by the attractive force of the mountain, from its proper direction perpendicular to the earth's surface, through a space capable of being estimated by the differences perceived in making observations on the star I from the opposite sides of the attracting mass.

62. The phenomena thus observed by the French philosophers having given rise to discussion among men of science in different countries, it was thought desirable to ascertain, by experiments made for that particular purpose, the validity of the cause assigned. King George III. therefore was induced to send the Astronomer Royal, Dr. Maskelyne, to Scotland, in 1772, to make

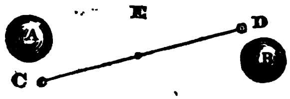
How may a comparison be made between the whole mass of the earth and an isolated portion projecting above its general level?

Describe and illustrate the experiments which have been instituted on this subject.

What amount of deviation did Dr. Maskelyne find in his plummet on the sides of Schehallien?

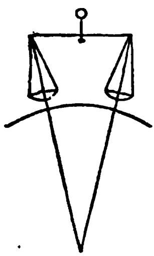
similar experiments on the north and south sides of Schehallien, a lofty and solid mountain in Perthshire, well adapted for the purpose. The deviation towards the mountain on each side, was found, after the most accurate observations, to exceed seven seconds; thus confirming the inferences of preceding observers, and proving the universal operation of gravitative attraction.

63. The influence of general gravitation was also experimentally demonstrated in a different manner, by Mr. Henry Cavendish, in 1788.



Two small metallic balls, C and D, were fixed to the opposite ends of a very light deal rod, which was suspended horizontally, at its centre E, by a fine wire. This arm, after oscillating some time horizontally by the twisting and untwisting of the wire, came to rest in a certain position. Two great spherical masses, or globes of lead, A and B, were then brought into such a position, that the attraction of either globe would turn the rod C D on its centre E, in the same direction. By observing the extent of the space through which the end of the rod moved, and the times of the oscillations when the globes were withdrawn, the proportion was discovered between the effect of the elasticity of the wire, and the gravitation of the balls towards the leaden globes; and a medium of all the observations being taken, the experimentalist was enabled to ascertain not only the actual influence of gravitation on terrestrial bodies in general, but likewise its relative influence as depending on the density of the attracting body.

64. As gravitative attraction draws bodies towards the centre of the attracting mass, it might be expected that bodies under the influence of gravitation would diverge somewhat from a line perpendicular to an horizontal plane beneath them.



This indeed is precisely what takes place; and if we imagine a pair of scales, as in the marginal figure, to be formed in such a manner as to bear a certain proportion to a sphere towards the centre of which each scale was attracted, the effect would be obvious. But the magnitudes of any bodies which we can make the subjects of experiment are so extremely inconsiderable when compared with that of the earth, as to render the deviation from the perpendicular, in lines which are actually convergent, quite imperceptible.

65. It must also be considered that though the grand and preponderating force of gravitation is directed towards the centre

Describe the method adopted by Cavendish to demonstrate the influence of gravitation, and the mean density of the earth?

What are the directions in regard to a horizontal plane of two bodies remote from each other, and obeying the force of gravitation?

(and all bodies, like those just mentioned, are attracted towards the earth's centre), yet every particle likewise has an attractive power, therefore the gravitation of bodies on the earth's surface is the effect of the attraction of its entire mass. Hence in the investigation of the phenomena of falling bodies, it may be assumed that all the particles of the same body are attracted in parallel directions, perpendicularly to an horizontal plane; for the spaces through which bodies fall, while under our observation, are not of sufficient extent to render it necessary that any allowance should be made for the effect of direct attraction towards the centre.

66. The slightest observation will enable any one to ascertain that the force of a falling body increases in proportion to the height from which it has fallen. When bodies are precipitated from a great height, they will strike with violence against a resisting surface, or penetrate deeply into a yielding mass. Aërolites or meteoric stones, which are heavy bodies, resembling iron ore, several of which have fallen at different periods, have sometimes been found to sink deeply into the earth; as was observed with regard to a meteoric stone, fifty-six pounds in weight, which fell in a ploughed field in Yorkshire, England, in 1795.

67. Experiments serving to illustrate the effect of accelerated velocity on falling bodies may be made by observing the rebound of an elastic body, when dropped from different heights. A marble or a cricket-ball successively suffered to fall on a pavement, from the respective heights of a foot, a yard, and double or treble that height, would rise higher and higher at each trial, according to the extent of the space through which it had fallen. More exact experiments might be instituted by forming three or four balls of soft wax or moist clay, exactly of equal weight, as one pound each, and letting them drop from different heights on some smooth hard surface; when it would be perceived that each ball was indented or flattened, on the side on which it had fallen, more or less deeply in proportion to the extent of the space it had fallen through.

68. Having thus ascertained that the velocity of a falling body, as denoted by its final force, is increased by the augmentation of the distance passed through, it becomes an interesting speculation to determine what are the relative degrees of velocity produced by given distances of descent. In other words, it is desirable to know whether a body falling through a space during two seconds, or two minutes, would fall as fast again in the second period as it did in the first, or three times as fast, ten times as fast, or in

Whence results the gravitation of bodies on the earth's surface?

How does the force of falling bodies vary with the heights from which they fall?

Exemplify this in the case of aërolites.

What familiar experiments with elastic and with soft bodies prove the relation between velocity and extent of fall?

What relation does the velocity of a falling body actually measure?

what other ratio of acceleration. This is obviously a question of the relation between time and space, for velocity is the measure of that relation. Now the motion produced by gravitative attraction is a continually increasing motion, so that a body under the influence of gravitation will not fall through exactly the same space in any two consecutive periods of time, however inconsiderable. For if we could suppose a single second to be divided into a thousand parts, a falling body would pass through a greater space in the second thousandth part of the second, than in the first thousandth part, and so on in like manner throughout its course. However, in order to find out the rate or ratio of the increasing velocity of falling bodies, it will be sufficient to know what is the distance passed through by a descending body in each succeeding second, minute, hour, or any other equal portion of the time of its whole descent.

69. When we consider the various circumstances which interfere with the motion of falling bodies, some arising from the resistance of the medium through which they pass, and other incidental sources of irregularity, others from the varying force of gravitation itself, at different distances from the centre of attraction, it will be at once perceived that the inquiry before us is surrounded with difficulties. It is no wonder then that very confused and erroneous notions concerning this subject prevailed till a comparatively recent period.

70. Aristotle, whose opinions were long regarded as indisputable, states, in his philosophical writings, that if one body has ten times the density of another, it will move with ten times the velocity; and that both bodies being let fall together, the first will fall through ten times the space that the other will in the same time; besides other erroneous doctrines, which were generally received till his theory was overturned by the discoveries of the celebrated Italian philosopher Galileo, towards the end of the sixteenth century. He showed that bodies, under the influence of gravitation alone, would fall through spaces as the squares of the times of descent: that is, that a body, which would fall through one inch in one instant, would fall through four inches in two instants, and nine inches in three instants; for the square of any number is the product of that number multiplied by itself, so four is the square of two, nine the square of three, &c. The principle thus laid down by Galileo, though disputed by some later philosophers,* has not

Will gravitation alone ever produce a uniform velocity of motion? exemplify this point.

How may the rate of increasing velocity be determined?

What prevented the early philosophers from obtaining exact notions of this subject?

What was Aristotle's opinion on the subject of falling bodies?

---

* The authority of Galileo was questioned, and different opinions were maintained by philosophers concerning the ratio of the acceleration of

only been triumphantly established as a positive law of nature, with regard to falling bodies, but, as already mentioned, it has been shown by Sir Isaac Newton that it is a general law of nature, extending to the motions of the celestial bodies composing the solar system.

71. In order to apply this principle to the purpose of ascertaining the precise ratio of the accelerating velocity of falling bodies, it is necessary to fix on some measure of time as the unit from which calculations must commence, and to determine what space a body will fall through in that portion of time; and these data being furnished, the application may be readily explained.

72. But before we proceed to the further consideration of the velocity of falling bodies, as the effect of a uniformly accelerating force, it will be proper to observe that it can only be thus strictly estimated with respect to bodies falling through limited spaces, as short distances from the surface of the earth, where the intensity of the gravitating force may be regarded as continuing the same during the whole period of descent. For not only does the velocity of gravitating bodies in descent become accelerated as they approach the centre of attraction, but the intensity of the accelerating force is also continually increasing. And on the contrary, the intensity of the force diminishes as the distance increases. Hence the velocity of a body falling from a great height, as fifty miles from the earth's surface, would increase in a smaller ratio at the beginning of its descent, and in a much greater ratio towards the end of its descent, than that of a body falling through only as many feet.

73. The force of gravitation is to be estimated by the same rule that has been already stated as applicable to the velocity of falling bodies. It increases as the squares of the distances of bodies decrease, and decreases as the squares of their distances increase. Thus, if one body attracts another with a certain force at the distance of one mile, it will attract with four times the force at half a mile, nine times the force at one-third of a mile, and so on in proportion; and on the contrary, it will attract with but one-fourth the force at two miles, one-ninth the force at three miles, one-sixteenth of the force at four miles, and so on as the distance increases. Applying this principle to the gravitative attraction of the earth, it follows that its force must be four times greater at the earth's surface than at double that distance from its centre;

What truth in regard to gravitation was first established by Galileo?

What measure must we adopt previously to applying the principles of gravitation?

Does the rate of acceleration by gravity continue the same at all distances above the surface? State the law applicable to this subject.

---

the velocity of falling bodies, even till the time of Newton's discoveries. —Vid. Regis Physic., lib. ii. cap. 23; also, Annotations of Dr. Samuel Clarke, on Rohault's Treatise on Natural Philosophy, a work which was considered as of standard authority in the beginning of the last century.

and as the weight of bodies is estimated by the pressure or gravitating force with which they tend towards the earth, a body weighing one pound at the earth's surface would have only one-fourth of that weight, if it could be removed as far from the surface of the earth as the surface is from the centre. And at the distance of the moon from the earth, which is 240,000 miles, the weight or gravitating force of the same body, as affected by the attraction of the earth, would be equal to only the 3600th part of a pound. For reckoning the distance of the earth's surface from its centre to be 4000 miles, that is, half its diameter,* the distance of the moon would be sixty times as great, and the square of that number, or 3600, would, as just stated, indicate the decrease of gravity, at the distance of 240,000 miles from the surface of the earth.

74. This decrease of weight, in proportion to the squares of increasing distances, might in some situations be made the subject of experiment. A ball of iron, weighing a thousand pounds at the level of the sea, would be perceived to have lost two pounds of its weight, as ascertained by a spring balance, if taken to the top of a mountain four miles high. The same body removed from Edinburgh to the north pole would gain the addition of three pounds; and if conveyed to the equator, it would suffer a loss of four pounds and a quarter. To account for the loss of weight in the last-mentioned situation, it must be recollected that the earth is not a perfect sphere, but that its figure is spheroidal, the diameter of the earth from pole to pole being somewhat less than in the line of the equator; the equatorial regions therefore must be more distant from the centre of attraction than the polar regions, and the force of gravitation at the former consequently less than at the latter. Hence the point of greatest attraction must be at either of the poles; for if the iron ball, just mentioned, could be conveyed to the depth of four miles within the bowels of the earth, it would be found to be lighter by one pound than at the surface; since it would be attracted on every side, and the force of gravitation upwards would in some degree counteract the preponderating force with which it would press downwards. If it were possible for the iron ball to reach the centre of the earth, it would necessarily there lose the whole of its weight, for the attraction of gravitation acting equally in every direction, no effect would

How much greater is the force of gravitation at the earth's surface, than at a semi-diameter above it? How much would a pound weigh if carried to the distance of the moon?

How might the decrease of weight in bodies removed to a distance above the surface of the earth be experimentally proved?

How is difference of weights in different latitudes to be explained?

What effect upon its weight would arise from carrying a body far beneath the surface?

What would be the weight of a body carried to the centre of the earth?

---

* The mean semi-diameter of the earth may be estimated more exactly at 3956 miles.

be produced, and the ball would be fixed, as if encircled by an infinite number of magnetic points.

75. Connected with this part of the subject there are some curious problems, the solution of which requires mathematical calculations, but the results alone are here introduced, as furnishing interesting illustrations of the power of gravitation.

Suppose the axis of the earth were perforated from pole to pole: a body falling through the perpendicular hole, being attracted on all sides, would be urged downwards only by a predominating force, proportional to its distance from the centre. The velocity acquired at this centre, reckoning the length of the axis 7900 miles, would be equal to 25,834 feet each second. The time of descent would be 1268⅓ seconds, or 21′ 8″⅓; and the whole time of passing to the opposite pole 42′ 16″¼.*

76. Conceive a body, under the mere influence of terrestrial attraction, to fall from the orbit of the moon to the earth's surface. At the mean distance of sixty semi-diameters of the earth from its surface, the initial force would be diminished 3600 times: with the same continued acceleration, therefore, it would consume a period of 526,578 seconds, or six days, two hours, sixteen minutes, and eighteen seconds, in performing the whole descent. The final velocity, on this supposition being 4680.69 feet each second. Such would be the time of descent under the influence of uniform acceleration; but the time required with an acceleration inversely as the square of the distance from the centre would be only 414,645 seconds, or four days, nine hours, ten minutes, and forty-five seconds. And in this case the final velocity would be 36,256.45 feet, or about seven miles each second. Abstracting, then, from the resistance of the atmosphere, a body propelled directly upwards, with this last velocity of 36,256.45 feet in a second, would mount to the orbit of the moon; but with the addition of one hundred and twentieth part more, or 305 feet to every second, it would reach the sun; and with the further acceleration of less than one foot, amounting to 36,562.43 feet each second, the body would be enabled to continue its flight into the regions of boundless space.†

What would be the velocity and the time of a body descending through a perpendicular hole along the axis to the earth's centre?

How long would it take a body to fall from the moon to the earth? and what would be its velocity on reaching the surface?

With what velocity must a body be shot upwards, in order to pass beyond the solar system.

---

* In the hypothetical case here propounded, it must be admitted that the acquired velocity of the body at the centre of the earth would overcome the obstacles to its ascent, and enable it to complete its passage.

† Leslie's Elements of Natural Philosophy, 2nd edit. Edinb. 1829. Vol. i. p. 106, 7.

Accelerated Motion.

77. The increase or acceleration of velocity, from the force of gravitative attraction, has been stated to be as the squares of the numbers representing equal portions of the time during which a body falls. It has been found convenient to consider the time of descent of falling bodies as divided into seconds, so that if a body, under the influence of gravitation alone, falls one foot in one second, it must fall four feet in two seconds, nine in three seconds, sixteeen in four seconds, and so on, in progression; the squares of the numbers of the seconds showing the number of feet passed through by the falling body at the end of each second. In order to discover the distance passed through in each particular second of the time, it is merely requisite to subtract, from the whole distance completed at the end of that second, the number of feet at the end of the preceding second. Thus, from 4 feet, the distance in two seconds, take 1 foot, the distance in the first second, and 3 the remainder, will be the number of feet passed through in the second second only; from 9, the distance in three seconds, take 4, the preceding distance in the first two seconds, and the remainder 5 will be the distance in the third second; so from 16, the distance in four seconds, the preceding distance of 9 being subtracted, will leave 7, the distance in the fourth second.

78. Gravitation being a continually acting force, a body falling through its influence alone would in every instant of its descent move faster than in the preceding instant, and consequently, at the end of any given time, it would be impelled by a force beyond that which carried it through the preceding space. This force may be estimated in the following manner. Suppose a body, after having fallen during one second, by the impulse of gravitation, to be no longer acted on by an accelerating force, but to continue its motion with the velocity already acquired, describing through the remainder of its descent equal spaces in equal times. In such a case it would be found that the falling body, in every successive second of its descent, after the first, would pass through twice the space through which it had fallen in the first second by the force of gravitation. And the velocity being estimated by the space described uniformly in one second, it follows that the velocity acquired in one second must be equal to double the space through which a body would fall freely by the action of gravity in one second. Since then the velocity increases in the same proportion as the time, it would be twice as great at the end of the second second, as at the end of the first, thrice as great at the end of the third second, and so on.

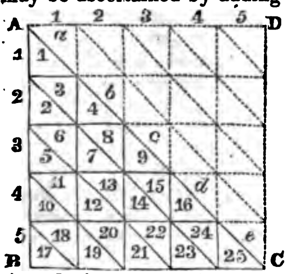
How can we discover the distance passed through in each separate second of the descent of a body? Exemplify this by a particular case.

With what uniform velocity per second would a body move, after having fallen for one second, supposing the force of gravitation to be then suspended?

79. The following table, constructed on the supposition t body would fall through one foot in the first second of its des as furnishing the most simple results, will afford some furth lustrations of the positions laid down.

Number of seconds of the period of descent.	Entire space fallen through in feet at the end of each second.	Velocity estimated by feet, at the end of each second.	Space in fallen thr in eac secon
1	1	2	1
2	4	4	3
3	9	6	5
4	16	8	7
5	25	10	9
6	36	12	11
7	49	14	13
8	64	16	15
9	81	18	17
10	100	20	19

80. It will at once appear from the inspection of this table t the time of descent of falling bodies increasing as the numb 1, 2, 3, &c., and the entire spaces passed through as the squa of those numbers, the augmentation of velocity will be rep sented by the even numbers, in regular progression, and the spac passed through in each second by the odd numbers. The su of the number of feet in the fourth column will of course gi the number of feet fallen through in the whole time; and the di tance fallen through in any part of the time may be found in tl same manner. Thus, 1+3+5, &c. to 19 inclusive will amou to 100. So the space fallen through in any number of secon may be ascertained by adding the corresponding numbers in tl



second and third columns, tog ther with the number representin the space fallen through in th first second of descent. Thus +4=8+1=9; 12+36=48+1= 49; 18+81=99+1=100. An the same results may be obtaine in any similar cases.

81. The nature of acceleratin velocity, as exhibited in falling bodies, may, perhaps, be somewha elucidated by reference to the series of triangles in the annexed diagram. Let the line A B denote the time of the descent of a falling body, divided into equal portions, as seconds; then the small numbered triangles may re-

Explain the relation, as exhibited in the table, between the time, the entire space fallen through, acquired velocity, and space described in each second. What series of numbers represents the augmentation of velocity?

In what geometrical figure may this relation be exhibited?

present the space fallen through, under the influence of gravitation: the number of the triangles in each line showing the number of feet passed through in each second, and the entire number the whole space described in five seconds. By completing the square, as with the dotted lines, it may be perceived how it happens that the velocity, acquired by a falling body at the end of each second, is more than is expended in its passage through the next second; and also it will appear that a body, moving uniformly with the velocity acquired at the end of any given second of time, will describe double the space described in the same time by a body falling under the influence of gravitation alone. For suppose the triangles *a*, *b*, *c*, *d*, *e*, to denote the surplus velocity at the end of each second, which must be sufficient to carry the falling body through one foot, they will, if added successively to the numbered triangles in each line, show the velocity acquired in each succeeding second; and therefore the triangles 17, 18, 19, 20, 21, 22, 23, 24, 25, and *e* will be ten in number, the amount of the velocity acquired at the end of five seconds. Now a body moving with the uniform velocity of ten feet in a second would pass through the distance of fifty feet in five seconds; while a body falling through gravitation only would pass through but twenty-five feet in the same time: and the space described by the uniformly moving body, at the rate of ten feet in a second, may be represented by the square A B C D; while the triangle A B C would represent the space described by a body moving with accelerated velocity, in the same time; and as the square is equal to the doubled triangle, so the former space would be double the latter.

82. Hence likewise a body moving uniformly, with half the velocity it would acquire at the end of any given time, would pass through a space exactly equal to that which it would describe moving with accelerating velocity during the same time. According to the preceding table, the velocity of a body at the end of ten seconds would be equal to twenty feet; now half that velocity, or ten feet in a second, would carry a body through one hundred feet in ten seconds, which is precisely the space it would have fallen through in that time, by the effect of gravitation.

83. Thus, the velocity acquired at the end of any given time being sufficient to have carried a body twice the distance it would reach with gradually accelerated velocity, it follows that the velocity actually expended in the latter case is only half the velocity that has been acquired; and since the final velocity in each second is represented by a number double that denoting the time, the real amount of accelerating velocity may be expressed by a number equal to the time. Hence as the space fallen through

With what velocity must a body move uniformly, in order to describe a given space in the same time as when uniformly accelerated by gravitation?

How may the real amount of accelerating velocity be expressed? By what product may the *space* be represented?

by a gravitating body is equal to the square of the time, that is the number representing the time multiplied by itself, so the time and the velocity being equal, the space must be as the square of the velocity, or as the time multiplied by the velocity.

84. We have already taken occasion to observe that the force of gravitation varies at different distances from the centre of attraction; and hence the absolute effect of gravitative influence must vary also. The consequence of this principle, as exemplified in the augmentation or reduction of the weight of bodies in different situations, has been pointed out. And since bodies in motion are acted on by gravitation in the same manner as bodies at rest, it follows that falling bodies will describe greater spaces in equal times, according to the increased intensity of gravitation, as occasioned by the diminution of the distance through which it acts.

85. In order therefore to discover by experiment the force of gravitation, as measured by the space through which a body would fall, in a given time, as one second, we must know what is the distance of the gravitating body from the centre of attraction. If, as already remarked, the earth were a perfect sphere, every part of its surface would be equidistant from its centre; but, since it is an oblate spheroid, or globe flattened at the poles, the attraction must there be strongest, and must decrease in the intensity of its force, in the direction of a line from either of the poles to the equator. Such a line would be a meridian of longitude, and the degrees of latitude measured on it would be so many points at which the intensity of gravitation was progressively diminishing.

86. Hence, in experiments made to ascertain directly the amount of gravitative force as measured by the space a body would fall through in one second of time, regard must be had to the latitude of the place where the experiment might be made, and if the utmost accuracy were required, the height of the spot above the level of the sea must also be taken into the account. These observations will be sufficient to show that no small degree of skill and attention would be requisite in order to ensure the perfect exactness of such experiments. Instead therefore of pursuing this train of investigation further at present, we shall proceed to state that numerous and very accurate experiments have been made, whence it appears that in the latitude of London, which is near the level of the sea, a heavy body falls, from the action of gravity, in the first second of its descent, through the space of sixteen feet and one inch, or 193 inches.

87. In making calculations relative to the phenomena of falling bodies, when extreme accuracy is not required, the space passed

What will enable us to discover by experiment the force of gravitation?

How does the figure of the earth affect its force of attraction at the different parts of its surface? Through what space will a body fall in the first second in the latitude of London?

What may generally be assumed for the space described in one second by a body falling freely?

through in one second of time may be estimated at 16 feet; and taking this as the common multiple of distances and velocities, a table similar to that already given may be constructed, by means of which the spaces fallen through in any given time may be ascertained with sufficient exactness. The following short specimen of such a table may be easily extended by the young student, so as to afford data for the resolution of several interesting questions.

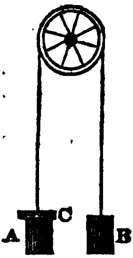
Seconds of descent.	Feet passed through at the end of each second.	Final velocity in each second.	Feet passed through in each second.
1	16	32	16
2	64	64	48
3	144	96	80
4	256	128	112
5	400	160	144

88. Suppose now we wish to discover the height of an eminence, or the depth of a well; by dropping a leaden bullet from the top of either, and observing how many seconds elapsed before it reached the bottom, a table like the above would show by inspection how many feet the space amounted to in either case. No notice, however, is here taken of the resistance of the air, which would greatly affect the motion of bodies falling from a considerable height. Several years ago a man dropped from the balcony of the Monument, near London Bridge, a height of about 200 feet: he would therefore have fallen to the pavement below in nearly three seconds and a half, but for the resistance of the atmosphere; notwithstanding which he must have been whirled downwards with a velocity, which perhaps rendered the miserable being insensible of the appalling catastrophe that awaited him. Sometimes aërolites have exploded in the air, and fallen in showers of meteoric stones, as happened near Sienna, in Italy, in 1794; and at L'Aigle, in France, in 1803. If the moment of such an explosion could be observed, and also that at which the stones, or any one of them, came to the ground, the height at which the phenomenon took place might be estimated with tolerable accuracy.

89. The obstacles which occur in the experimental investigation of the laws of gravitation are partly owing to the very extensive space that would be required for direct experiments on falling bodies, even for a few seconds; and to these would be added the variable effect of atmospheric pressure against bodies moving with great velocity. The consideration of these difficulties led Mr. George Attwood, an ingenious philosopher who died in the early part of the present century, to contrive a machine in which the influence of gravitative force might be moderated without destroying its characteristic efficiency, in the production of an accelerated

How might the height of an exploding meteor be estimated?

What obstacles occur in the direct experimental investigation of the laws of falling bodies?



motion. This piece of machinery was very elaborately constructed, and some parts of it could not be correctly described without entering into extensive details, and giving delineations on a large scale, but the principle on which it acted may be concisely explained. Equal weights A and B, being suspended by a fine silken cord, passing over a wheel moving with the least possible degree of friction: then by adding a certain quantity to one of the weights, as by placing on it a small bar C, descending motion may be produced, differing in intensity from that caused by the unrestrained power of gravitation, but obeying the same law of accelerating velocity; so that, though the loaded weight might be made to descend only one inch in one second, its continued motion would be found to proceed in the regular ratio of the squares of the times of descent.

90. It might be imagined, that as the large weights counterbalance each other, the small bar ought to descend as freely as if they were removed; but the gravitating force expended in producing motion is partly consumed in overcoming the inertia of the large weights, and therefore the portion of it which acts as a moving power will bear the same proportion to the whole force, as the weight of the bar alone bears to the entire moving mass, for it is expended in drawing down the loaded weight A on one side, and raising the weight B on the other side, at the same time. Thus if the weights were two pounds each, and the bar weighed but half a pound, the force expended would be but one-ninth part of the whole force; and the loaded weight A would descend but one-ninth part of sixteen feet in the first second of time, and with the same reduced velocity, as the squares of the times, throughout its descent. By means of this machine a variety of most interesting and important experiments may be performed, and the laws of gravitation satisfactorily demonstrated.

91. Bodies projected directly upwards will be influenced by gravitation in their ascent as well as in their descent; but its force must be calculated inversely, producing continually retarded motion while they are rising, and continually increasing motion during their fall. So that a body propelled perpendicularly through the air, leaving out of the question the resistance of the medium through which it passed, would rise to a height exactly equal to that from which it must have fallen to acquire a final velocity the same as it had at the first instant of its ascent. And the velocity would be the same in the corresponding parts of the ascent and descent. The time likewise which the propelled body required to attain its utmost height would be just equal to that during

Describe the principle of Attwood's machine. What portion of the gravitating force of the bar added to one of his equal weights is employed in producing motion?

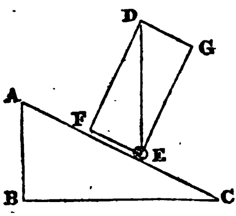
What laws of motion apply to bodies projected directly upwards? What relation exists between the times of their ascent and descent?

which it would be falling to the ground. Hence the laws which regulate uniformly accelerated velocities will apply equally to uniformly retarded velocities: that is, the velocity lost in any given time, by the influence of a uniformly retarding force, will be as the time; the space passed through as the square of the time, or the square of the velocity; and so on, as in the case of accelerating forces.

Motion of Bodies on inclined Planes and Curves.

92. Among the varieties of accelerated motion depending on the influence of gravitation, that of bodies passing along inclined planes requires to be noticed, as exhibiting the modified effect of a most extensively acting force. When pressure is applied in a vertical direction to a body supported by a horizontal plane, it is manifest that no motion can ensue; and the force of gravitation thus acting can be measured only by the direct weight of the body so situated. But if the plane surface on which the body rests be inclined in any degree, the efficient weight will be proportionally diminished; and if the inclination of the plane be sufficient to enable the body to overcome the resistance to its motion arising from friction and similar causes, the body will move down the plane with a velocity so much the greater as the surface over which it moves approaches to a vertical direction. The motion in this case will be a continually accelerated motion, differing in degree of relative velocity from that caused by the direct influence of gravitation, but subject to the same law of acceleration.

93. In order to estimate the force with which bodies are impelled down inclined planes, we omit for the present all consideration of the resistance occasioned by friction; and therefore suppose a plane to have a perfectly smooth surface, and the figure of the moving body to be globular, and of the same density in every part, so as to be capable of motion in any direction.



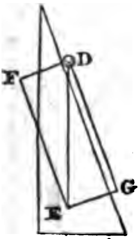
94. Let A C represent the declivity of an inclined plane, A B its perpendicular height, and D E the absolute weight of an ivory ball on its surface; now this weight, by the parallelogram of forces, will be found to act in two directions; D F, or G E, denoting the direct pressure perpendicular to the declivity of the plane, and D G, or F E, in the direction of that declivity: the former force it is

How can the force of gravitation in a body pressing a horizontal plane be measured? What effect on the pressure of the plane will result from its becoming inclined? When will motion commence on the inclined plane?

Of what nature will be the motion over the inclined plane?

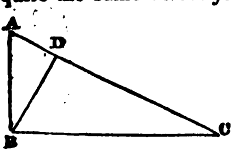
What circumstances are we to omit in first estimating the force of motion on inclined planes? Describe the diagram relating to this subject.

obvious will be destroyed by the resistance of the plane, and the ball will consequently move down the plane with a force bearing the same relation to the force of gravity that D G does to D E, that is, it would move down the plane through a space equal to D G, while it would fall through a space equal to D E by the force of gravitation.



95. Whatever may be the declivity or inclination of the plane, the force of a body moving down it may be estimated on the same principle. Thus suppose the obliquity of the plane to be very considerable, as represented in the margin, the line D G would be nearly equal to D E; and the force of the body moving on such a plane would manifestly be little inferior to that of the same body falling freely.

As the force of a body moving on an inclined plane is less than that of a body moving by the influence of gravitation, its final velocity in a given time must also be less; and the distance through which it must move on a declivity to acquire a certain final velocity must be greater than that through which it must fall freely by the effect of gravity to acquire the same velocity.



96. It may be demonstrated that a body moving down any inclined plane will acquire the same final velocity, in passing from A to C, that it would have gained in falling through the relative distance A B. For let A D be the space through which the body would move down the plane in the same time that it would fall from A to B, it follows that, in order to acquire the same velocity that it would gain by falling from A to B, it must pass through a space bearing the same proportion to A B that A B does to A D; and as the triangles A D B and A B C are similar, their corresponding sides must have the same relations to each other; therefore A D will be to A B, as A B to A C. Hence the proposition will universally hold good, that a body rolling down an inclined plane of any extent or obliquity, but for the effect of friction or similar causes, would acquire the same final velocity, as if it had fallen directly through a space equal to the perpendicular height of the summit of the plane.

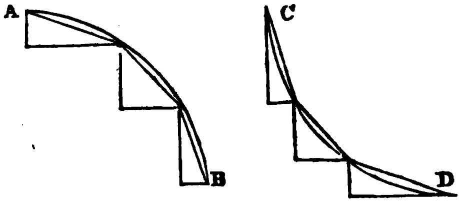
97. Bodies moving on curved surfaces would not exhibit uniformly accelerated velocity, like those moving on inclined planes;

What relation will the final velocity of a body moving on an inclined plane, bear to that which it would acquire in falling perpendicularly through the same distance?

What relation will the velocity of a body falling freely, and of one descending an inclined plane, bear to the length and height of the plane?

With what sort of velocities will a body move down a curved surface? Why would not the motion be uniformly accelerated?

for the resistance occasioned by the peculiar form of the curve in which any such body might move would be continually changing, and the result of that resistance would be a consequent change in both the velocity and the direction of the moving body. Some idea of the nature of this perpetual change may be obtained from considering what would be the effect of presenting to a moving



body a succession of inclined planes, either ascending or descending, the outline of which would form a rude resemblance to a curved surface. From the mere inspection of the preceding figures, it may be comprehended that a body passing over a convex surface, as from A to B, would encounter a perpetually diminishing resistance; and in passing over a concave surface, as from C to D, the resistance would progressively increase. For in the former instance, the effect would be as if the moving body rolled down a number of declivities, each one more oblique than the preceding; and in the latter, it would be as if the body passed over a series of declivities, each of which approached nearer than the preceding to the figure of a horizontal plane.

98. Having thus endeavoured to explain the manner in which curvilinear motions are produced by the constant action of variable forces, we can now proceed to investigate the phenomena of curvilinear motions in general. When a body moves through an entire circle, with uniform velocity, as it must be impelled by forces continually varying in intensity and direction, those variations must be supposed to take place momentarily, or in inconceivably minute portions of time and space. So that such a body might be considered as moving in the circumference of a polygon having an infinite number of sides.

99. In the case of a body moving over a curved surface and in contact with it, there must be a certain pressure of the body on the surface over which it passes, and a corresponding resistance, or pressure on the body, in every instant of its progress. Now this pressure shows the degree of force to which the continual variation of direction, or deflection of the moving body is to be attributed. Suppose a leaden bullet, or a billiard-ball to be made to move round within a hoop laid flat on a table or any level surface, it would obviously press against the inside of the hoop, thus ma-

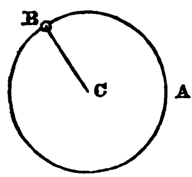
How are the forces which impel a revolving body supposed to vary?
Into what figure may we conceive the circle to be resolved?
How would a body moving within a curved surface be affected by it?

nifesting a constant tendency to escape from the circle in which it was moving, and only withheld by the counterpressure, or resistance of the hoop. If then the hoop were suddenly lifted while the ball was passed round within it, the circular motion would no longer be continued; but the ball would fly off in a right line from the point where it was set at liberty. The force operating on the moving body in this case would be precisely similar to that which would propel forwards a stone discharged from a sling, on letting go the cord which retained it during the previous circular motion or whirling, whence it would acquire its subsequent velocity.

100. The forces which act on bodies revolving in circles or other orbits may be regarded as antagonist powers, one of which perpetually impels the moving body in a right line from the centre of motion, and the other draws it towards that centre; and by the joint action of these forces curvilinear motion is produced. The former, or the repellant power, is named centrifugal force, or force causing bodies to fly from a centre; and the latter is styled centripetal force, or that which attracts moving bodies towards the centre of motion.

101. These opposing forces have also received the common appellation of central forces. It may be here observed that the line in which a body will move, on escaping from the circle around which it must have been previously whirled, will always form a tangent to that circle, or in other words, it will extend in a direction perpendicular to another line drawn from the centre of the circle to the point of escape. Hence this force has been sometimes called a tangential force; but its usual appellation is that of centrifugal force.

102. These forces must necessarily differ in degree according to circumstances,—such as the mass of the moving body, the extent of the circle in which it may move, and the velocity of its motion.



Thus a ball, B, of two pounds weight, would require a greater centrifugal force to make it revolve round the circle A, in any given time, than another ball weighing only one pound. The extent of a circle is to be estimated by its radius, or the line C B, passing from its centre to some point in its circumference, and consequently always equal to half the diameter. Now the centrifugal force or pres-

What line would such a body describe, if suddenly relieved from the confinement of the curved surface?

How may we explain the motion of a stone discharged from a sling?

What is meant by the terms *centrifugal* and *centripetal*, as applied to forces? What common appellation is applied to them? When a body escapes from the influence of its centripetal force, what will be the line of its subsequent path? What is signified by the term *tangential force?*

By what circumstances are central forces caused to vary their intensity? Exemplify the principles applicable to this variation.

sure must increase, as the radius of the curve in which a body moves increases. In a circle the same radius will apply to every part; but if a body should move in any other curve, as an ellipse, the degree of curvature, and consequently the length of the radius, will differ in different parts. Hence the expression, radius of curvature, has been used to denote the line which may be drawn from the centre of motion to any given point of the curve described by a revolving body. The velocity of revolving bodies may be estimated by the actual space passed through in a given time, or by reference to the time in which any such body would pass from one point in the circuit in which it moved to another point. These distances, being measured by the angle formed by lines drawn from the centre of motion to the points just mentioned, the velocity indicated may be styled the angular velocity of the moving body.

103. The amount of centrifugal force in different circumstances may be experimentally determined by means of a machine called a whirling table, which is so constructed that different weights may be whirled at any given distance from the centre of motion, and with any required degrees of velocity; and the measure of the centrifugal force expended is obtained by causing the revolving weights, by their rotatory motion, to draw up other weights, which are suspended freely; and thus the effect of centrifugal force may be ascertained in a satisfactory manner. From the results of experiments with the whirling table, it appears, that the centrifugal force will increase as the mass of the moving body increases; that the centrifugal force will be doubled, other circumstances remaining the same, if the radius or curvature be doubled; that if the radius of curvature remain the same, and the angular velocity be doubled, the centrifugal force will be quadrupled; and that if equal masses be made to revolve within circles, the radii of which are as 2 to 3, and with angular velocities as 1 to 2, the centrifugal force will be as 2 to 12, or as 1 to 6. Hence it appears that the centrifugal force increases in direct proportion to the mass of the moving body, and to the distance from the centre of motion, and also as the square of the angular velocity. Thus:—the radius of the circle being 2—the angular velocity 1, the square of which is 1—the centrifugal force will be the product, $2\times1=2$; the radius of the circle being 3—the angular velocity 2, the square of which is 4—the centrifugal force will be the product, $3\times4=12$; thus, as above, the centrifugal force in the different cases would be as 2 to 12.

What is meant by radius of curvature?

In how many ways may the velocity of a revolving body be estimated? What is meant by *angular velocity?*

What apparatus is employed to demonstrate the laws of centrifugal forces?

What relation have these forces to the masses of the revolving bodies? What relation to the radius of curvature? What to the angular velocity?

104. In order to obtain the amount of centrifugal force at any given point, the square of the number of feet expressing the angular velocity in one second of time must be divided by the number of feet denoting the radius of curvature, and the quotient will give the centrifugal force, as estimated by the number of feet a body impelled by it would describe in one second. Thus, a sling, two feet long, circling vertically, with the velocity of eight feet each second, would communicate to a stone a centrifugal force equal to thirty-two feet in a second, which would be the final velocity of a body falling during one second, and the centrifugal force therefore would be just sufficient to counteract the influence of gravitation, and enable the sling to support its load. If the motion of the sling were accelerated so as to perform a complete revolution in one second, the tension of the string would uphold the stone with a force $2\frac{1}{2}$ times greater than the attraction of gravitation.

105. An amusing experiment, illustrative of the influence of centrifugal force in overcoming that of gravitation, may be performed by placing a tumbler filled with water, in a sling, or fixing it upright in the bottom of a net, when it may be whirled round with such velocity that not a drop of the water will be spilled, though the mouth of the glass will be turned downwards during a part of each revolution.

106. The centrifugal force at the equator may be computed by taking the time of one diurnal revolution=86,164 seconds, the equatorial radius of the earth=20,921,185 feet, and the ratio of the earth's circumference to its diameter=3.14159:1. Then $4 \times 3.14159^2 \times 20,921,185 \div 86,164^2 = 0.1,112,259$, which is the centrifugal force at the equator. Now as the actual force of gravitation, determined by experiments, the nature of which will be subsequently described, is, 32.08818; and therefore, if the earth were at rest, it would be $32.08818 + 0.1,112,259 = 32.1,994,059$, it follows that the centrifugal force at the equator is to the force of gravity in the proportion of the numbers 0.1,112,259 to 32.1,994,059, or nearly as 1 to 289. So that the force of gravitation is 289 times greater than the centrifugal force, at those parts of the earth's surface where the action of the latter is most powerful.

107. Now since 289 is the square of 17, it will follow that if the diurnal revolution of the earth had been completed in one-seventeenth part of the time, which it now takes up; that is, had

How may we obtain the amount of centrifugal force at any given point? How may we compare centrifugal force with that of gravitation?

How may it be familiarly shown, that this force is often superior to that of gravitation?

How may we compute the centrifugal force of the earth at the equator?

What is the actual force of gravitation there, as determined by experiment? What is the amount of centrifugal force, and by how many times does the former exceed the latter?

How much must the velocity of the earth's revolution be increased, in order that bodies at the equator should lose all their weight?

the earth revolved on her axis in eighty-four minutes, instead of nearly twenty-four hours, the centrifugal force would have counteracted that of gravitation, and all bodies would have been absolutely destitute of weight; and if the centrifugal force were further augmented, the earth revolving in less time than eighty-four minutes, gravitation would be completely overpowered, and all fluids and loose substances near the equinoctial line would fly off from the surface.

108. Among the abundant examples of the effects of centrifugal forces that might easily be adduced, a few may here be noticed, in addition to those already given. The astonishing power of this force, even when exerted on a small scale, appears from its destructive influence on hard solid bodies; as when grindstones are whirled about with extraordinary velocity in our manufactories, they will sometimes split, and pieces fly off with amazing force. The more regulated, but no less powerful operation of centrifugal force may be observed in some parts of the machinery employed in certain branches of the arts: as in the fly-wheel which regulates the motion of a steam-engine, and in the coining press; but these and other modifications of mechanical power will be noticed elsewhere. Semifluid and soft but tenacious substances, under the influence of centrifugal force, assume in a greater or less degree the form of a compressed globe; and thus a rudely-shaped ball of clay, placed on a potter's wheel, with the assistance of gentle pressure while in the state of revolution, gradually acquires a symmetrical form; and globular glass vessels owe their figure to the analogous manipulations of the glass-blower. Liquids exposed to a whirling motion are similarly affected; as may be perceived if a glass of water be suspended by threads, and made to turn with great velocity by the twisting and untwisting of the threads, when the water would sink in the centre, and rise on the sides so as to escape in part over the edge of the glass. In all cases centrifugal force tends to make bodies under its influence recede from a central point, and when it acts in conjunction with a centripetal force, the effect will be revolving motion, whether those powers be exerted in keeping a peg-top, or a teetotum spinning on a floor or table, for a few minutes; or in causing the vast globe which we inhabit to revolve with undiminished energy through countless ages.

Oscillation of the Pendulum.

109. Oscillation or vibration is a peculiar kind of curvilinear motion, depending on the influence of gravitative attraction, and it not only affords the means for ascertaining the variation of the force of gravitation in different latitudes, but likewise furnishes

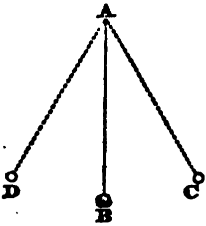
Give some examples of the effects observed to result from centrifugal force.

What is meant by oscillation?

To what purposes in science and arts is it applicable?

the most accurate method for measuring time, and leads to various important results in the investigation of many natural phenomena.

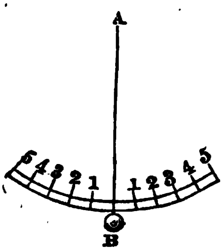
110. When any heavy body is suspended by a string or small wire, it will take a direction in a line vertical to that point of the earth's surface over which it hangs, as in the case of the plumb-line of a mason's level when placed on a horizontal plane. Now the laws of oscillation are those which would regulate the motion of a body thus suspended, if drawn aside from the vertical line in which it would rest, and then let go and suffered to oscillate or swing forwards and backwards undisturbed. In treating this subject it will be most convenient to consider the phenomena of oscillatory motion simply and independently of the effects of the resistance of the air, the friction of the suspending line on the point of suspension, and the varying extension of that line; all which it is obvious would affect the results of actual experiments, and would therefore require attention in making calculations founded on them.



111. Suppose A B to represent a pendulum at rest in the vertical position, if it be then drawn from B to C and let fall, it will return to B, with an accelerated motion, which, however, will not be uniformly accelerated, since it must depend, partly on the gravitation of the pendulum towards the earth, which acting alone would cause it to fall perpendicularly from the point C, but which being modified by the tension of the line, it is forced to describe the arc C B. Now at B the direct power of gravitation will be not merely modified but destroyed, for the line being stretched to its full extent would prevent any further descending motion; but when arrived at B, the pendulum would have acquired a certain degree of velocity during its previous descent, which would be just sufficient to overcome the force of gravity tending to retain it at the point B, and make it move forward from that point to D, with a retarding velocity, which would there be entirely expended; and since the pendulum at D would be in a situation exactly corresponding with that in which it was placed at C, it must again describe the same arc D B C, but in a retrograde direction, first with a gradually accelerated velocity, and then with a velocity progressively retarded. Thus, but for the obstacles already mentioned, and the wear and tear of materials, a pendulum, once put in a state of vibration, would go on regularly oscillating for ever.

112. The vibrations of any one pendulum will be described in equal times whatever be the extent of the arc through which it moves, provided that arc do not exceed a certain limit.

What circumstances affect the results of experiments on oscillation? What forces combine to produce oscillatory motion? What causes the ascending part of an oscillation?



Thus when the vibration of a pendulum is progressively weakened by the resistance of the air, every succeeding arc passed through will be less than the foregoing; and yet it will be found that though the pendulum moves slower and slower continually, there will be but little difference in the time taken up by the ball in moving from 5 to 5, 4 to 4, &c., on each side of the line A B, till it stops entirely. It is this remarkable property of the pendulum that makes it so useful as a measure of time; and clocks, or time-keepers, regulated by a pendulum, are nothing more than trains of wheel-work kept in motion by weights, and so arranged as to register the beats of pendulums which oscillate seconds. This equality of vibration of bodies in certain curves was discovered by Galileo, whose attention is said to have been excited by remarking the motion of a chandelier hanging from the ceiling of a church at Pisa; for, noticing that it moved with uniformity as to time, independent of the space passed through, he was induced to make experiments, which established what has been termed the law of Isochronism, or equality of time.*

113. As it is only when oscillating in very small arcs of circles that pendulums preserve this regularity of vibration, it became a subject of inquiry among philosophers whether a curve could not be found in which the isochronism of a pendulum would be perfect; and such a curve was discovered by the celebrated Dutch mathematician, Huygens, the contemporary of Newton. It has been named a cycloid,† and from its property an isochronal curve, and it differs little from an arc of a circle, except in rising somewhat more abruptly at each extremity. But it is the less necessary to enter into any further description of its nature and properties, as it has been found after all to be less adapted for practical purposes than small circular arcs, in which therefore the pendulums of time-keepers are made to oscillate.

114. The vibrating weight of a pendulum does not influence its motion; for whether a great or a small weight be affixed to a vibrating line, its oscillations will be similar, provided the length of the line, measured from the point of suspension to the centre of oscillation, remains the same. Sir Isaac Newton made experi-

What is meant by the isochronism of oscillations? By whom was this character discovered?

In what form of curve must oscillations be performed, in order to be isochronous?

What influence has the weight of a pendulum on the time of its oscillation?

* From the Greek Ισος, equal, and Χρονος, time.

† From the Greek Κυκλος, a circle, and Ειδος, a resemblance.

ments on a great variety of substances, as metals, stones, woods, salts, portions of flesh, &c., whence he ascertained that how greatly soever they might differ in weight, the addition of any of them to a pendulum would not interfere with its rate of oscillation, so long as its length remained unaltered. Thus, as heavy bodies and light ones would fall to the earth, through a given space, in the same time, but for the resistance of the air, so they would be found to vibrate in equal times at the end of a line of a given length, provided atmospherical resistance could be made to act on them in the same manner, or be entirely excluded, as by inclosing the vibrating bodies in an exhausted receiver.

115. It is on the length of the pendulum that the rate of oscillation principally depends; that is, the greater the distance between the point of suspension and the point of oscillation, the longer will be the period of each vibration; and on the contrary, the shorter that distance, the quicker will the vibrations take place. Now, as gravitation is the power on which oscillatory motion depends, so the same law that regulates its operation on falling bodies is observable in its action on oscillating bodies: for as the intensity of gravitative force decreases as the squares of the increasing distances of bodies, thus the time of a vibration will increase as the square root of the length of the pendulum, or the distance from the point of suspension to the point of oscillation, increases. If then a pendulum 1 yard in length, would make one vibration in one second, a pendulum $\frac{1}{4}$ of a yard long would vibrate half seconds, one 4 yards long, would vibrate once in two seconds, one 9 yards long, in three seconds, and so on; for $\frac{1}{2}$ is the square root of $\frac{1}{4}$, 2 of 4, 3 of 9, &c.

116. But in order to obtain the absolute length of a pendulum that would swing seconds, it is necessary to take into consideration the intensity of gravitation, which, as already stated, varies at different parts of the earth's surface, depending on their relative distance from the centre of gravitative attraction. The greater the intensity of gravitation at any place, so much the quicker will be the vibrations of a pendulum of a given length: so that a pendulum which would oscillate seconds at London would perform each of its oscillations in somewhat less than a second, if it could be removed to the north pole; and on the contrary, would take up more than a second in one vibration under the equinoctial line.

117. The intensity of gravitation at any given point of the earth's surface thus corresponding with the vibrations of a pendulum of a given length, it follows that if the intensity of gravita-

What resemblance in this respect has the pendulum to bodies falling freely?

On what circumstance in a pendulum does the time of its oscillations depend? Between what two points is the true length of a pendulum to be taken? Illustrate the law of its motion by an example.

What local circumstance must be taken into view in obtaining the absolute length of a pendulum?

tion at any place, as estimated by the space which a body falling freely would describe in any time, as one second, be known, the length of a pendulum, which would vibrate seconds at that place, may be ascertained by computation. For since the time of vibration is to the time of descent through half the length of the pendulum, as the circumference of a circle to its diameter, that is, as 3.14159 to 1, let the time of vibration be 1 second, then the length of the pendulum may be thus found: the time of descent of a body during 1 second, in the latitude of London, by the influence of gravitation, has been already stated to be about 16 1-12 feet, or 193 inches; and since the spaces of descent are as the squares of the times, therefore $\overline{3.14159}^2 : 1^2 :: 193 : 19.0625 = 19\ 1\text{-}16$ = half the length of the pendulum, which must therefore be $19\ 1\text{-}16 \times 2 = 39\frac{1}{8}$ inches.

118. In order to determine the length of a second's pendulum by experiment, a pendulum of a known length must be made to oscillate for a certain time, as one hour; then the square root of its length will be to the square root of the length of the required pendulum, inversely, as the number of vibrations performed in an hour, by the pendulum which has been the subject of the experiment, to the number of seconds in one hour. Thus, if in any latitude it could be ascertained that a pendulum 9 yards in length oscillated 1200 times in an hour, then as the number of oscillations, 1200, to the square root of the pendulum, 3, the square root of 9, so inversely would 3600, the number of oscillations required to be performed by the seconds pendulum, be to the square root of its length: that is, as $3600 : 3 :: 1200 : 1$; since $1200 \times 3 \div 3600 = 1$, the square of which would be 1; therefore a pendulum 1 yard long would swing seconds in any place where a pendulum 9 yards in length would make but 1200 vibrations in an hour.

119. It will be obvious, from what has been already stated, relative to the effect of friction, atmospheric resistance, and the extensibility of the line of suspension of a pendulum, that a multitude of precautions would be requisite in making direct experiments on the lengths of pendulums, with reference to the times of vibration at any given place. Dr. Halley, in the early part of the last century, estimated the length of a second's pendulum at 39.125 inches, $= 39\frac{1}{8}$ inches; and that estimate has been generally adopted, as sufficiently correct for practical purposes. From the most recent and accurate researches of men of science, it appears that the length of a pendulum which oscillates seconds, *in vacuo*, at the mean temperature of 62 degrees of Fahrenheit's thermometer, in the latitude of London, 51° 31′ 8″ N., must be 39.13929 inches: and as the further result of experimental inves-

By what proportion may we find the length of a second's pendulum, when we know the intensity of gravitation?

How may that length be ascertained by experiment?

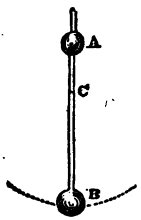
State some of the lengths actually found necessary in different parts of the earth, in order to produce the same number of beats per hour.

tigation, it may be added that at Melville Island, in the Polar Sea, Lat. 74° 47′ 12″ N., the length must be 39.207 inches; at the Galapagos Islands, Lat. 32′ N., 39.01719 inches; and at Rio Janeiro, Lat. 22° 55′ S., 39.01206 inches.*

120. As the force or intensity of gravitation decreases as the distance from the earth's centre increases, it follows that a pendulum, which would oscillate seconds at the bottom of a mountain one mile in perpendicular height, would not perform so many complete oscillations as there are seconds in an hour, if removed to the top of the mountain. Suppose the radius of the earth's circumference to be 4000 miles, as a second's pendulum would at that distance from the centre of attraction vibrate 3600 times in an hour, and therefore $86400 = 3600 \times 24$ in a day, it follows that it would lose the 4000th part of 86400 seconds in a day, at the distance of 4001 miles from the earth's centre. Now $86400 \div 4000 = 21.6$, that is, the loss would be 21.6 seconds in a day.

121. The length of a pendulum vibrating seconds being known, that of one which will vibrate half seconds, like those in most table clocks, or any other portion of time, may be readily calculated. For the times of vibration being as the square roots of the length of the pendulum, hence, as one second to 6.255, the square root of 39.125, so will half a second be to the square root of the pendulum required; that is as 1 : 6.255 : : 0.5 : 3.1275, the square of which will be 9.78. But the length of the half seconds, or any other pendulum, may be also found by taking the squares of the times, which will be directly as the lengths of the pendulums; thus as$(1 = 1^2)$sec. : 39.125 : :$(.25 = \frac{1}{2}^2)$sec.: 9.78, as before, or 9.7 inches, the length of a half second's pendulum.

122. A pendulum may be so constructed as to have its centre of oscillation far beyond the limits of its actual dimensions; and thus a pendulum only one foot in length, may be made to oscillate as slowly as another 12 feet long. Suppose a rod of iron, A B, to be loaded at both ends, and suspended at C, so that it might vibrate freely, it is manifest that though the arc described in each vibration would be limited by the length measured from the point of suspension, the velocity of the ball B, would be checked by the counterweight of the ball A, and the latter being moveable on the rod, the rate of vibration might be regulated at pleasure.



What would be the effect on the rate of a clock, of carrying it to the top of a high mountain? Why?

How may we calculate the true length of pendulums to vibrate in other times than *seconds*, when that of the latter is known?

How may the centre of oscillation be carried beyond the limits of a pendulum? Will this increase or diminish the number of its oscillations in a given time?

* See Abstracts of Papers printed in the Philosophical Transactions, from 1800 to 1830, vol. ii. p. 144, and p. 194.

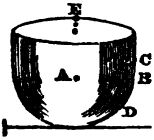
An instrument of this kind, called a Metronome, is used to mark, by its oscillations, the time in performing pieces of music.

123. A rod of uniform dimensions might be made to vibrate as a pendulum, without any ball or appendage whatever; but in that case the centre of oscillation would be raised, and such a pendulum must consequently be longer than one of the usual form. In a uniformly shaped rod or bar suspended at one extremity so that it might vibrate freely, the centre of oscillation would be at two-thirds of the distance between the point of suspension and the other extremity of the rod. Force applied at that part to arrest the motion of the rod would take complete effect, but at any other part a stroke would cause a tremour or irregular action of the moving body. Hence this point has been called the centre of percussion. In using a weapon of considerable length and nearly the same size throughout, as a cudgel or a sabre, the most effective stroke would be when the point of impact coincided with the centre of percussion; the situation of which must be at about two-thirds of the length of the weapon, its exact place depending chiefly on the relative weight of that extremity with which the blow is inflicted.

Centre of Gravity.

124. In every body or mass of matter at rest, there must be a certain point, in the direction of which, any force acting parallel to the surface on which the body is placed, will either be resisted by the weight and friction of the mass, so as to produce no effect, or if it be sufficiently powerful to overcome the resistance, the body will move in the direction of the force applied; but the same force acting against any part of the surface of the mass, not horizontally nor perpendicularly opposite to the point already mentioned, may cause the body to vibrate or be overturned, according to circumstances. This point is commonly called the centre of gravity, and sometimes the centre of inertia; and from the property just stated it might be termed the point of greatest resistance.

125. The annexed figure will serve to exemplify the phenomenon now described. Let A be the centre of gravity of a solid body with a hemispherical base resting on a horizontal plane, then if pressure be applied vertically at E, it is manifest that it can produce no motion; but if applied at B, directly opposite to the centre of gravity, its effect will depend on the degree of force, as a small force will be destroyed by the inertia of the solid



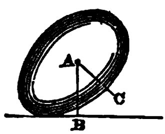
What substitute might be employed as a pendulum instead of the rod and balls?

Where would the point of oscillation of such a pendulum be found?

When such a pendulum is to be suddenly arrested, where must the resistance be applied? Describe and illustrate the centre of percussion?

What is meant by the terms "centre of gravity," centre of inertia," and "point of greatest resistance," when applied to bodies? What states mass, while a great force will be partly employed in counteracting the inertia, and partly in propelling the mass steadily along the level plane. Now if force be applied at C or D, or any other point above or below B, it will have some effect, however inconsiderable, causing the body to rock or vibrate, if the force be small, and to be overturned if the force be great.

126. The centre of gravity in all bodies is that point at which the influence of gravitation seems to be concentrated; and hence, in any body, unless that point be supported, motion will take place, and be continued till the body settles in a position in which the centre of gravity cannot sink lower. Therefore when no obstacle is opposed to the motion of a body, either by its peculiar figure or that of the surface beneath, it will always take such a position that a line drawn from the centre of gravity to the point where the body comes in contact with the surface below it will be the shortest that can be drawn from the centre to any part of its superfices. Thus an oviform body, placed as in the annexed figure, would not stand in the position represented, but would turn till the shorter line, A C, became perpendicular to the supporting surface, instead of the longer line A B.



127. If a body be supported from above, that is, if it be suspended from a fixed point, hanging freely, the centre of gravity will always settle in a vertical line beneath the point of suspension.

128. The exact situation of the centre of gravity must depend partly on the figure and partly on the uniform or varying density of the whole mass of any body. Suppose a body to be of uniform density throughout, its centre of gravity may be experimentally ascertained by balancing it on the edge of a square table, in two positions, when the lines of equilibrium will intersect each other at a point over the centre of gravity, which manifestly must be in the centre of the mass. A body of small dimensions may be more accurately balanced on the edge of a knife; or if the body can be conveniently suspended, and a plumb-line let fall from the point of suspension, its direction being traced from two such points, will be found to intersect each other as before, at a point on the superfices which will indicate the situation of the centre of gravity. If a body varied in its density in different parts, and possessed considerable thickness in proportion to its length and breadth, holes bored through the mass in directions vertical to different points of suspension, would meet at the centre of gravity of such a body.

of bodies result respectively from the support, and from the want of support to their centres of gravity?

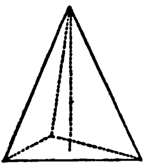
Of what comparative length will a line be found, between the centre of gravity of a body and the point of its superfices on which it rests?

What relative positions will be found between the centre of gravity of a body and its point of suspension?

On what two circumstances must the position of the centre of gravity depend? How can its situation be mechanically determined?

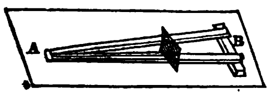
129. When the density of a body is uniform and its figure regular, the centre of gravity will be the central point of the mass; as in a globe, an elliptical or oviform spheroid, or a parallelopiped.

The surface of a triangle, its three sides, and its angular points, will all have the same centre of gravity, situated at two-thirds of the length of a right line passing from the vertex of the triangle to the middle of the base line. The centre of gravity of a cone will be at three-fourths of the length of its axis; and that of a hemispherical solid at five-eighths of the radius.



A pyramid and its four terminating points will have the same centre of gravity. The figure of a body may be such that the centre of gravity will not be included within the mass. Thus a hollow cone, as a common extinguisher, or any body of similar shape, would obviously have its centre of gravity in the void space within it; and so would a basin-shaped body or hollow hemisphere. A piece of wire twisted into the form of a horse-shoe, or of a hoop, would also have its centre of gravity, not in the wire, but in the open space within it.

130. The manner in which the centre of gravity of a body, when unsupported, tends towards the lowest point it can reach, may be illustrated by an amusing experiment, made with a piece of wood or any suitable substance turned in the shape of a double cone united at the base, then if a jointed two-foot rule be opened a little way, and raised at the open end, so as to form a sort of inclined plane, the piece of wood on being placed at the bottom of the plane, will roll along to the raised extremity of the rule, seeming to ascend the inclined plane, passing as in the annexed figure, from A to B. This is, however, merely an optical deception, for the centre of the double cone, which must be its centre of gravity, really sinks lower and lower between the sides of the rule as it advances to the open end.



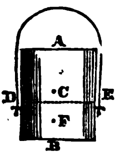
131. A somewhat similar experiment with an inclined plane, serves to show the effect of the different distribution of density or weight, in different parts of the moving body. Suppose a cylinder to be made of light wood or cork, and to have a plug of lead passed through it from end to end, so that its centre of gravity would be near its surface: if then it were placed on a moderately inclined plane with the loaded side towards the ascent, it would necessarily turn till that side rested on the plane; but it could plainly move no further, unless replaced, as in the marginal figure.

Where will it be found in bodies of uniform density and regular figure? How can you ascertain the centre of gravity in a triangle? a cone? a hemisphere? a pyramid? Does the centre of gravity necessarily fall within the mass of every figure?

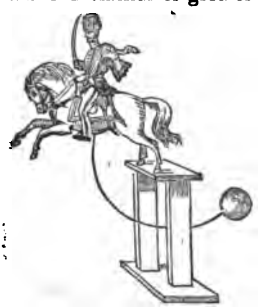
What experiment illustrates the descent of the centre of gravity when unsupported? What one exhibits the influence of distribution of density?

132. The necessity of supporting the centre of gravity in every situation appears from the manner in which we move in the act of rising from a seat. When a person is sitting the centre of gravity of the body will be supported by the seat, from which it will be impossible to rise without bending the body forward so as to bring the centre of gravity over the feet, previously to assuming the erect position; or else lifting the body by resting the hands on the back or sides of the seat or some other point of support. The utter incapability of locomotion that takes place when an animal is so situated that it cannot by its own efforts raise the centre of gravity of its body, is strongly exemplified in the case of a fat sheep, or ewe with lamb, which has been so unlucky as to lie down on the border of a shallow ditch or trench in a field, and roll over on its back into the hollow, where, in spite of its utmost efforts, it would lie with its feet in the air till it perished with hunger, if not assisted to rise. A tortoise thrown on its back affords another striking example of the same kind; in this manner sea turtle are captured on shore.

133. From what has been stated it is evident that the stability of a body must be increased by lowering its centre of gravity.



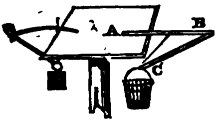
A cylindrical vessel A B, suspended by a handle turning on pivots fixed near the bottom, would inevitably overset when empty, as the centre of gravity C would then be above the points of suspension; but if a very heavy substance as quicksilver, or steel-filings, were poured into it, so as to fill it to the line D E, the centre of gravity would be reduced to F, and the vessel might be suspended with safety. Hence it may be perceived why vans and stage-coaches, if heavily loaded at the top, will be very liable to be overturned, while a similar or greater weight placed low down will prove a security from danger; and on this principle "safety coaches" have been constructed, with receptacles for heavy luggage under the bodies of the vehicles.



134. The effect of placing the centre of gravity of a body in a very low situation is shown in vibrating figures, such as that represented in the margin, and other toys for the amusement of children, formed on similar principles. Thus likewise a long stick or ruler, placed loosely on a bench or table, with more than half its length projecting beyond the edge of the board, may be made

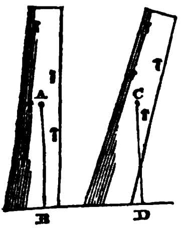
How is the position of centre of gravity illustrated in the manner of rising from a seat? How is its importance shown in the positions of animals? What effect on the stability of a body has the depression of its centre of gravity? What familiar applications can be adduced?

to support a bucket of water or a half hundred weight suspended



on it. The manner in which this is effected will be easily comprehended from the annexed figure, in which let A B represent the stick, which must have a notch or noose at the end B, against which rests another stick or prop, and the handle of the bucket being suspended by a string from the first stick, the prop pressing against the string at its junction with the handle C, fixes the bucket in such a position that the greater part of its weight and consequently the centre of gravity of the whole apparatus is supported by the table; and therefore, so long as the parts remain connected, the equilibrium will be preserved, for the end of the stick B cannot be depressed without raising the centre of gravity. A common tobacco-pipe, in the same manner, may be made to sustain any weight short of that which would completely crush it.

135. As a body of any kind cannot retain its position unless its centre of gravity be supported, it follows that stability may be preserved so long as a line directed from that centre vertically towards the surface below falls within the polygon formed by the base of the body in question. Hence the broader the base of any body the more securely will it stand; and on the contrary when the base is extremely narrow a body will easily be thrown down. If a portion of any mass overhangs its base, it may still remain standing so long as the vertical line from the centre of gravity falls within the base. Thus a column, an obelisk, or a steeple



might incline somewhat from the perpendicular, and yet stand firm. From the inspection of the annexed figures it will appear that the inclination of a column might be greater than is represented in the first figure, where the line A B falls within the base, without endangering the stability of the body; but it must be less than that in the second figure, where the corresponding line C D falls without the base.

136. Most very lofty buildings swerve in some degree from the perpendicular after a time, yet there can be no hazard of their destruction if properly erected. The monument built by Sir Christopher Wren, near London Bridge, to commemorate the great fire in 1666, and the elevated spire of Salisbury Cathedral, have both become slightly inclined, but they will probably long remain to afford standing evidence of the consummate skill of their respective founders. Travellers have frequently no-

How do vibrating figures exemplify the position of centres of gravity?

What advantage does an extended base afford for preserving the stability of bodies? What examples prove that leaning bodies may sometimes have a stable position?

ticed the leaning towers of Bologna and Pisa, especially the latter which is one hundred and thirty feet high, and inclines so much that the summit overhangs the base fifteen or sixteen feet; yet the line of direction from the centre of gravity dropping within the base, the structure has continued to stand or rather to lean for some centuries, and will probably endure centuries longer.

137. A change of the position of a body which leaves its centre of gravity unsupported, must necessarily destroy its stability. Hence a high carriage is liable to be overset when one side is raised more than the other by the wheels passing over a bank or by the sloping direction of the road; and an over-freighted boat may be capsized somewhat in the same manner, by a sudden lurch throwing the weight on one side. Such an accident may likewise happen in consequence of a person incautiously rising when a boat inclines to one side, the situation of the centre of gravity being thus altered, so as to swamp or upset the boat.

138. The impossibility of preserving any position without keeping the line of direction of the centre of gravity within what may be termed the area of stability, or polygonal surface by which the body is supported, may be experimentally illustrated by observing the effect of placing a person to stand with his heels close together and in contact with a perpendicular wall; for with such a position of the feet it would be found that he was unable to stoop sufficiently to touch the floor with one hand. The act of stooping is performed by bending the lower part of the body backward while the upper part is inclined forward, and thus though the situation of the centre of gravity is lowered, its line of direction still falls vertically between the feet. Now a person with his heels and of course his back also against a perpendicular wall could not possibly bend backward, and in attempting to lean forward he would inevitably lose his balance and fall down. So that one might scatter a handful of silver or gold on the floor before a person stationed as just described, and offer him all that he could pick up, while he kept his feet unmoved, without the slightest risk of losing one's money. For the sake of any one who might choose to try the experiment it should be remarked that the terms specified must be strictly adhered to; for if the heels are raised so that the body is supported by the toes, it will no longer be impossible to stoop sufficiently to touch the floor without falling: the requisite condition therefore should be that the heels must remain in contact with both the wall and the floor.

139. A body will remain at rest, or in the state of equilibrium only in two cases, namely, when the centre of gravity is either as near as possible to the point of support, or as far from it as pos-

What facts prove the importance of preserving the line of direction of a body within its base? What is meant by *polygonal surface* or *area of stability?* What experiment shows the application of the principles of stability to the human body?

Under what two circumstances can the equilibrium of a body be preserved?

sible. In the former case, the stability of the body will be secure; in the latter, extremely insecure; thus a heavy elliptical solid laid lengthwise would require a considerable force to remove it from its place, but poised endwise the slightest impulse would cause it to roll over. When the centre of gravity is at the lowest point, a body is said to be in a state of stable equilibrium; and when it is at the highest point, in the state of instable equilibrium.

140. Many feats of dexterity, as walking on stilts, dancing on the tight rope, standing on a slack wire, and balancing bodies either in motion or at rest, depend chiefly on the power of maintaining the state of instable equilibrium. Walking on stilts, sometimes practised by school-boys, as an amusement, is adopted as a matter of convenience by the shepherds in a district called the Landes, in the south-western part of France. The country there being a sandy level sometimes covered with water, the shepherds on leaving home take their lofty stilts, and may be often seen striding along, on their artificial supports, at an immense rate. The art of rope-dancing is facilitated by holding in the hands a long pole in a transverse direction; for a trifling elevation of one end of the pole and consequent depression of the other may be made at any time, to prevent the lateral deviation of the centre of gravity from its proper position vertically above the rope. Standing or walking on the slack wire appears to be a more arduous feat than moving on the tight rope; yet it is practised merely by keeping the arms extended to preserve the equilibrium; and sometimes in that attitude the performer will make a further display of skill, by balancing bodies, one above another, on his chin. Occasionally an exhibition of dexterity on the slack wire is made to appear more difficult, by the performer having handed to him a chair, and a small table which he fixes across the wire, by resting on it the rails which connect the legs of the chair and of the table, then seating himself in the chair and placing his feet above the front rail of the table, he keeps the whole accurately equipoised even when the wire is made to swing from side to side. But though this feat has a more imposing effect than standing alone on the wire, there is no doubt that it may be performed with greater facility; for the table, and in a less degree the chair also serve, like the pole in the hands of the rope-dancer, to assist in maintaining the centre of gravity in its proper place.

141. These feats, curious as they are, appear much less wonderful than the exhibitions described by some ancient writers of respectability, in which elephants are represented as walking on a tight rope. The difficulty of preserving the centre of gravity of so unwieldly an animal, moving on such a narrow line seems

How do we distinguish the two states of stable and unstable equilibrium? What feats of dexterity refer to the conditions of equilibrium for their explanation?

What remarkable feats are related to have been executed on the same principle by quadrupeds?

nearly to approach impossibility; but the evidence of the fact appears to be deserving of credit.*

Mechanic Powers.

142. Nature presents to our notice force capable of producing motion, under various modifications. The weight of solid bodies, the impulse of flowing water, the pressure of currents of air, the muscular exertions of men or brute animals afford familiar examples of different kinds of forces or means of originating motion; and it is the peculiar province of mechanical science to supply rules for the accumulation, distribution, application, and expenditure of these or any other forces, in the most advantageous manner, by means of machinery.

143. In investigating the effect produced by any machine, there are three things to be considered: 1. The nature of the force applied, generally styled the power; 2. The force opposed to it, called the resistance; and 3. The point or points of connexion between the power and the resistance, which when there is only one point, as in the most simple machines, may be termed the centre of action, and where there are two or more such points, the action of the antagonist forces must be distributed over those points.

144. Weight being in itself one of the most efficient kinds of force, and at the same time a common property of all bodies to which force can be applied, it has been very properly adopted as a convenient measure or medium of comparison of moving forces in general. But as the mere weight of a body in motion can afford no just indication of its impulsive force, the term moment or momentum has been adopted to denote the absolute force of a moving body with reference to the effect it is capable of producing. The difference between the force of a body at rest and that of the same body in motion, that is between its weight and its momentum, in different circumstances, will be obvious on the slightest consideration. Thus a musket-ball which might not be heavy enough to break through a sheet of tissue-paper, when laid gently on it, would perforate a much firmer substance, if dropped on it from a considerable height, and fired from a gun it would penetrate a thick deal board. The momentum of a body then must be estimated by its weight and velocity taken together.

Enumerate some of the natural forces capable of producing motion.
What has mechanical science to do with these forces?
How many and what things require to be considered in examining the effect of a machine?
What is meant by the term *centre of action?*
What is the difference between force and momentum?

---

* "Notissimus Eques Romanus elephanto supersedens per catadromum, id est funem, decurrit."—*Suetonius in Vita Neronis.* References to other writers, ancient and modern, who have noticed the exhibitions of elephants on the tight rope, are given in *Beckmann's Hist. of Invent. Eng. Tr.* vol. iii. p. 311.

145. From what has been stated elsewhere, it may be inferred that any force which would drive a body weighing two pounds a given distance in one minute, would drive a body weighing but one pound twice as far in the same time; and hence the velocity of the latter body would be double that of the former, though both impelled by the same force. Both bodies also would have the same momentum, as will appear on multiplying the velocity of each body respectively by its weight: for the velocity of the first-mentioned body may be represented by 1, and that of the last-mentioned, being double the other, by 2; then 2lb. $\times$ 1 $=$ 2, and 1lb. $\times$ 2 $=$ 2. And the same result will be obtained if we take the whole distance passed through by each body in a given time as the measure of its velocity; for suppose the body weighing two pounds to run a quarter of a mile in a minute, and that weighing one pound half a mile in the same time; then $\frac{1}{4}$ m. $= .25 \times 2 = 50$, $\frac{1}{2}$ m. $= .50 \times 1 = 50$; the sum expressing the momentum of either body being the same. Since the momentum of a moving body is to be estimated by its weight multiplied into its velocity, it follows that a comparatively small body may by the celerity of its motion produce a much greater effect than a body of far superior bulk moving slowly. Suppose the weight of a battering ram (such as was anciently used in war), to be 20,000 pounds, and that it moved at the rate of one foot in a second; and the weight of a cannon-ball to be 32 pounds, and that it moved 1000 feet in a second, then the momentum of the former would be 20,000 $\times$ 1 $=$ 20,000, and that of the latter 1000 $\times$ 32 $=$ 32,000; and consequently the effective force of the cannon-ball would be more than half as great again as that of the ram, notwithstanding its immense superiority of weight.

146. The mechanic powers are simple machines, or instruments, by means of which the acting force technically styled the power, is to be applied to the force which must be overcome, or that called the resistance. The advantage which is obtained by using these mechanical agents arises from the distribution of the resisting force among the different parts of the machine, so that the portion of it which is directly sustained or counterbalanced by the power bears but a small proportion to the whole; and thus a power insufficient to communicate motion to a body or support its pressure, without mechanical assistance, may effect the purpose for which it is employed, by transferring a part of the weight to one or more of those points already noticed, whether it be the fulcrum of a lever, the wheels of a pulley, or the surface of an inclined plane.

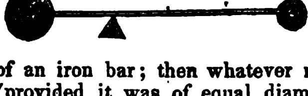
147. Different authors have varied considerably in the enumeration of the simple machines or mechanic powers, from the combination of which and their several modifications all other machines, including those of the most complicated nature, are pro-

Give some examples to illustrate this difference.
What is the nature and what are the objects of the *mechanic powers?*
Under how many general divisions may all mechanic powers be classed?

duced. Considered as modes of the application of impulse to overcome resistance, all the mechanic powers may perhaps be most correctly arranged under three divisions: 1. The Lever; 2. The Multiplied Cord; 3. The Inclined Plane. To these some have added the Wheel and Axle, the Pulley, the Wedge, and the Screw. But the wheel and axle is only a variety of the lever, the principle which regulates the action of both machines being precisely the same. The pulley, so far as it possesses any distinguishing property, must be considered as a multiplied cord; but in practice it is always used with wheels, and consequently it partakes in some degree of the nature of the lever. The wedge is nothing more than a double inclined plane applied in a peculiar manner, and acting exactly as a single inclined plane, but with twice the effect. The screw is a modification of the inclined plane, usually operating through the assistance of a lever. All these instruments have been commonly regarded as so many simple machines; it may therefore be as well to describe them separately, and in such order that the developement of their respective properties may illustrate the analogies among them which have been just pointed out.

The Lever.

148. The principle of action of all the mechanic powers is founded on the doctrine of equilibration, and is therefore intimately connected with the theory of the centre of gravity, which has been already explained. As no single mass of matter can remain in the state of equilibrium unless its centre of gravity be supported, so any number of bodies connected together must have some common centre of gravity on which they will rest securely, if undisturbed, or oscillate round that centre, when impulse is applied on either side of it.



149. Suppose two balls of iron, A, weighing three pounds, and B, weighing but one pound, to be fixed to the opposite ends of an iron bar; then whatever might be the length of that bar, (provided it was of equal diameter throughout,) the centre of gravity of the three connected bodies would be situated at a part of the bar just three times as far from the lighter ball as from the heavier, the weight of the latter being three times as great as that of the former; and the bar being supported at that point the equilibrium would be maintained. Such a bar would be a kind of lever, with respect to which the large ball might represent the resistance, or force to be overcome; the small ball the power applied; and the

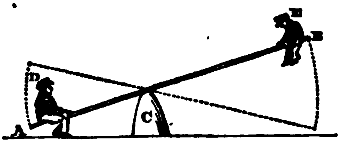
To which of these does the wheel and axle belong? to which the wedge and screw?

With what theory is the action of all mechanic powers connected?

What numerical relation exists between the length of the two arms of a lever and the forces applied at their extremities when in equilibrium?

supporting point the prop or centre of action, technically styled the fulcrum, which is a Latin word, signifying a prop.

150. The mode of action of the lever may be further illustrated by observing what takes place when two or more boys amuse themselves with a see-saw, or vertical swing.



Here the plank A B forms a lever, of which the block C is the fulcrum, and in order for the plank to be equipoised, it must be shifted into such a position that the greater weight of the boy D nearest the fulcrum, may be compensated by the greater distance from that fulcrum of the boy E.

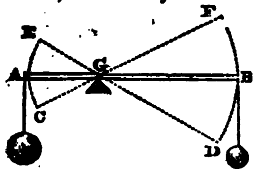
151. Any number of boys might be placed at either side of the fulcrum, provided that the sum of the weights of all the boys on one side, multiplied by their respective distances from the fulcrum, were equal to the sum of the weights of the boys on the other side, multiplied by their distances respectively from the same point. Thus, suppose the plank to be twelve feet long, and the fulcrum to be placed four feet from the end A, then a boy weighing thirty pounds at the end B would counterpoise another weighing sixty pounds at A; or the same boy at B would support two boys weighing forty pounds each, one being placed at A, and the other two feet nearer the fulcrum. This will appear from calculation, for the weight of the boy E, 30×8, his distance from the fulcrum, gives for the product 240; the weight of the boy D, 60×4, his distance from the fulcrum, also gives 240; and the weight of one boy at A, $40 \times 4 = 160$, and another at two feet from the fulcrum, $40 \times 2 = 80$, will by the addition of the products make 240. The plank being thus brought to a state of equilibration must, in order to make it vibrate, have some impulse given to it, either by the boys moving simultaneously upward on one side and downward on the other, and so on; or by pressing alternately with their feet against the surface below, as either end preponderates; or by any corresponding motion.

152. It has been proposed to adopt the principle of the see-saw in the construction of machinery for economical purposes. In the Journal des Savans, June 13, 1678, an engine is described, by means of which cripples, if even deprived of their limbs, being placed on the extremities of a long lever, might, by the alternate inclination of their bodies in opposite directions, produce sufficient effect to work the pistons of pumps for raising water. And in the same journal a description is given of a vibrating quadrangular frame, at one end of which four persons standing or sitting, might by their regulated efforts in depressing and raising the

From what species of amusement may a familiar illustration of this truth be derived?

In what manner has it been proposed to apply the principle of the see-saw to useful purposes?

frame, communicate a vertical motion to a saw for cutting timber: horizontal motion to surfaces for polishing marble, or levigating powders; force to a pair of shears for cutting through plates of metal; or rotatory motion to a wheel for any purpose. *



153. Since the momentum of a body is always to be estimated by its weight and velocity multiplied together, and the velocity by the space described by a moving body in a given time, it will follow that the momentum of bodies in a state of equilibration must be the same. For let A B represent a lever kept in equilibrium by two leaden balls, the larger weighing two pounds, and the smaller one pound; then suppose the weights were removed, the lever would take the direction E D, the extremity A would describe the small arc A E, and the extremity B the arc B D, and those arcs would denote the spaces moved through by the respective ends of the lever. Hence the momentum of the two weights necessary to preserve the equilibrium of the lever may be found by multiplying the absolute weight of each by the number representing the velocity, or space described; if therefore the arc B D be two inches, and A E one inch, it must be obvious that the products of the respective weights and velocities multiplied together will in each case be two, which would express the momentum or moving force exerted by each weight to preserve the equipoise of the lever. It must also be noticed that the arc B D, or F D, will always be in a direct proportion to the line G B, and the arc A C, or E C, will bear the same proportion to the line G A; so that, whether the number of pounds in each weight be multiplied by the number of inches in its corresponding arc, or by the number expressing its distance from the fulcrum, the result will show the momentum of both weights to be the same. For let G B be 12 inches, and G A 6, then $12 \times 1 = 6 \times 2 = 12$.

154. A lever theoretically considered must be an inflexible rod, of uniform weight in every part, turning freely on a fixed point or fulcrum. There are three kinds or orders of levers: 1. That in which the power P and the resistance R act in the same direction, having the fulcrum F between them; 2. That in which the power and resistance are in opposite directions, the latter being between

What is meant by momentum, when applied to bodies at rest? Exemplify this in the case of the lever.

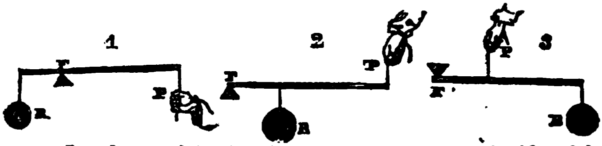
What are the three characters of a lever assumed in theoretical investigations?

How many orders of levers may be enumerated? How are the several orders usually distinguished?

---

* This simple kind of machinery, known in French by the name of *bascule*, has been proposed for various other objects.—See *Borgnis Traite des Machines.*

the fulcrum and the power; 3. That in which the power and the resistance are also opposed, the former occupying the intermediate position, and being opposed to the fulcrum.



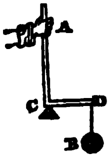
155. In a lever of the first kind, those parts on each side of the fulcrum are termed the arms of the lever; and the greater the relative length of that arm with which the power is connected compared with that to which the weight or resistance is attached, with so much stronger effect will the power be enabled to act. As the power will retain the lever in equilibrium when its momentum is barely equal to that of the resistance, it must have a greater momentum in order to produce motion. Now its momentum or acting force, so far as it depends on the lever, is derived from the superior length of the arm with which it is connected; and therefore in order to raise the weight or resistance, it must descend through a space as much greater than that through which the weight rises, as the length of the arm to which the power is applied is greater than the length of that arm to which the weight is appended. Thus by means of the lever, a small power can move a great weight; but in this case the space passed through by the power will always be greater than that through which the weight moves; and the greater the advantage which the power derives from the lever, the greater must be the difference of the lengths of its arms, and consequently the less will be the motion of the weight.

156. A long lever turning on a strong iron pin, as shown in the margin, is used by artillery-men to raise pieces of ordnance or other great weights. Wheelwrights and coachmakers employ a lever of similar construction, but having a shorter handle, and a higher fulcrum, and with this they raise a carriage on one side, when they want to remove a wheel. Crowbars and handspikes are levers of a similar kind, as also is the instrument called a jemmy, used by thieves, in breaking open doors or wrenching off locks or other fastenings. A pair of scissors, snuffers, or pincers, consists of two levers turning on a rivet, which serves as the ful-

What are signified by the *arms* of a lever? From what is the mechanical efficiency of the *power* derived?

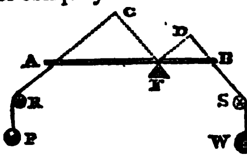
In what ordinary implements is the first order of levers exemplified? In what familiar example do the force and resistance act at right angles to each other?

crum, on one side of which power is applied to overcome resistance on the other side.

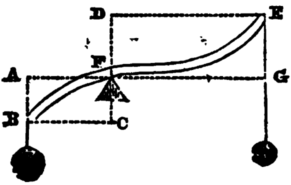


A common claw-hammer may be employed as a lever, acting with considerable effect in drawing out nails. In this case the line of direction of the power will be perpendicular to that of the resistance, as appears from the marginal figure.

157. Here the advantage obtained by the power is to be estimated by its vertical distance from the fulcrum A C, compared with the horizontal distance C D, between the fulcrum and the resistance, represented by the weight B. When the power, or resistance, or both act obliquely, their effect will be diminished, according to the degree of obliquity.



Suppose A B to represent a lever turning on a fulcrum at F, and let A R be the direction of the power P, and B S that of the weight W; then if the line R A be continued to C, and the line S B to D, and the perpendiculars F C and F D be drawn from the fulcrum to meet the lines of direction in the points C and D, the momentum of the power will be as its weight multiplied by the number denoting the length of C F, and the momentum of the resistance will be as its weight multiplied by the number denoting the length of D F.



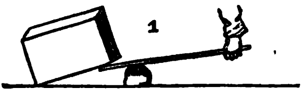
158. Let B E be a curved lever supported at F, and having the power suspended at E, and the weight at B; then the momentum of the former will be found by multiplying its weight by the line F G, or D E, and that of the latter by multiplying its weight by the line A F, or B C. These lines A F, and F G, are both shorter than the curve arms of the lever. If the fulcrum F be in a straight line between B and E, this lever will possess the same character as if the lever were straight; but if the fulcrum be situated out of a straight line while the force and resistance continue parallel, the lever will be progressive. This is the character of the bent steelyard, in which the poise being uniform, the weight is estimated by the height to which it will elevate the poise.

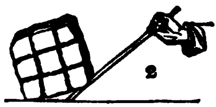
159. Whatever may be the nature of the lever employed, as whether it be of the first, second, or third kind, its mode of action is in every case to be explained according to the principles already

How is the advantage obtained by the *power* estimated when the directions of the force and resistance are not parallel?

Describe the bent lever. How may the mode of action of all levers be explained?

laid down. Thus in a lever of the second kind, in which the resistance, or weight to be overcome, is placed between the fulcrum and the power (see 154), the advantage of the latter will be increased in the same ratio, as that of the distance or space between the power and the fulcrum to the space between the resistance and the fulcrum.





160. The annexed figure (1) represents the manner of using a handspike or bar as a lever of the first kind: (2) shows how a similar bar may be employed as a lever of the second kind; the point of the lever here being fixed against the ground or surface below the body to be moved, and the power applied to the opposite end of the lever. Among the various examples which might be adduced of levers of the second order, may be mentioned the knife used by druggists for chipping sassafras, quassia, and other medicinal woods; one end being connected with a table by a hinge on which it moves as its fulcrum, the power is applied to the handle at the opposite extremity, and the substance to be chipped, forming the resistance, is placed between them, and is cut through by the edge of the knife pressing it against the table. The cutting blade used by chaff-cutters, and those of coopers, and last makers are likewise made to act on the principle of a lever of the second order.

161. In rowing a boat, regarding it as the weight or resistance to be moved, the water must be considered as the fulcrum, against which the pressure of the blade of the oar, acting as a lever of the second kind, moved by the hand of the waterman, as the power, at the opposite extremity, produces the motion of the boat. A pair of nut-crackers is formed by two levers of the kind just described, moving on a hinge as a fulcrum; and so likewise is a lemon-squeezer. When two men bear a weight on a hand-barrow, one of them may be considered as occupying the place of the power, and the other that of the fulcrum. If they have both the same degree of strength, and can support the barrow in a horizontal direction, the weight or burden should be exactly between them; for if it be placed nearer to one than to the other, an advantage will be given to the man stationed furthest from it.

162. In a lever of the third kind, (see 154) the power being nearer the fulcrum than the weight or resistance, the advantage lies on the

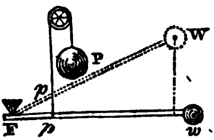
What implement illustrates the second order of levers?

In what manner may we explain the effect of oars in rowing?

How are we to compute the relative portions of a given weight borne by two persons on a pole?

How are the power, fulcrum, and weight arranged in a lever of the third order?

side of the latter; and therefore a greater degree of force would be requisite to support or move the weight by means of such a lever than that which would suffice to produce the same effect without the aid of any machine. But in this case the power will raise the weight through a greater space than that through which the power itself passes, and will consequently cause the weight to move with a velocity beyond its own. This will appear from the inspection of the marginal figure, in which the power P, acting over a pulley, from the point of the lever *p*, will, in moving the lever to the position F *p* W, raise the weight or resistance from *w* to W, while the power only passes through the space from *p* to *p*; or more accurately the line described by the weight will be the arc *w* W, and that described by the point from which the power acts, will be the very small arc *p p*.



163. This kind of lever therefore is not used to overcome great resistance, but either to move a weight with great speed, or from its peculiar adaptation to some particular purposes. Thus, a builder in raising a long ladder from the horizontal position, to place it against a wall, finds it convenient to fix the foot of the ladder against a block or stone, as a fulcrum, and laying hold of the ladder at half or three-fourths of its length, he supports at first the greater part of its weight, but gradually bringing it nearer and nearer to a perpendicular position, he shifts his hands accordingly from the point where he first grasped it, till he can bring them low enough to keep the ladder upright, and then it may be removed to the required situation. The treadle of a turning lathe, or grinding machine, affords a familiar example of a lever of the third order, in which the pressure of the foot becomes the power, which, acting between the fulcrum and the resistance, sets the machine in motion. In a pair of tongs, or shears used in clipping the wool from sheep, two such levers are connected so as to have the fulcrum at the point of junction, and the hand in using one or the other, acts as the power between the fulcrum and the resistance.

164. But the most interesting examples of the application of such levers may be found in the structure of animals. Thus the fore-arm, connected with the upper part of the arm by the elbow-joint, moves on that joint as a fulcrum, the power that lifts or bends it being supplied by the contraction of muscles, acting from points between the elbow and the wrist. The whole arm is raised from the side of the body to a horizontal position in the same manner, chiefly by the action of a strong muscle called the Del-

What sort of mechanical advantage is it the purpose of levers of the third order to attain?

What practical applications of this order of levers can be named?

What parts in the structure of animals exemplify the third order of levers?

toid, forming the fleshy part of the shoulder, and stretching down on the outside of the arm, with the bone of which it is firmly connected. The bending of the knee-joint and the hip-joint in walking, is performed by the corresponding action of strong muscles; and in various parts of the human frame motion takes place in a similar manner. In the lower orders of animals an analogous kind of machinery may be discovered, as in the wings of birds, which are thus made to move with extraordinary velocity, that they may be enabled to act on a medium having so inconsiderable a degree of density as the air.

165. Any number of levers may be connected together, so as to constitute a composition or system of levers, the power acting on the end of the first lever raising the end of the second, and that depressing the end of the third, so as to raise a weight at the opposite extremity; or the alternate action may be continued through a great number of levers, the effect of which would be to augment vastly the momentum of the power, and to diminish in the same proportion the velocity of the weight, or resistance, so that the space through which that resistance would be moved would in general soon become very insignificant. The effect of such a system of levers must be estimated according to the relative distances of the power and the weight respectively from the fulcrum, whether the levers were all of one kind, or some of one kind and some of another.

166. Among the various applications of the lever, one of the most useful and important is in the construction of the common balance, styled, from its adventitious appendages, a pair of scales. The beam, which is the essential part of the machine, is nothing more than a lever of the first order, having equal arms, and turning freely on its fulcrum, or centre of action. It is hardly necessary to add, that its use is to ascertain the weight of bodies by equipoising them with an authorized standard; and the principle on which this is effected has been already amply illustrated. There are however some circumstances requisite to insure the accuracy of a balance, which deserve to be noticed.

167. The beam of the balance should be so formed that its centre of gravity may be placed just below the axis or centre of motion; for if the centre of gravity and centre of motion coincided, it must be obvious that the beam would rest in any position instead of assuming the horizontal direction necessary to indicate the equality of weights on each side. However, when a very delicate balance is required, its beam must be so constructed that the centre of motion may be as near as possible to the centre of gravity, but somewhat above it. The extremities of the arms of a balance are named the points of suspension, to which are fixed the scales; and those points should be so situated that a straight

In what manner may levers be combined together for the production of any desired effect?

How is the effect of such a system of levers to be estimated?

What circumstances are requisite to insure the accuracy of a balance?

line extending from one to the other would touch the point on which the beam turns. The sensibility of the balance is likewise influenced by the form of the fulcrum; and in the most accurate balances the beam rests on a knife-edge moving on agate, polished steel, or some very dense and smooth surface. Equal nicety is required in the suspension of the scales, which should hang from thin edges.

168. Having thus stated the method of rendering a balance as exact as possible, it may be proper to notice some of the imperfections of common balances, caused as they are too frequently by design, for the purpose of fraudulent deception. If the two arms be not precisely of the same length, the scale appended to the longer arm will turn with a less weight than that hanging from the shorter arm, and the purchaser of goods may thus be cheated: so also if one arm of the lever be heavier than the other, the scale on that side must preponderate. But deceptions of this kind may be discovered by changing the places of the weight and the article to be weighed; for the lightest scale would no longer keep equipoised. And yet with such a pair of scales the true weight of a substance might be ascertained; since by weighing it first in one scale and then in the other, multiplying together the two weights, and extracting the square root of the product, we should obtain the true weight.*

169. The steelyard is another well-known kind of balance, more directly involving the principle of the lever in its construction than the common balance. It consists of a lever with unequal arms, turning on its fulcrum, and having on the longer arm a moveable weight, so that the body, whose weight is required, being suspended from the shorter arm, the equilibrium is attained by shifting the weight to the necessary distance from the fulcrum, and the longer arm being graduated and numbered, the weight appears from inspection. This is sometimes called the Roman balance, as alleged from its resemblance to the Roman statera; though it has been stated that the original term was Romman, and that it was so called in the East, from the shape of the weight, resembling a pomegranate.† Such a balance as the steelyard, but of small dimensions, and made of ivory or wood, is used by the Chinese for weighing pearls, precious stones, and other small objects.

170. The Danish balance is a straight bar or lever, having a heavy weight fixed at one end, and a hook or scale at the other,

What are some of the defects liable to be found in balances?
How may a false balance be detected?
How may the true weight of an article be obtained by means of such a balance?
How is the action of the steelyard to be explained?
What is the construction of the Danish balance?

* See Leslie's Elements of Natural Philosophy, vol. i. p. 186.
† Idem, p. 187.

with a moveable fulcrum, the situation of which indicates the weight of any substance which may be tried by it. The bar of course is graduated, and thus the weight may be determined, but the divisions becoming smaller in proportion as the weight increases, inconvenience occurs in ascertaining the exact amount ot the weight of very heavy bodies.

171. The weighing-machine used at toll-gates on turnpike-roads, to discover the weight of loaded carriages, consists of a system of levers supporting a quadrangular floor. Four levers turning on their fulcrums extend from the angles of a box beneath the floor towards its centre where they are connected together, and also with another lever extending across the middle of the box, and passing beyond its limits; this last lever acts on a third which presses on a spring or is connected with the arm of a balance, by means of which the amount of pressure on the whole system may be ascertained.

The Wheel and Axle.

172. Though the lever may be considered as the most generally applicable, and consequently the most useful of all simple machines, yet from the limited effect and intermitting action of power employed to overcome resistance by means of the lever, its grand utility must ever be confined to cases in which a momentary effort is required to change the place or position of a body of a great weight, by the application of comparatively small power. Thus, if it be necessary to remove a heavy block of marble or granite from one place to another, and a lever can be applied in such a manner to one side of its base as to shift the position of its centre of gravity sufficiently to make the block turn over, it may thus be rolled to any given distance: but supposing the utmost effect of the lever be to raise the mass but one inch, or any space through which it would fall back to its first position, the lever alone would manifestly be quite useless. Hence different methods have been contrived for rendering the lever more effective, as by employing a German machine, called a Hebstock, by which the weight is propped or supported during the intervals between the successive operations of the lever; by the French machine, termed Roue de la Garosse, from the name of the inventor, and by means of which a lever is kept in a raised position by a ratchet wheel; or by using the Universal Lever, which also acts by means of a ratchet wheel.*

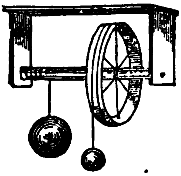
To what objection is it liable?
What is the construction of weighing machines for carriages?
What circumstance limits the utility of the simple lever? How has it been proposed to obviate this defect?

---

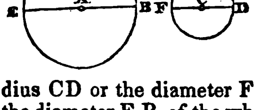
* This kind of wheel can only move forwards or in one direction, being prevented from turning the other way, by a spring detent falling between teeth on its periphery.

173. But these modes of operation must be nearly useless where it is requisite to raise a body to a great height, or move it through a considerable space, and for such purposes may be advantageously employed the wheel and axle, sometimes called Axis in Peritrochio,* which has generally been ranged among the the simple machines, or mechanic powers, though it is in fact only a more complicated form of the lever, and it might with propriety be styled a perpetual lever.

174. It consists of a wheel or large flat cylinder, with a smaller cylinder passing through its centre, as an axle, to which it may be fixed so as for both to move together about the same centre, or the wheel may turn on its axlê, in which case the effect will be different from that where the parts of the machine are connected.



In investigating the operation of the wheel and axle both parts must be considered as turning on a common centre. Let the annexed figure represent a horizontal axle, resting at its extremities on pivots, or supported by gúdgeons, so that it may revolve freely, carrying round with it the attached wheel. On the axis is coiled a rope which sustains the weight; and round the periphery of the wheel is coiled another rope, in a contrary direction, to which is suspended the power. Then supposing the machine to be put in motion, the velocity of the power will be to that of the weight, as the circumference of the wheel to that of the axle; for it will be perceived that the power must sink through a space equal to the circumference of the wheel, in order to raise the weight through a space equal to the circumference of the axle. And as the momentum of any body may be found by multiplying together its weight and its velocity, it follows that if the number of inches in the circuit of the wheel multiplied by the number of pounds in the power, produce a sum equal to the product of the measure of the axle multiplied by the number of pounds in the weight, then the power and weight will remain in equilibrium.



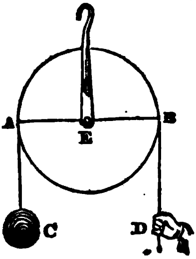
175. As before stated, the momentum of bodies moving in circles will be as the products of their weights and the radii of the circles they respectively describe, therefore when the power bears the same proportion to the weight as the radius CD or the diameter F D of the axle does to the radius A B or the diameter E B, of the wheel, the machine will preserve the equi-

What name might properly be applied to the wheel and axle? Of what does it consist? In what ratio are the power and weight to each other when this machine is at rest?

* From the Greek Αξων, an axis, and Περιτρεχω, to turn round.

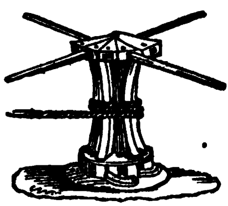
librium; so that the effect of this machine will depend on the superiority of the radius, or diameter of the wheel to that of the axle.

176. The wheel may be moved by a weight acting on its periphery, as already described; by projecting pins, or by a bent handle, such as is used for the common draw-well; but whether the power be applied directly to the circumference of the wheel, to the extremities of the projecting pins, or to the handle, its effect must be estimated by the extent of the circle described.



177. That the wheel and axle differs not in principle from the lever may be demonstrated from considering the effect of a single wheel used not for the purpose of increasing power, but merely in order that a power may be enabled to act in some required direction. For let C be any weight, as ten pounds, suspended over a wheel by a line held at D, it will be obvious that setting aside the effect of friction, a power equal to ten pounds must be applied to keep the weight equipoised. Now the pivot on which the wheel turns will manifestly be the centre of motion or fulcrum, supporting the joint action of the power and the weight; and the lines A E and B E will represent the equal arms of a lever held in equilibrium, like a balance loaded with equal weights.

178. A Venetian window-blind is usually suspended in this manner, by an endless line passing round two wheels; and while both sides of the line are equally stretched, the blind will remain at any height, but destroying the equilibrium, by pulling the line on one side or the other, will raise or lower the blind at pleasure. In the wheel and axle the radius of the wheel represents the longer arm of a lever, and the radius of the axle the shorter arm; and hence the advantage this machine affords. And as its action may be continued indefinitely, each revolution producing an uninterrupted effect, the power may be regularly applied till the object in view be attained.



179. One of the most efficient forms of the wheel and axle is displayed in the capstan used on board ships and in dock-yards. It consists of a vertical spindle fixed firmly as in the deck of the vessel, but turning on its axis, and supporting a drum, or solid cylinder connected with it, and having its periphery pierced with holes directed towards its

On what will the effect of the wheel and axle depend? How is the effect of the wheel to be estimated, when the cord is not applied directly to its periphery? How can you prove the identity of the wheel and axle, and the simple lever? Of what practical applications is this machine susceptible? What is the construction of the capstan, and how is its effect to be computed?

centre. It is then worked by long levers, inserted in the holes by men who walk in succession round the capstan, and thus make it revolve, while a rope or cable wound about the spindle may act with force sufficient to weigh a ponderous anchor, or warp a heavy-laden vessel into harbour.

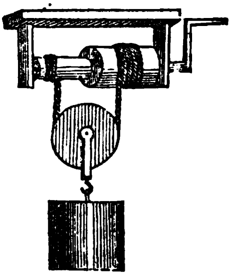
180. The treadwheel is anothor modification of the wheel and axle, in which the weight of several persons stepping constantly at the circumference of a long wheel make it revolve by their weight; as may be readily comprehended from the annexed figure. A somewhat similar wheel turned by the weight of one man is used in Persia and some other oriental countries, for raising water.

One or more horses may be made to work a mill, by harnessing them to the extremity of shafts or long levers fixed to an axis, which they turn round by walking in a circle; as in a machine for triturating clay for brick-making, and in some malt-mills. A treadwheel of a peculiar form is used in some parts of the United States acted on by horses, oxen, or other animals.

181. The axle of a wheel sometimes has a conical or tapered shape, which affords an advantage when a varying force is to be overcome. The mainspring of a watch, the power of which is employed to uncoil a chain, acts thus on an axis, called the fusee, on the surface of which is cut a spiral groove to receive the chain; and when the watch is newly wound up, the spring acts with its greatest intensity to turn the fusee while the chain passing round that part where the diameter is shortest, affords but a small leverage; and as the elastic force of the spring gradually diminishes by its relaxation, it obtains greater and greater purchase by the increasing diameter of the fusee as the chain is uncoiled; so that by this means an equability of action is maintained, without which the watch would be useless. A similar contrivance is adopted to equalize the effect of power applied in raising ore from a deep mine; for the rope, when at its greatest length, (and consequently when the resistance of the weight is greatest), is coiled about the narrow end of the axle, and the successive coils advance towards the wider extremity, as the resistance diminishes by the shortening of the rope.

182. As the efficiency of the wheel and axle, whatever may be its peculiar construction, is to be estimated by the ratio of the diameter of the wheel to that of the axle, it follows that increasing the former or diminishing the latter will augment the effect. Either method may be adopted to a certain extent; but if the wheel be extremely large it may be inconvenient and unmanageable; and on the other hand, if the axle be very slender, it will be weak and insecure. Both these evils are avoided in the construction

For what purpose is the treadwheel used in Persia?
What is the construction and advantage of the watch fusee?
How is the principle of the fusee applied in mining operations?



of the double capstan, an ingenious contrivance, said to have been brought from China. It consists of two cylinders differing in diameter, connected, as in the marginal figure, turning about the same axis, while the weight is suspended by the loop of a long cord, one end of which uncoils progressively from the smaller cylinder, as the other laps round the larger: thus the weight is elevated at each revolution through a space equal to half the difference between the circumferences of the two cylinders. So that the mechanical advantage of the machine, with its pulley, will be in the ratio of the diameter of the larger cylinder to half its excess above that of the smaller one; and therefore the equilibrium will be preserved, when the product of the power multiplied by the former is equal to that of the weight multiplied by the latter. This is true when the machine is moved by a hand rope applied to the larger cylinder; but when the crank is employed, twice *its* length must be substituted for the diameter of the larger cylinder.

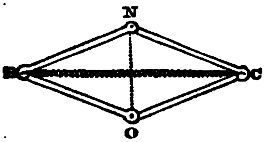
183. The efficiency of wheel-work may also be indefinitely augmented by a system or composition of wheels and axles, as in the case of the lever Thus the effect of the power that acts at the circumference of the first wheel may be transmitted to the circumference of its axle, with which a second wheel being connected may act through its axle on a third wheel, and so on to any given extent. One wheel may be made to turn another merely by the friction of their surfaces, when but little force is required; but the most direct and accurate method of connecting trains of wheel-work is by teeth or cogs, on the peripheries of the wheels; and on this principle a great variety of complex machines are constructed. Different wheels may also be connected by a strap or band, as is the case with spinning-wheels and the wheels of turning-lathes.

The Machine of Oblique Action, or Multiplied Cord.

184. To this kind of mechanic power may be referred all those cases in which force is transmitted by means of flexible cords or chains, from one point to another. It has also been styled the funicular system, but as including a variety of modes in which power can be applied by means of inflexible rods or bars, as well as by flexible lines, to produce an equilibrium depending on the

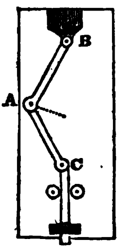
How is the double capstan, or *differential axle*, formed?
How much is a weight elevated by each turn of this machine?
How may the efficiency of wheel-work be augmented?
In how many methods may motion be transmitted from one wheel to another?

composition of forces, it might be, perhaps most properly, designated the machine of oblique action. From the theory of the composition of forces, which has been elsewhere illustrated, it may be assumed that a force applied in the proper direction will balance any two forces; but if one of these be sustained by some fixed point, the first force may be considered as acting only against the other; and power may thus be indefinitely augmented.



185. Suppose B N, N C, C O, and O B, to be four bars connected by joints or hinges at B, N and O, and by a spiral spring passing from the joint B, so as to unite it with the ends of the bars N C and O C at C. Pressure applied in the direction O N would elongate the spring with an effect which would increase in proportion to the decrease of the angle N C O, so that at the collapse of the bars B O and C O into a rectilineal position, the effect would be incalculably great.

186. If the end B of a pair of jointed rods be firmly fixed, and the extremity C made to act by pressure, as by a man pushing at A, the force at C, when the bars are brought nearly into a straight line may be equal to the weight of many tons. On this principle that part of the Russel printing-press is contrived by means of which the paper is applied to the types to take off impressions; instead of using a screw turned by a lever, as in the common printing-press. The same kind of mechanic power is employed for extracting the steel core from the hollow brass cylinder used as a roller in the printing of cottons; and various modifications of it have been adopted, with great advantage in several operations of art, where a vast momentary effort is requisite to produce a given effect.



187. The theory of the machine of oblique action, as it applies to flexible cords, has been sufficiently explained in treating of the composition of forces. (See 35 & 36.) It may, however, be here stated, that if a cord be acted on by equal forces in opposite directions, its tension will be measured by one of those forces or weights, and must of course be uniform throughout; and whatever flexures the cord may undergo, and however numerous be the fixed points it passes over, provided its motion be unimpeded, the weights required to keep it in equilibrium must be equal. But if a cord be fastened at one extremity and variously deflected, the effect of weights suspended to different parts of it will be modi-

On what theoretical principle is the machine of oblique action founded? Illustrate its application in the hinged apparatus or *toggle-joint*.

How is this machine applied in the printing press?

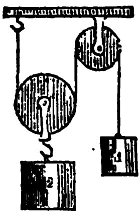
For what species of effort is it peculiarly adapted?

What measures the tension of a cord stretched by equal weights at the extremities?

fied according to their situation; so that a great weight acting near the point of suspension may be counterbalanced by a comparatively small force at the opposite extremity of the cord.

The Pulley.

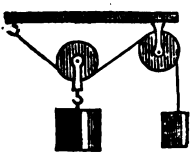
188. This is rather a compound than a simple machine; for from the investigation of its nature and properties it will be evident that it is merely a combination of the wheel and axle with the multiplied cord; and as the wheel, though a very useful, is not an essential part of the pulley, this machine may be regarded as a variety of the funicular system, or multiplied cord.



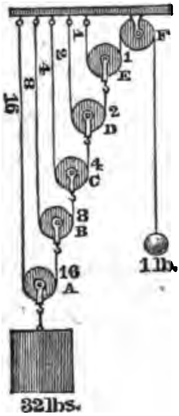
189. The effect of a single pulley, or moveable wheel suspended by a cord from a hook at a fixed point, as in the annexed figure, will be to diminish the resistance by one-half, so that a power equal to one pound will support a weight of two pounds. This must be manifest from considering that half the weight is supported by the hook, consequently the other half only is opposed to the power. The same conclusion will be derived from attending to the result of the action of the power in raising the weight; for double the length of rope must pass over the fixed pulley on the side of the power compared with that which passes over it from the weight; so that the power must descend two inches in order to raise the weight one inch. Thus the power will move as fast again as the weight, therefore its velocity must be double that of the weight, and its effect must be increased by such a pulley in the same ratio.

190. The fixed wheel or pulley here, has no other effect than that of altering the direction of the power. (See 177.) Though a pulley might obviously be made to act without wheels, and the cord might be deflected by passing through rings or by other means, so that the wheel must be considered as a sort of adventitious appendage to the pulley, yet, as already observed, it is an extremely useful one. For the wheel enables the cord to move freely, by destroying in a great measure the friction which would otherwise take place between the cord and the surface over which it passes, and which would weaken, and in some cases interrupt, the action of the pulley. The wheels also serve the important purpose of keeping the deflected parts of the cord stretched in parallel lines; for the effect of the power would be diminished in

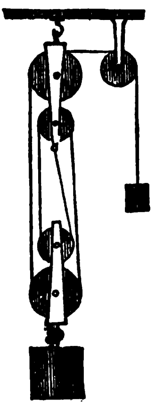
When one extremity of a cord is fastened to an immoveable point, how will weights applied to intermediate points affect the cord?
How may the pulley be regarded in a theoretical view?
How are we to compute the effect of a single moveable pulley?
What is the effect of a single fixed pulley?
What is the advantage of the wheel in the construction of this machine?



any other position of the cord. Thus when the deflections of the cord form an angle, as represented in the margin, the power must be equal to more than half the weight, in order to keep the latter suspended; the machine will become less and less efficacious as the angle formed by the sides of the cord increases; and when the two parts of the cord supporting the weight approach nearly to a straight line, the power must be greater than the weight to enable it to preserve the equilibrium.

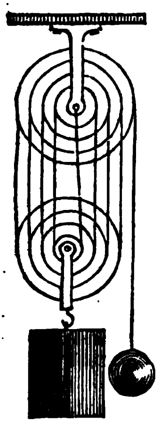


191. In the pulleys just described, is exhibited the effect of the power when the weight is partly supported from one fixed point; but that effect may be vastly augmented by such a system of pulleys as that in the annexed figure, in which the weight is suspended from the lowest of a series of wheels, each having its own cord attached to a fixed point. Here the resistance is diminished by the distribution of the weight over five fixed points; so that supposing the weight to be thirty-two pounds, the wheel A, with its cord, will support the whole of that weight; the wheel B, with its cord, half the weight or sixteen pounds; C, one-fourth of the weight or eight pounds; D, one-eighth or four pounds; E, one-sixteenth or two pounds, which being divided by the two sides of its cord, leaves but one pound to be supported by that side which is extended over the fixed pulley F; and thus a power equal to one pound will counterbalance a weight of thirty-two pounds.



192. When one cord only is used, which passes over two or more fixed and moveable pulleys, the power will be to the weight, as unity, or the single part of the cord supporting the power, to the number of the deflections made by the cord in passing over all the fixed and moveable pulleys. Hence if the power be augmented, so as to raise the weight, the former must descend through as many inches more than the latter ascends, as the number of bends in the cord supporting the lower block exceeds unity: that is, the power must sink four inches or feet to elevate the weight one inch or foot; and such will be the ratio of its efficiency with such pulleys as that shown in the marginal figure, the advantage gained depending on the number of wheels and consequent deflections of the cord.

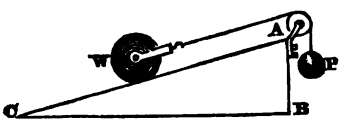
How does the obliquity of the cords affect the relation between the



193. A great variety of systems, or, as they are commonly termed tackles of pulleys, have been contrived; but the advantages they respectively afford may always be estimated by reference to the spaces relatively described by the power and the weight or resistance. The greatest inconvenience occurring in the practical application of the pulley, is owing to friction, and consequent irregularity of action. Various plans have been adopted to remedy this defect; one of the most ingenious of which consists in cutting a proper number of concentric grooves on the face of a solid wheel, with diameters, as the odd numbers, 1, 3, 5, &c., for the lower block, and corresponding grooves on another such wheel, with diameters, as the even numbers, 2, 4, 6, &c., for the upper block. Then the cord being passed in succession over the grooves, as represented in the margin, it will be thrown off by the action of the power, in the same manner as if every groove formed a separate and independently revolving wheel. A machine of this construction is called White's pulley, from the name of the inventor, Mr. James White, who obtained a patent for it.

194. Tackles of pulleys are used on board ships, where the wheels are fixed in blocks, by means of which the sailors can raise the masts, hoist the sails, and conveniently perform other necessary operations. Various combinations of pulleys are likewise used on land, as by builders, in raising or lowering great weights; and in removing from one level to another heavy bales of goods, or other merchandize.

The Inclined Plane.



195. This is the least complicated of all the simple machines. It is, as the name implies, a plane surface, supposed to be perfectly smooth and unyielding, inclined ob-

power and the weight? How many times is the power multiplied by means of the system of attached cords and moveable pullies combined? In what manner is the weight distributed among the cords in this arrangement? How is the relation between the power and weight to be discovered when a single cord is combined with a system composed of fixed and moveable pullies?

In what general manner may the advantage of a tackle be computed?

What practical difficulty is encountered in the use of pullies with separate wheels? How does White's pulley obviate this difficulty? State some of the useful applications of the pulley.

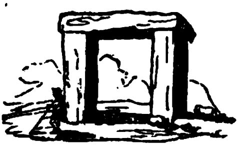
What theoretical character is assumed in treating of the inclined plane?

liquely to a horizontal plane; and its effect, as commonly used, is to diminish resistance, and thus enable a moderate power to sustain or overbalance a great weight. The mode of action of the inclined plane has been already fully explained (see 93 to 96), and the method of estimating its efficiency, in any given case, may be readily comprehended by reference to the relative velocities of two bodies, one falling through a space equal to the vertical height of the inclined plane, and the other passing down its declivity. Suppose the height A B to be one foot, and the inclined surface A C to be four feet, then a weight of four pounds, W, resting on the plane, will be equipoised by a weight of one pound, P, hanging freely over a pulley. And as the inclined plane is commonly employed to facilitate the rolling or shifting of ponderous bodies from a lower to a higher level through a moderate space, its efficiency will be in the ratio of the length of the inclined plane to its vertical height; thus with the machine just described, one-fourth of the force necessary to lift a great weight through the space A B, or the vertical height, would be sufficient to impel it up the declivity, from C to A.

196. In this more than in most other machines great allowance must be made for the effect of friction, which must materially modify any calculation as to the advantage it affords. Instances of the application of the inclined plane to practical purposes so frequently occur, that it can scarcely be necessary to advert to them. Roads formed on declivities are a kind of inclined planes; and railways are sometimes thus constructed, in such a manner that any weight, as a loaded sledge, may be made to ascend one plane or inclined railroad by the impulse of another carriage with which it is connected, and which passes simultaneously down an adjoining railroad.

197. The very simple nature of the inclined plane renders it probable that it was the earliest of the mechanic powers known and brought into use. It has been conjectured that it was employed by the Egyptians in raising the immense blocks of stone which form the pyramids, and in executing other gigantic works, which have excited the astonishment of successive ages. Mr. Warltire, a gentleman who delivered lectures on natural philosophy, in the latter part of the last century, endeavoured to prove that the ancient British Druids were the founders of Stonehenge, on Salisbury Plain; and that they erected the massive trilithons, which partly compose that curious structure, by rolling or rather by shifting the transverse blocks into their places by means of temporary inclined planes of earth or rubbish, forming a sort of road-ways for the passage of the several block. The annexed figure

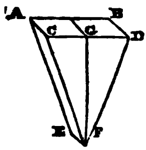
How is its mechanical efficiency estimated?
What familiar applications of the inclined plane may be enumerated?
What conjectures have been formed respecting its use among the ancients?



will afford a sufficiently accurate idea of one of the trilithons of Stonehenge, and when the structure was perfect, several of these were arranged in a circular figure. It will not be difficult to conceive that a sloping bank or declivity, having but a small degree of inclination, might be formed, up which any mass might be impelled or dragged, with a force not much greater than would be required to draw or push it forward on level ground.

The Wedge.

198. A wedge is the solid figure called by Geometricians a triangular prism, bounded on two sides by equal and similar triangles, and on the other three sides by rectangular parallelograms. It is composed of two inclined planes united at their bases; as will appear from the annexed representation. Its use is to divide solid bodies, the edge E F being impelled against them by pressure or some other force applied at the surface A B C D; and if the force be estimated by its weight, its effect will be in the ratio of the line D F to the line G D, that is as the sides of the wedge to its breadth. So that the advantage derived from using this machine increases in proportion as the angle which forms its edge diminishes. But the wedge is generally used for cleaving blocks of wood or other hard substances, and the force applied to it is that of percussion, with a heavy hammer or mallet, the effects of which are so different from those of direct pressure, and are so much modified by circumstances, as to render any theoretical calculation utterly inaccurate and useless.



199. It appears from the results of some experiments made in the Dock-yard at Portsmouth, England, on the comparative effect of driving and pressing in large iron and copper bolts, that a man of medium strength striking with a mall weighing eighteen pounds, and having a handle forty-four inches in length, could start or drive a bolt about one-eighth of an inch at each blow; and that it required the direct pressure of 107 tons to press the same bolt through that space, but it was found that a small additional weight would press the bolt completely home.*

200. But numerous and varied experiments would be requisite to obtain any results which might afford data for computing

What is the geometrical form of the wedge? What relation has the advantage of this machine to the angle formed at its edge? Of what nature are the forces usually applied to the wedge?

What has experiment proved in regard to the difference between pressure and percussion?

* Encyclop. Metropol.– Mixed Sciences, vol. i. p. 52.

the effect of impact or percussion on wedge-shaped bodies; and if that effect could be exactly estimated, further difficulties would arise from considering the very heterogeneous nature of the resistance, depending on the relative hardness, tenacity, and other properties of those substances on which the wedge is made to act. This instrument must therefore be regarded as one the effect of which can seldom be precisely determined; but which notwithstanding may be often very advantageously employed in certain circumstances.

201. Among the less frequent modes of application of the wedge may be mentioned its having been used to restore to the perpendicular position a building which declined slightly in consequence of some defect in the foundation. The voussoirs of arches are so many wedges; and piles used for the foundation of the piers of bridges may be considered as wedges, driven into the bed of a river by the percussion of a powerful machine. Sharp-edged and pointed instruments in general act as wedges; thus chisels, planes, and axes used by carpenters manifestly produce the effect of wedges; and knives, razors, awls, pins, and needles, and indeed all cutting and piercing instruments display an obvious analogy to the common forms of this mechanic power.

The Screw.

202. The screw, though commonly reckoned among the mechanic powers or simple machines, cannot be considered as such when applied to any practical purpose, as it would be found almost wholly ineffective without the assistance of the lever, which is therefore usually combined with it, and thus it becomes a most powerful machine, applicable to a variety of important purposes. The general form of the screw must be too well known to require description: it may however be stated, that it consists of two parts, namely a solid cylinder, sometimes called the male screw, and a corresponding cylindrical cavity, to receive the former part, and therefore styled a female screw; round the surface of the cylinder passes what is termed the thread of the screw, describing from one end to the other a curve sometimes inaccurately represented as a spiral, but which is really a helix, precisely resembling a common corkscrew, which, in fact, is nothing more than the helical thread of a screw without the core. The hollow screw has a similar helical thread winding within it, exactly adapted to the interval between the turns of the thread of the solid screw;

Why is the actual effect of the wedge more difficult to be computed than that of other machines?

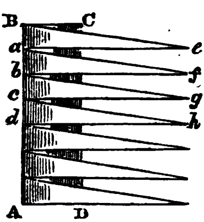
Of what applications is the wedge susceptible in the art of architecture?

Name some of the familiar applications of the wedge in ordinary instruments.

What is the nature of the screw in its practical structure?

and thus either part being made to revolve while the other is kept steady, motion or pressure may be produced to any extent.*

203. In order to obtain a correct estimate of the mechanical effect of the screw, it will be necessary to develope its construction, from which it will appear that it is, in principle, identical with the inclined plane; and it might be conceived to act as a system of revolving inclined planes. This will appear from reference to the annexed figure. Let A B C D represent a cylinder divided longitudinally into a number of equal parts, B *a*, *a b*, &c., and let lines *a e*, *b f*, &c., be drawn perpendicular to the side A B, each equal to the circumference of the base; then by joining B *e*, *a f*, *b g*, *c h*, will be formed so many right-angled triangles B *a e*, *a b f*, *b c g*, *c d h*, as the number of equal parts into which the cylinder has been divided. Now suppose these triangles to be rolled upon the cylinder, so that the point *e* should coincide with the point *a*, *f* with *b*, *g* with *c*, *h* with *d*, and so on, the hypothenuses or longest lines of the triangles, B *e*, *a f*, *b g*, *c h*, &c. would form on the surface of the cylinder one continued helical line, representing the thread of a screw. These triangles might be considered as a series of inclined planes; and therefore if such a screw were fitted to a hollow or female screw, fixed so that the former might act vertically, it will be obvious that one revolution of the male screw would raise or depress it through a space equal to the height of one of the inclined planes, and the effect of the screw, independent of friction, would be as the length of its base to its height, or as the line *a e* to B *a*. If then B *a* be ⅛ of an inch, and *a e* 1½in. or 12-8, a power equal to one pound acting by means of the screw would balance a resistance equal to twelve pounds. The power must here be supposed to act parallel to the base.



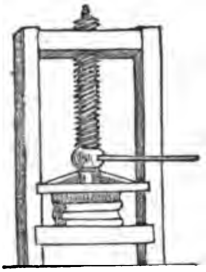
What is the distinction between a helix and a spiral? How is an accurate estimate of the effect of the screw to be obtained? With what other simple machine is its principle of action to be compared? How much does one turn of the screw raise the weight or remove the resistance?

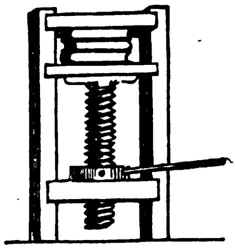
* A spiral or volute is a line which can be described on a plane; but no two points of a helix are in the same plane, and therefore it cannot be correctly described on a plane surface.

Spiral Line.

Helical Line.

204. But the resistance arising from friction between the parts of the solid and the hollow screw would in most cases require great additional power to produce any considerable effect. This therefore renders the application of a lever necessary to constitute the screw an effective machine. The lever may be added to the solid screw, to turn it within a fixed hollow screw; or to the hollow screw, to turn it round the solid screw. The manner in which the lever is applied in either case will appear from the following figures; the former of which shows how pressure may





be produced by a solid screw acting within a hollow screw in a fixed beam; and the latter exhibits the similar effect of a hollow screw pierced in a block turning by means of a lever on a fixed screw; the pierced block thus adapted to a solid screw is called a nut.

205. As the effect of the screw is always to be estimated by the proportion between the space described by the power, in one revolution of the screw, and the space between any two of its contiguous threads, it must follow that when the power is applied to a long lever instead of being made to act directly on the circumference of the screw, the effect must be vastly augmented. Thus if the threads of a screw be as much as half an inch apart, and it be turned by means of a lever extending three feet from the centre of the screw, the effect or advantage of such a machine will be as the number of half inches in the space described by the extremity of the lever to unity. Now reckoning the circumference of a circle in round numbers to be three times its diameter, the circumference described with a radius of three feet will be $36 \times 2 = 72 \times 3 = 216$ inches, and double that number, or 432 to 1 will be the measure of the advantage afforded by the machine.

206. Hence it will be apparent that the efficiency of the screw acted on by the lever might be indefinitely increased by extending

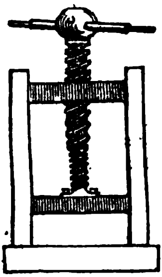
Why is the addition of a lever necessary in this machine? In what two modes may the lever be applied?

How is the effect of the screw to be estimated?

How far might the efficiency of the screw, theoretically considered, be increased?

the length of the lever, or by diminishing the interval between the threads of the screw. But a very long lever would be awkward and inconvenient, and extremely thin threads would be broken by the pressure when any considerable force was applied to turn the screw; so that either method of improving its action could be practically serviceable only to a limited extent. There is, however, a kind of double or compound screw, invented by John Hunter, the celebrated surgeon, bearing much analogy to the double capstan or axle, already described, (see 182) by means of which the mechanical efficacy of the machine may be augmented to any extent without at all diminishing its strength or compactness.

207. The marginal figure, which will show how this object is attained, represents a larger screw turning in a hollow screw or nut in the fixed beam, and having within it a concave screw adapted to the lower or smaller screw, and so arranged that while the larger screw passes forward the smaller one will be retracted; hence as both screws must revolve together, in each revolution, the moveable beam will be pressed downward through a space equal to the difference of the distances between the threads of the larger and the smaller screws. Therefore such a machine, in which the threads of the upper screw were 1-20 of an inch apart, and those of the lower screw 1-21 of an inch, would have the same effect as a simple screw, the threads of which were only 1-420 of an inch apart; for 1-20 —1-21 = 1-420, the difference between the distances of the threads of the double screw just described.



208. A solid screw revolving on fixed axes, and having its thread adapted to teeth on the periphery of a wheel, is called an endless screw; forming a part of a compound machine of considerable power and utility. Fly-wheels, as that of a common jack for roasting meat, are sometimes turned by the action of a toothed wheel on an endless screw.

209. Besides its usual application to the purpose of producing a high degree of compression, as in the cider-mill, the common printing-press, and a variety of similarly acting machines, the screw is likewise employed to measure extremely minute intervals of space. The manner in which this object is attained will be best understood by referring to the theory of the screw, (see 205) where it is demonstrated that any circle described by an arm or index

By what two expedients might this increase be effected?

What practical difficulties prevent the unlimited augmentation of the power of the screw?

What is the construction of Hunter's differential screw?

Through what extent does a single turn of this screw move the platen of the press?

In what manner is the endless or tangential screw applied for mechanical purposes?

revolving parallel to the circumference of the screw will have a certain relation to the space between any two contiguous threads; and therefore a small arc of such a circle may be conceived to measure the indefinitely minute space through which the point of the screw would advance or retreat in any given portion of one complete revolution of the screw. Suppose the threads to be ¼ of an inch apart, and a circle fixed to the head of the screw to be divided on its border into 100 equal parts, then on turning the screw, the index would show the motion of the point of the screw through as small a space as 1-400 part of an inch. The interval between the threads of a screw for such a purpose might be extremely minute, or Hunter's screw might be adopted; and the circle of equal parts might be of sufficient extent to be divided into 360 degrees, or any larger number of parts; and thus the means would be afforded for measuring with perfect accuracy the almost invisible fibre of a spider's web, or for taking the dimensions of the capillary vessels through which circulate the juices of plants and animals, or for discovering the size of microscopic insects or other objects too minute to be perceived by the naked eye. An instrument adapted to a microscope for such purposes is called a micrometer,* and its screw a micrometer screw.

Compound Machinery.

210. The advantage derived from combining together two of the mechanic powers, as the lever with the wheel and axle, or with the screw, has been already detailed; and it is by means of combinations of the simple machines, under their various modifications, that a vast multitude of complex machines are produced, which are adapted to facilitate the numerous operations required in the several departments of the arts, manufactures, and domestic economy.

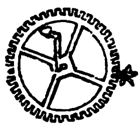
211. Among all the simple machines there is no one so generally useful, and therefore so frequently making a part of compound machinery as that modification of the lever called the wheel and axle. Its advantageous adaptation to the purposes of the mechanist is partly owing to the nature of the motion to which it gives rise, namely rotation, which is capable of being uninterruptedly continued through a period of indefinite extent; and to this advantage may be added the extreme facility with which wheels may be connected in various modes with other kinds of machinery. Hence there are few complex machines of which

What is the construction and use of the micrometer screw?
On what are the divisions of a thread measured in a screw of this description?
In what manner are the simple machines commonly adapted to the mechanic arts?
By what peculiarity is the wheel and axle rendered more serviceable to the mechanist than the other simple machines?

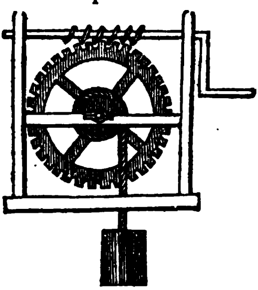
* From the Greek Μικρος, little; and Μετρον, a measure.

wheels do not constitute the most effective or essential parts. Thus are formed a vast variety of mills, from the coffee-mill to the powerful and complicated engine called a rolling-mill, for compressing plates of iron and cutting them into rods or bars; all the multifarious kinds of wheel-carriages; turning-lathes, and grinding-machines; clocks, watches, and timekeepers, in general; spinning-jennies, and many other machines used in the cotton, linen, woollen, and silk manufactures; and steam-engines under many of their modifications, to accommodate them to the purposes to which they are devoted.

212. The peculiar methods in which the parts of machinery are connected, or the modes of action of one mechanic power upon another, or upon a different form of the same power, are variously diversified to suit particular purposes. The wheel and pinion,



represented in the margin, consists properly of two wheels of unequal dimensions, the larger having teeth on its circumference which are adapted to correspondent teeth, or as they are sometimes called leaves, in the smaller wheel or pinion: thus a pinion may be made to act on a crown wheel, that is a wheel with teeth placed at right angles to its circumference; as may be observed in a watch, or timekeeper. The endless screw is connected with the teeth of a wheel in the manner represented in the annexed figure.



213. A little attention to the mode of action of many machines in constant use will afford opportunities for observing numerous instances of the different ways in which trains of wheel-work are combined together, or made to aid the effect of the other mechanic powers. These are, however, generally reducible to two methods of proceeding, namely, either by teeth, cogs, or some similar parts, acting against each other, as just described; or by bands, as cords, chains, or other flexible lines passing wholly or in part round one or more wheels and axles, so as to produce simultaneous motion.

214. With respect to the use of either of these methods, it is of importance to observe the peculiar nature of rotatory motion, which differs most essentially from what is termed a motion of translation, or passage from one place to another, though it may or may not accompany such a motion. Suppose any body, as a billiard-ball,

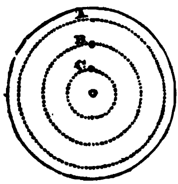
Enumerate some of the applications of wheel-work. Describe the wheel and pinion.

By what two methods is motion communicated from one part to another in a system of wheel-work?

How does a motion of simple rotation differ from one of translation?

to be pushed from A to B, every particle of the ball must have partaken of the motion; but if it be made to spin round in one place, the centre of the ball will remain unmoved; for imagine such a ball, or a large globular bead to be pierced centrically, and have a wire passed through it, the ball might be made to revolve with any degree of velocity, while the wire was held perfectly steady.

215. Let a circular disk of paper or any thin substance be made to revolve in this manner, on a pin, it will be perceived that the exterior surface of such a miniature wheel must move with greater velocity than any other part; so that the point A will pass over more space in each revolution of the wheel than the point B; and the latter over more than the interior point C. Hence it must follow that every circle within the circumference of a revolving wheel will have a relative velocity corresponding with its diameter; so that the degree of velocity communicated by a wheel in motion to some other part of a compound machine must depend not merely on the actual velocity of the wheel, but on that taken in conjunction with the relative distance from its centre at which the communication takes place; whether it be by means of teeth, projecting pins, or cords running in grooved cavities.



216. When teeth are made the medium for the communication of impulse, their peculiar form requires attention; but it can here only be generally stated that the teeth should be so constructed as to act upon each other steadily, without jerking or rubbing, which would soon derange the machine; and that the teeth most accurately adapted to produce the required effect, are such as have their corresponding surfaces forming peculiar curves, the exact figure of which in any case may be ascertained by geometrical construction.*

217. It is likewise desirable that the teeth of one wheel should work successively in those of the corresponding wheel, and that the same teeth should not meet in each consecutive revolution of the larger wheel; as they will thus act more uniformly, and wear away more slowly than if the same teeth came in contact more frequently. This object is effected by making the numbers of the teeth of wheels acting together, or of a wheel and its pinion,

How may this difference be illustrated in the motions of a billiard ball?

By what will the velocity of motion of every circle in a revolving wheel be determined?

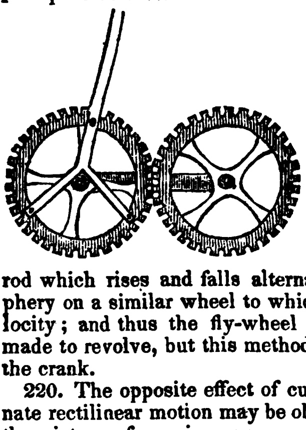
On what two circumstances in a *driving* wheel will the degree of velocity in the *driven* machinery depend?

What circumstance requires particular attention in the construction of toothed wheels?

* See Leslie's Elements of Nat. Philosophy, vol. i. p. 199—207.

as discordant as possible; so that the number of the teeth in the small wheel may never be an aliquot part of the number in the larger wheel. Thus, if a wheel of sixty teeth be turned by a pinion having but ten, each of the latter would come in contact with the same teeth of the former in each of its revolutions, or in every sixth revolution of the pinion; but if the larger wheel have sixty-one teeth, it must be manifest that no two corresponding teeth of the wheel and pinion respectively can meet more than once in every sixty-one revolutions of the pinion, during which the wheel will have revolved ten times. The odd tooth or cog by which this effect is produced is called by millwrights the hunting-cog.

218. In the construction of complex machines, it is not merely requisite that they should afford the means of communication between the power and the resistance, and enable the former to overcome the latter by the combined assistance of two or more of the mechanic powers, or simple machines; but it also often becomes an object of the highest importance to change the direction of any given moving power or acting force, without which it may be utterly inapplicable to the intended purpose, and therefore quite useless.



219. Reciprocating rectilinear motion may be changed into circular motion, by a crank applied to turn a wheel, as may be seen in the common knife-grinding machine, and in the turning-lathe; and the same effect is produced by what has been fancifully styled the sun and planet wheel, represented in the margin; one wheel fixed at the extremity of a vertical rod which rises and falls alternately, acting by teeth on its periphery on a similar wheel to which it communicates a double velocity; and thus the fly-wheel of a steam-engine was formerly made to revolve, but this method is now generally superseded by the crank.

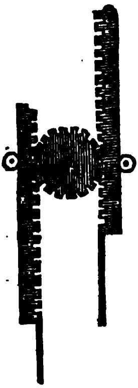
220. The opposite effect of curvilinear motion producing alternate rectilinear motion may be observed in the manner of working the pistons of an air-pump, or a fire-engine, as in the marginal figure below. A very ingenious contrivance for the conversion of rectilinear into curvilinear motion, or rather for producing an accurate correspondence between such motions, is displayed in the

How is the irregularity of wear, from the frequent meeting of the same teeth in a wheel and pinion to be avoided? What is meant by a "*hunting cog?*"

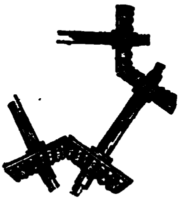
How may reciprocating rectilinear motion be changed into circular motion?

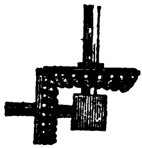
How is curvilinear converted into rectilinear reciprocating motion?

system of jointed bars used to connect the piston-rods of the steam-engine and its air-pump with the great beam, whose reciprocating motion transmits the necessary force to the fly-wheel and other parts of the machine. A much clearer idea of the nature of this contrivance, termed the parallel motion, may be attained from inspecting a steam-engine at work, than from a detailed description, even with the aid of a figure representing its construction.



221. The universal joint, invented by the celebrated Dr. Robert Hooke, affords a simple and efficient mode of transferring rotatory motion from one axis to another in an angular direction; but this may be done with greater accuracy by means of beveled wheels, which, as will be understood





from the foregoing figures may be made to act on each other at any angle whatsoever.

222. The regulation of the velocity or rate of motion is of the highest consequence to insure the efficiency of compound machinery. When two or more of the mechanic powers are made to act in concert, they must necessarily have certain points of contact; and the material substances of which machines are constructed, being subject to variations of density and dimensions from the action of heat and cold, or other causes, regularity of action cannot be perfectly attained, unless some mode can be adopted to prevent the changes just mentioned from taking place, or to counteract their effects; so that there may be such a stability in the points of contact of the mechanic powers, as to produce uniformity of combined action. Thus, in a clock or timepiece, uniform motion is propagated throughout trains of wheel-work, by means of a pendulum oscillating seconds; and the pendulum therefore acts the part of a regulator to the clock.

223. In describing the pendulum and its peculiar kind of motion, it has been stated that to beat seconds it must have a certain

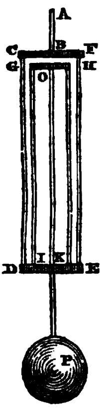
What was the purpose of Watt's jointed bars, used in the construction of his steam-engines?

For what purpose are beveled wheels applied in the construction of machines?

To what great purpose are regulators applied in the movements of machinery?

length, corresponding to the latitude of the place of observation, or more strictly speaking to the distance of that place from the earth's centre. Now it has been discovered from observation that a pendulum-rod of brass, steel, or in fact of any substance adapted for such a use, will be elongated by heat, and contracted by cold; and that to such an extent by the common changes of temperature in the atmosphere at different periods, that a pendulum which would vibrate once in a second in the winter, would take up more than a second in performing one vibration in the summer; and hence it would require to be shortened at the latter period, and lengthened again at the former to make it act with any tolerable degree of uniformity. To regulate a clock in this manner it is obvious that the error must be observed before it could be corrected, and therefore this method though it might serve for common purposes, would be nearly useless to the astronomer or the navigator, requiring a uniform and accurate measurement of a considerable period of time, by means of an instrument more or less exposed to alternations of temperature. The construction of a pendulum which should preserve its length unalterably in all situations, thus became an object highly interesting both to philosophers and mechanics; and the contrivances which different individuals have adopted or proposed have been numerous and diversified.

224. The general principle on which compensation pendulums, as they are termed, act, may be comprehended from the annexed figure and description.



Suppose C D E F to represent a steel frame, and G H a bar of metal connected by the copper rods G I and H K with the bar D E, to which they are firmly fixed. The rod O P being fastened by a pin to the bar G H, descends from it through an aperture in the bar D E, hanging freely from the point O, and supporting the pendulum-bob P: the pendulum turning on the suspension-spring A B. Now when the longitudinal rods are dilated by heat, the elongation of the rods G I and H K, will tend to raise the bar G H to which the rod O P is attached; but the corresponding elongation of the latter will tend to lower the point P; and if the apparatus be properly arranged the lengthening of one set of rods will compensate that of the other, as they must take place in opposite directions. On similar principles are constructed Harrison's gridiron pendulum and the numerous subsequent inventions, the common object of which has been to obtain a pendulum-rod, the point of contact

What character in the pendulum is indispensable in order to make it beat seconds?

By what circumstances is it prevented from acting in its simple form as a perfect regulator?

At what season of the year would a clock with a simple pendulum move most rapidly?

or axis of suspension of which shall be at a certain and invariable distance from the centre of oscillation.

225. Thus it has been shown how the effect of a single cause of irregularity of action in machinery may be obviated; but in the greater number of the complex machines employed for various purposes connected with arts and manufactures, there are often several different circumstances contributing more or less to prevent regular or uniform action. Besides the difficulty of maintaining certain points of contact between the moving parts of machines, owing to inequality of temperature and consequent contraction and expansion of solid bodies, there are additional difficuities arising from the gradual wearing away of surfaces by friction and from other causes.

226. But admitting the possibility of preserving the points of contact of the parts of a machine invariable for a certain period, abundant causes of irregular action might still exist; among which may be mentioned, as one of the most important, the irregular effect of the moving power. A familiar example of such a case will occur in the common handmill, used by grocers to grind coffee or cocoa; for a greater degree of strength must be exerted to turn the winch or handle of such a mill at the lowest point of the circle which it forms, in turning, than at the highest point; and thus the machine could not be made to act with an equable motion, but for the heavy fly-wheel, connected with the axis of the mill, which equalizes the effect, and enables the man to turn the mill with any required velocity, working without interruption or extraordinary efforts.

227. The variable inciting forces are, by the intervention of a heavy wheel, blended together in creating one great momentum, which afterwards maintains a nearly uniform action. The use of the fly in mechanics hence resembles that of a reservoir, which collects the intermitting currents, and sends forth a regular stream.* That distinguished philosopher has given a description of a machine called the concentrator of force, by means of which an inconsiderable power, acting on a fly-wheel, may be made to produce a vast momentary effect. On this principle of the effect of the concentration of force depends the action of the coining-press used for striking pieces of money. The momentum communicated to the machine by a man whirling round for a few seconds the balls at the extremities of a horizontal bar, will cause

How does the compound pendulum obviate the irregularity of a clock's movement?

What other difficulties besides those already enumerated interfere with the action of machines?

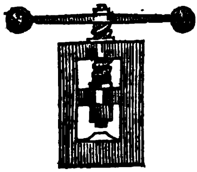
What is one of the most important sources of irregularity in a machine?

What familiar illustration of this irregularity?

By what means can force be concentrated?

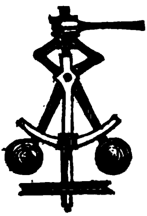
How is the coining-press enabled to produce its intense pressure?

* Leslie's Elements of Natural Philosophy, vol. i. p. 177.



the screw to descend with such force, carrying the die against a circular disk of metal, as to give it the required impression at one stroke. This machine is said to have been invented by Nicholas Briot, mint-master (*tailleur-general des monnoies*) to Louis XIII. of France; and by using it one man may do as much work as twenty, striking coins with a hammer, which was the old method of coining.*

228. A complicated machine, such as the steam-engine, requires various modifications or adaptations of its essential parts, and the addition of some peculiar parts to equalize or compensate irregular movements, and enable the engine to work with due accuracy and effect. Besides the fly-wheel, which is a necessary appendage to the common low-pressure steam-engine, there is another very ingenious and important contrivance, called the governor. It



consists of two heavy balls, connected by jointed rods with a revolving axis, by any increase in the velocity of which they diverge or separate from each other, and draw downwards the jointed rods; while a slower motion of the axis causes the balls to approach each other, and the system of rods to be contracted laterally and be extended upward. The grand effect produced by this means depends on making the ascending and descending extremity of the jointed rods raise or lower the end of a bar which acts as a lever, and moves a valve which regulates the supply of steam from the principal steam-pipe. A similar method of controlling the effect of moving power is applicable to wind and water mills, and other kinds of machinery.

229. Whatever may be the complexity of a machine, or however varied its action, its effect, theoretically considered, is to be estimated according to the principles already laid down relative to simple machines. There must be in every case an equality of effective action in the power and the resistance in order to produce equilibrium; and consequently the efficient force of the power must, with the assistance of the machine, exceed that of the weight or resistance, before motion can take place.

230. It may be generally stated that a power can counterbalance any given resistance, when the momentum of the former is rendered equal to that of the latter. This has been repeatedly demonstrat-

In what manner was the process of coining performed before the period of Briot's invention?
On what principle of motion is the mill governor constructed?
How is the effect of a compound machine to be estimated?
When will motion succeed to a state of rest in any given machine?

* V. Sigaud de la Fond Elemens de Physique, 1787, t. ii. p. 124.

ed in treating of the several simple machines. Thus, it has been shown that a lever can be kept in equilibrium only when the number of pounds in the power, multiplied by the number of feet it would describe, if put in motion, gives a product exactly equal to that of the number of pounds in the resistance multiplied by the number of feet in the space relatively described by it; so that the spaces passed through by the power and the resistance must always be in the inverse ratio of their respective weights, or actual independent forces. Hence it follows that whatever advantage is afforded by a machine, so as to enable a small weight or other weak power to overcome a great weight or resistance, must depend on communicating to the power a degree of velocity, or causing it to act through a space which shall more than equalize the momentums of the antagonist forces.

231. It may perhaps be remarked that machines, regarded in this point of view, give no additional force; since in order to raise a weight of 500 pounds, a power must be made to act with an effect superior to 500 pounds, either weight or pressure. The object of machinery certainly is not to create force, which is impossible, but to accumulate, distribute and apply it, so as to produce certain effects; and the advantage thus afforded is often of the highest importance. Thus, a man, with a crow-bar, may be able to turn over a log of wood, or a block of stone, which unassisted he could no more move than he could one of the Egyptian pyramids. But to raise such a mass of wood, or stone with a crow-bar or lever, he must make the end of the bar to which he applies his strength move through a space, probably fifty or sixty times as great as that through which he would move the log or block. So likewise if a man, who could pull with a force only equal to 50 pounds, wanted to raise a bale of goods weighing 500 pounds through the space of 12 feet, he might do it by means of a tackle of pulleys, but if it afforded him the assistance precisely necessary to supply his deficiency of strength, it must be so constructed that he would have to pull down 120 feet of rope, in order to make the bale ascend 12 feet. These examples will probably suffice to illustrate the nature of the equilibrium of action resulting from the application of machinery; and hence it will be apparent that whatever be the moving power employed for any purpose, though its actual force cannot be increased by any machine, as such an increase would involve physical impossibility, yet its effective force may often be indefinitely augmented; that is, its actual force may be made by a machine to overcome an actual resistance, to which, alone, it would be utterly inadequate.

In what proportion to the power and resistance must be the spaces which they respectively describe at the commencement of motion?

On what must the advantage of a machine for overcoming a great resistance always depend?

What is the true object of machinery in regard to mechanical force?

How may this be illustrated in the raising of a weight by the aid of a lever?

232. The action of machinery necessarily requires time to produce any given effect. Motion can in no case be instantaneous, however rapid; and when it is the result of the operation of complicated machinery, it must be relatively slow. It may indeed be the real object of a piece of mechanism to extend a series of consecutive movements through a certain period; and of such an arrangement examples may be found in common clocks and watches. In an eight-day clock, for instance, a couple of weights are wound up to a certain height, and left suspended to act by their own gravity in setting in motion trains of wheel-work which shall cause the indexes, or hour and minute hands, to describe given circles in certain spaces of time, so as to furnish a method for the equal measurement of time; and the gravitating powers of the weights are so opposed by the resistance distributed over the numerous wheels and pinions, that though the weights may each amount to several pounds, they may descend so slowly as to be more than a week in passing through the space of five or six feet.

233. A story is told by an ancient writer, relative to the celebrated Archimedes, from which may be drawn a most pointed illustration of the immensity of time and space required to produce mechanical effect, where the disproportion between the power and the resistance is extremely great. In relating the history of the siege of Syracuse by the Romans, Plutarch, in his Life of Marcellus, the Roman general, says that Archimedes told Hiero, king of Syracuse, whose confidence he possessed, as being related to that prince and highly esteemed by him, that by his mechanic skill, he could, if there was another earth for him to stand on, move the solid globe which we inhabit. Hiero, astonished at this assertion, requested the philosopher to afford him some demonstrative evidence of its truth, by letting him behold a very large body moved by a small force; and the historian adds, this effect was exhibited by Archimedes, who sitting on the sea-shore drew into port, with one hand, a large ship heavily laden, and having a number of men on board. This he is stated to have done by gently moving the handle of a machine called polyspaston, a pulley.

234. It has been remarked, that if Archimedes had proposed to move the earth by means of a lever, and had obtained not only the place he required to stand on, but also another whereon to fix his fulcrum, with an hypothetical lever of requisite length and strength, and had also been endowed with muscular power sufficient to enable him to act on the end of his lever so as to move it with the

With what are the action and effect of machinery necessarily connected?

How are mechanical forces made capable of supplying a measure of time?

How is the importance of time to mechanical actions exemplified in the celebrated assertion of Archimedes?

How did that philosopher illustrate the truth of his statement?

velocity of a cannon-ball, he would not have shifted the earth more than the twenty-seven millionth of an inch in a million of years; and supposing him to have had but the average power of a strong man, it would have taken him 3,653,745,176,803 centuries to have moved the earth with the machine he had in view in his address to his royal relative.*

235. Paradoxical as these statements may appear, it may be easily shown that they are founded on mathematical evidence. To comprehend this it will be only necessary to consider how far into boundless space such a theoretical lever as that imagined for Archimedes must have extended, and the consequent incomprehensible immensity of the arc which such an imaginary lever must be supposed to describe.

236. Those who have leisure and inclination for making such computations may ascertain what length of theoretical rope must be drawn over imaginary pulleys, to raise through the space of one inch, by means of a power equal to seventy-two pounds, a spherical mass 8000 miles in diameter, having a mean density five times that of water, and taking the weight of a cubic foot of that fluid to be 1000 ounces avoirdupois. The result of such a calculation would afford an approximation to a fair estimate of the fancied task of Archimedes; and would strikingly evince the utter insignificance of human skill and science when contrasted with the powers of nature.

Observations on Friction; on the Rigidity of Cordage; and on the Strength of Materials.

237. In making calculations or estimates of the effective force of moving powers applied to machinery, it is always necessary to admit certain deductions on account of the obstacles to freedom of motion arising from friction, the rigidity of cordage, or the imperfections of the materials of which machines must be constructed. All these subjects are of the highest importance to practical mechanicians, and are therefore deserving of the most accurate attention; but it will be sufficient here to describe briefly the nature of these obstructing or retarding forces, and to notice the methods usually adopted for lessening or correcting the inconveniences they may produce.

How rapidly might the theoretical lever of Archimedes have enabled him to move the earth?

What are the elements of calculation to show the practical result of such an attempt?

In what light would the computation place human skill and artificial powers?

On what accounts are deductions from the theoretical effects of machines rendered necessary?

---

* Recreations in Mathematics and Natural Philosophy, edited by Dr. Charles Hutton, vol. ii. p. 19.

238. It is the well-known consequence of friction that when one substance moves in contact with another, either at rest or moving in an opposite direction, more or less force must be applied to produce motion in proportion to the roughness or smoothness of the surfaces of the two bodies. No substance can be perfectly smooth: not even polished steel or glass. Those surfaces that to the naked eye seem free from the slightest inequalities are found, when examined by a powerful microscope, to be covered with innumerable rising points and hollows, like the face of a file; and sometimes to be intersected by abundance of irregular ridges and furrows. Now when surfaces, such as have been just described, are made to move in contact, the prominent parts of the one will pass into the depressions of the other, and thus occasion more or less difficulty in procuring lateral motion.

239. Though friction, from its effect in retarding motion, lessens the advantage derived from machinery, and often causes inconvenience, yet it is one of those properties of matter which we find to be of almost indispensable utility. If all bodies were destitute of friction it would be very difficult for us to grasp or retain in our hands any solid substance; a penknife, a ruler, or a book would slip through our fingers, if not held tightly; and in using our hands for any purpose, such a degree of muscular power must be exerted as would be extremely fatiguing and inconvenient. But without friction it would be still more difficult to use our feet than our hands; and no man could walk upright unless he possessed the skill and activity of a tight-rope dancer, or a performer on the slack-wire.

240. The consequence of losing the advantage derived from friction in walking, may be easily conceived, when we reflect on what takes place when friction is partially destroyed by the streets and open pavements being covered with ice, as occasionally happens during the winter season. Arming the soles of the shoes with list, or with projecting nails, and covering the ice with saw-dust, ashes, or other loose substances, are among the usual methods resorted to at such times, to restore friction, and enable people to walk steadily.

241. Friction is likewise advantageously used as a means of sharpening or polishing various substances, by rubbing, grinding, and other operations of great importance in several arts and manufactures. This property of matter may even be applied to the production of motion; at least it may be made the medium of communication between one part of a machine and another. Thus

To what is the resistance from friction always proportioned?

What is the true nature of surfaces commonly considered *smooth?*

By what means is the true character of surfaces to be detected?

What is supposed to be the real mode of action by which friction opposes, retards, or destroys motion?

Of what advantage is friction in the ordinary purposes of life?

How is its importance in walking made apparent?

How is friction employed in manufacturing processes?

wheels are sometimes covered on their peripheries with buff-leather, and one of them being set in motion will then turn the other, by the friction of the rough surfaces of the leather, acting as if the wheels had been furnished with innumerable series of minute teeth.

242. Such are the benefits of friction, but in many cases it proves a very inconvenient property of matter, hindering freedom of motion, and tending to obstruct it entirely; and hence in the construction of machinery various contrivances are adopted to lessen or destroy the effect of friction. Systematic writers have distinguished this property of matter into two kinds: namely, 1. That which takes place when two flat surfaces are moved in contact, so that the same points of one surface are constantly applied to some part of the other; and 2. The friction that takes place when one body rolls over another, so that the points of contact of both surfaces are perpetually changing. The former may be styled dragging friction, and the latter rolling friction.* It must be obvious that the retarding effect of the former must be vastly greater than that of the latter kind of friction. It is for this reason that plumbers, masons, and carpenters, when they want to move a heavy mass of metal, stone, or wood, place beneath it several cylinders of hard wood, by means of which such a mass may be dragged forward without coming in contact with the ground, and the immense friction of the first kind or dragging friction which must otherwise occur, is changed into rolling friction or rolling motion. On the other hand rolling friction is converted into dragging friction, by shoeing or locking the wheel of a carriage in going down a steep hill.

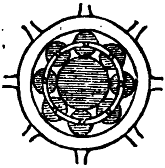
243. On the principle just stated depends the utility of those parts of some complex machines, called friction-wheels. In wheel-work the chief friction takes place between a wheel and the axle on which it turns; and to diminish its effect it is usual to

How may it serve as a means of communicating motion?
Into how many kinds has friction been divided by systematic writers?
Which of these exists in the mechanical devices for moving heavy masses?
What kind of friction exists at the axle, and what at the periphery of a carriage-wheel?
How is the friction of the axis of carriage-wheels diminished by means of rollers?

---

* The terms *rolling* and *dragging* friction seem more appropriate than *interrupted* and *continued* friction; as expressive of the mode of action by which they are respectively produced. A true case of rolling friction takes place only when the rollers are so situated as to have no necessity of employing axles; as when cylinnders or cannon-balls are placed beneath heavy weights. The wheel-carriage is not a case of this kind, for it only transfers the friction which would take place at the periphery if the wheel were locked to the axle, which experiences a dragging friction within the box.—See on this subject Journal of the Franklin Institute, vol. 5, p. 57.—Ed.

construct the axle and the box, or central part of the wheel, of very hard substances, the surfaces of which are not only rendered as smooth as possible, but also covered with oil, or some other unctuous matter, which facilitates the motion of the corresponding parts. But where it is necessary to obtain the utmost facility of motion, a method has been adopted for subdividing friction, by letting the axle of a principal wheel move on two or more small wheels, as in the marginal figure. These are named friction-wheels.*



244. In estimating the effect of friction, so many circumstances must be taken into the account, that the result, in any given case, may afford but little assistance in deciding others. It may however be stated, as the most important deduction from repeated experiments, that friction does not depend on the extent of the surfaces on which it acts, but chiefly on the degree of pressure to which they are subjected; so that, the surfaces continuing in the same state, increase of pressure will produce increase of friction.

245. When a heavy body is placed on an inclined plane, it will have a tendency to slide; and consequently will remain at rest on such a plane, only when the retarding effect of friction is greater than the tendency for motion, caused by the inclination of the plane. Hence the angle of inclination at which motion on an inclined plane commences, has been styled the *angle of friction*; and it will of course be different in different cases, according to the nature of the rubbing surfaces, and the degree of pressure.

246. The rigidity of cordage is another property of solid bodies which interferes with the freedom of motion in some kinds of machinery. It must necessarily depend on the peculiar nature of the materials used, since the more flexible they are, the more readily will they become adapted to the wheels or spindles around which they are coiled; and the smaller will be the interruption of regular continued motion. It is principally when very thick lines are used, such as the cables for heaving anchors for very large ships, that this rigidity of cordage becomes a serious impediment to motion, requiring the expenditure of great force to overcome it. Iron chains have been advantageously introduced into the maritime service, instead of cables; and are likewise employ-

What is one of the most important deductions from experiments on friction?

What is meant by the *angle of friction*?

Is this angle constant or variable?

To what does the rigidity of cordage usually offer its resistance?

What substitutes for large cables have of late been adopted?

---

* The railroad cars of Winans, Howard, and several others, employing friction-wheels, have been invented in the United States, and will be found described in the early volumes of the Journal of the Franklin Institute.—Ed.

ed for various purposes in the arts to which ropes alone were formerly considered applicable.

247. In the construction of machines much must depend on the strength and firmness of the materials of which they may be composed. Thus, in the case of one of the most simple machines, the lever, suppose a long pole to be applied to raise a considerable weight, much of the effect of any power would be lost in consequence of the bending of such a wooden lever at that part which rested on the fulcrum; and therefore an iron bar, nearly inflexible, of the same length with the pole, would enable a man to move any given weight or resistance with less exertion.

248. The hardness, tenacity, elasticity, and other properties of bodies, on which their relative strength must principally depend, vary so greatly even in different specimens of the same substance, as wood or metal, that few rules of general application can be given for computing the degrees of force, which may be applied with safety to the particular parts of any complex machine. Any solid substance, as a bar or rod of iron, may be subjected to tension or pressure in different ways: as, (1), by suspending to it a great weight, or endeavouring to stretch it longitudinally; (2), by weight or pressure applied to crush or compress it; and (3), by weight or pressure applied to the centre of a bar or rod its extremities alone being supported.

249. It appears from experiment, that in the first case, the length of a rod remaining the same, its strength will be increased or diminished in proportion to the area of its transverse section; thus, as 27 tons weight will tear asunder an iron bar one inch square, so a bar but half a square inch in the section will be broken by a weight of 13½ tons; and so on in any given proportion. Concerning the capacity of bodies for resisting compression, but little is known with certainty. Much appears to depend on the form of a body, for a cubic inch of English oak required to crush it a weight of 3860 pounds; but a bar an inch square and five inches high gave way under the weight of 2572 pounds; and if longer it would manifestly have broken with a less weight. Mr. Rennie, one of the architects of London Bridge infers from calculation that the granite of which the great arch of that bridge is constructed would bear a pressure equal to four tons upon every square inch of its upper surface.

250. As to the strength of bodies exposed to transverse or lateral pressure, one or both ends being supported, it depends on the dimensions of a section of the body in the direction of the pres-

On what circumstances must the usefulness of machines chiefly depend?

Name some of the physical properties of materials which vary their usefulness in the mechanic arts.

In how many ways may a solid rod of any material be subjected to mechanical action?

How is direct *tension* applied? how *crushing pressure?* how *cross strain?*

What inference has been drawn by Rennie from experiments on granite?

sure. Thus a beam having the same length and breadth with another, but twice its depth, will be four times as strong; and a beam double the length of another, but with the same breadth and depth, will have but half as much strength. Hence the strength of solid bodies is not by any means to be estimated by their absolute magnitude.

251. Hollow cylinders are much stronger than solid ones of equal length and weight; and therefore it appears an admirable provision of nature that the bones of men and other animals in those parts requiring facility and power of motion are more or less of a cylindrical shape, with cavities in the centre, which in birds are filled only with air, whence partly their capacity for flight; but in men and beasts the cavities are filled with a light oily fluid, which congeals after death, forming marrow. The strength or efficient power of an animal depends chiefly on the accurate construction and adaptation of its several parts.

252. Some very small creatures possess muscular power, in proportion to their bulk, incomparably greater than that of the largest and strongest of the brute creation. A flea, considered relatively to its size, is far stronger than an elephant or a lion; as will appear from comparing the distance the insect would leap at one bound with its actual dimensions, with reference to the spring and dimensions of the quadruped. Some marine animals, as the whale, are of vast bulk; nature having provided for their convenience by giving them a medium of great density to inhabit.

Moving Powers.

253. The original forces which produce motion, and which have been denominated Moving Powers, or Mechanical Agents, are of various kinds, depending on the natural properties of bodies. Gravitation or weight is an extensively acting power affecting matter in all its different forms, and affording the means of originating motion for many useful and important purposes. By the proper application of weight is excited and maintained the equable motion of wheel-work, as in a common clock; and the same power differently adapted is made to act by percussion, in pile-driving and numerous other operations. Currents of water owe their velocity to the weight of the descending liquid, yielding a kind of moving power on which depends the effective force of water-wheels and other hydraulic engines.

254. Elasticity is another property of matter which gives ener-

What relation exists between the dimensions of a beam and the resistance which it is capable of opposing to cross strain?

What advantage does the hollowness in the bones afford to the strength of animals?

How are we to judge of the relative strength of insects and of large animals?

What is one of the most common mechanical forces, and in what different modes is its efficacy applied?

gy to various mechanical agents. Elastic metals, as steel, manufactured into springs, are used in the construction of watches or chronometers; and the contractile force of springs is employed for many other purposes, as in roasting-jacks and weighing-machines. Liquids, though compressed with difficulty, display a high degree of power when thus treated; and machines of vast energy have been invented, the effect of which depends on the expansive or elastic force of compressed water. The elasticity of air is likewise an abundant source of moving power. Steam-engines, such as were used in the early part of the last century, were made to act through atmospheric pressure, arising from the joint influence of the weight and elasticity of the air; but since the vast improvements in machines of this description, in consequence of the researches of Watt, and other experimental philosophers, steam or elastic vapour is employed as the sole moving power, and so managed as to produce effects far beyond those of the old atmospheric engines.

255. Heat must be regarded as a moving power, the efficacy of which depends on its tendency to dilate different kinds of matter. It also converts solid bodies to the liquid state, and liquids under its influence are changed into vapours or gases. Hence indeed is to be explained the operation of the steam-engine, in which alternating motion is produced by the expansive force of steam or water raised to the state of vapour by means of heat. Combustion is a chemical process, often excited by heat, and during the progress of which heat is always developed; and from this source is derived moving power of vast intensity, as occurs in the discharge of shot or balls from fire-arms, through the explosion of gunpowder. In this case the moving power arises from the sudden expansion of gases formed by the combustion of solid matter; but engines have recently been constructed the action of which depends on the formation of a partial vacuum by the inflammation of oxygen and hydrogen gases in close vessels, and the consequent production of water.

256. Machines may be set in motion by means of electricity, galvanism, or magnetism; and forces, which have been chiefly regarded as objects of curiosity may be extensively applied to useful and important purposes. In a French periodical publication (Journal de Geneve, 1831), some account is given of an electrical clock, invented by M. Bianchi of Verona. This timekeeper has neither weight nor spring, instead of which the constant vibra-

State some of the applications of elasticity to purposes connected with the arts?

What is the difference in principle between the atmospheric engine of Newcomen and the modern steam-engines of Watt and Evans?

On what is the efficacy of heat as a moving power dependent?

In what other modes is heat occasionally applied to produce mechanic ction?

What other imponderable agent, besides heat, is occasionally employd as a moving force?

tion of the pendulum is maintained by the impulse of electricity, which it receives by moving between two galvanic piles, the ball or or bob being furnished with a conductor, which in its oscillations, approaching either pile, alternately, is repelled by the discharge of the electric fluid; and the regular action of the whole of the machinery is kept up.

257. These cursory observations will afford some general ideas of the nature and extent of the moving powers originating from the influence of elastic fluids, heat, and electricity; but the further discussion of these topics must be referred to the subsequent portion of this work, where the phenomena connected with these subjects will be distinctly noticed. There are, however, besides those moving powers, the operation of which depends on the physical properties of matter in different states of aggregation, other mechanical agents, the effects of which arise from the vital energy of animated beings; and concerning these some details may here be properly introduced.

258. The application of the natural strength of man must have preceded the employment of all other moving powers; and we know from history, that ever since a very remote period brute animals have likewise been rendered subservient to the purposes of art and industry. The employment of oxen and horses in the labours of the field must have originated in the earliest ages; and the art of training beasts of different kinds to exert their strength for the benefit of man has been known and practised among almost all nations except those in the very rudest state of society.

259. The mechanical effects produced by the muscular exertions of living beings cannot be subjected to calculation on precisely the same principles as the moving power of a weighing-machine or a steam-engine; nor even can they be estimated with so much precision as the efficient power of a windmill or a water-wheel; but there are modes of obtaining data whence to determine the value of animal strength as a mechanical agent, which may serve to indicate the comparative product of labour from that and other sources, and enable us to discover their relative importance for any given purpose.

260. The usual method of computing the mechanical value or efficiency of labour is from the weight it is capable of elevating to a certain height in a given time, the product of these three measures (weight, space, and time) denoting the absolute quantity of performance. But these measures have obviously a mutual relation which will affect the result; for great speed will occasion a

Describe Bianchi's galvanic clock.

On what do the effects of animal efforts depend when employed for mechanical purposes?

What were among the earliest *zoolic* moving forces employed in the arts?

Can the power of animals be accurately computed by their weight and velocity?

What three elements enter into the computation of animal power?

waste of force, and shorten the period during which it can be exerted. It was computed by Daniel Bernoulli and Desaguliers that a man could raise two millions of pounds avoirdupois one foot in a day. But some writers have calculated that a labourer will lift ten pounds to a height of ten feet every second, and continue to work at that rate during ten hours in a day, raising in that time 3,600,000 lbs. But these estimates are certainly incorrect, and appear to have been founded on inferences drawn from momentary exertions under favourable circumstances. Smeaton states that six good labourers would raise 21,141 cubic feet of sea-water to the height of four feet in four hours; so that they would raise about 540,000 pounds each to the height of ten feet in twenty-four hours.

261. Coulomb has furnished some of the most exact and varied observations on the measure of human labour. A man will climb a staircase from 70 to 100 feet high, at the rate of 45 feet in a minute; and hence, reckoning the man's weight at 155 pounds, the animal exertion for one minute would be 6975, and would amount to 4,185,900, if continued for ten hours. But such exercise would be too violent to be thus continued. A person might ascend a rock 500 feet high by a ladder-stair in twenty minutes, or at the rate of 25 feet a minute: his efforts are thus already impaired, and the performance reduced to only 3875 in a minute.

262. But with the incumbrance of a load the quantity of action must be yet more remarkably diminished. A porter weighing 140 pounds, who could climb a staircase forty feet high two hundred and sixty-six times in a day, was able to carry up only sixty-six loads of fire-wood, each weighing 163 pounds. In the former case, his daily performance was very nearly 1,489,600; while in the latter it amounted to only 799,920. The quantity of permanent effect in the latter case* therefore was only about 800,000, or little more than half the labour exerted in mere climbing. A man, drawing water from a well by means of a double bucket, may raise 36 pounds one hundred and twenty times a day, from a depth of 120 feet, the total effect being 518,400. A skilful labourer working in the field with a large hoe produced an effect equal to 728,000. When the agency of a winch is employed in turning a machine, the performance is still greater, amounting to 845,000.

263. The effective force of human exertion differs according to the manner in which it is applied. From some experiments made by Mr. Robertson Buchanan, it was ascertained that the labour of a man employed in working a pump, turning a winch, ringing

What are the suppositions adopted by Bernoulli and Desaguliers in regard to the amount of human effort?

To what results did Coulomb arrive in respect to the speed of human movements, and to the continued daily labour of men when working only to raise their own weight, and when carrying up additional burdens?

According to what circumstances does the effective force of human exertion vary?

* The *useful* effect in the former case was 0; in the latter it was 430,320.

a bell, and rowing a boat, might be represented respectively by the numbers 100, 167, 227, and 248. Hence it appears that the act of rowing is an advantageous method of applying human strength.

264. A London porter is accustomed to carry a burden of two hundred pounds at the rate of three miles an hour; and a couple of Irish chairmen will walk four miles an hour, with a load of 300 pounds. But these exertions are by no means equivalent to those of the sinewy porters in Turkey, the Levant, and other parts bordering on the Mediterranean. At Constantinople, an Albanian will carry 800 or 900 pounds on his back, stooping forward, and assisting his steps by a short staff. At Marseilles, four porters commonly carry the immense load of nearly two tons, by means of soft hods passing over their heads, and resting on their shoulders, with the ends of the poles from which the goods are suspended.

265. The most extraordinary instances of muscular exertion in the carriage of burdens are those exhibited by the cargueros or carriers, a class of men in the mountainous parts of Peru, who are employed in carrying travellers. Humboldt, in relating the circumstances of his descent on the western side of the Cordillera of the Andes, gives some account of the cargueros. It is as usual in that country for people to talk of going a journey on a man's back, as it is in other countries to speak of going on horse back. No humiliating idea is attached to the occupation of a man-carrier, and those who engage in it are not Indians, but Mulattoes, and sometimes whites. The usual load of a carguero is from 160 to 180 pounds weight, and those who are very strong will carry as much as 210 pounds. Notwithstanding the enormous fatigue to which these men are exposed, carrying such loads for eight or nine hours a day, over a mountainous country, though their backs are often as raw as those of beasts of burden, though travellers have sometimes the cruelty to leave them in the forests when they fall sick, and though their scanty earnings during a journey of fifteen or even thirty days is not more than from 11 to 12 dollars, yet the employment of a carguero is eagerly embraced by all the robust young men who live at the foot of the mountains.*

266. The different races of mankind display much diversity of muscular strength; though in all cases much must depend on the constitution and habits of the individual. M. Peron † has stated the results of some interesting experiments which he made to

In what kind of exertion did Buchanan find the greatest, and in what the least advantageous employment of the strength of men?

What striking examples can you enumerate of the transportation of heavy loads?

Who are the cargueros, and what feats of strength are related of them by Humboldt?

---

* See Humboldt's Researches concerning the ancient inhabitants of America; with Descriptions of the most striking Scenes in the Cordilleras. London, 1814.

† Voyage de Decouvertes aux Terres Australes, fait par ordre du gouvernment pendant les annees 1800—4.

discover the relative mechanical power of individuals of different nations. For that purpose he used an instrument called a Dynamometer, which, by the application of spiral springs, to a graduated scale, afforded the means of estimating the forces exerted by the persons who were the subjects of his experiments. He collected by this method a number of facts, which he conceived sufficient to enable him to deduce from them the medium forces or powers of exertion of the inhabitants of the Island of Timor, of New Holland, and Van Diemen's Land, and to compare them with those of the English and the French. The following is the order of arrangement, commencing with the weakest: Manual force—Van Diemen's Land, N. Holland, Timor, French, English. The proportion between the two extremes is nearly as 5 to 7. Lumbo-dorsal force, [*force des reins*]—the order the same as before; but the proportion between the extremes, as 5 to 8.

267. The labour of a horse in a day is usually reckoned equal to that of five men; but then the horse works only eight hours, while a man can easily continue his exertions for ten. Horses display greater power in carrying than in drawing; yet an active walker will beat them in a long journey. Their effective force in traction seldom exceeds 144 pounds, but they are able to carry six times that weight.* The pack-horses in the West Riding of Yorkshire, England, are accustomed to convey loads of 420 pounds over a hilly country; and in many parts of that country the mill-horses will carry the burden of even 910 pounds, for a short distance.

268. The most advantageous load for a horse must be that with which his speed will be greatest in proportion to the weight carried. Thus, if the greatest speed at which a horse can travel unloaded be 15 miles an hour, and the greatest weight he could sustain without moving be supposed to be divided into 225 parts, then his labour will be most effective when, loaded with 100 of those parts, he travels at the rate of five miles an hour. The common estimate of horse-power adopted in calculating the effect of steam-engines is wholly hypothetical. It is stated by Watt to be that which will raise a weight of 33,000 pounds the height of one foot in a minute of time, equal to raising about 90 pounds four miles an hour. Another estimate reduces the weight to 22,000 pounds raised one foot in a minute, equivalent to 100 pounds 2½ miles an hour. This mode of calculation seems to have been introduced as a matter of convenience, when the use of horses in mills and factories was superseded by that of steam-engines; and must have been adopted in order to show the superiority of steam-

To what extent did Peron discover that different nations vary in the forces which they can exert in different modes of exertion?

In what manner do horses exert their strength to greatest advantage?

What is generally found to be their effective force of traction?

What will be found the most advantageous load for a horse?

What is the estimate of horse-power assigned by Watt in calculating the effect of steam-engines?

* It does not follow that it is better to use *pack-horses* than wagons.—Ed.

engines over horses according to the most exaggerated statement of the power of the latter.

269. The ass, though far inferior to the horse in strength, is yet a most serviceable beast of burden to the poor, as he is easily maintained at little cost. It has been found that in England, an ass will carry about 220 pounds twenty miles a day; but in warmer climates, where he becomes a larger and finer animal, he may be made to trot or amble briskly with a load of 150 pounds.

270. Dogs are now frequently used for draught in various countries. The Kamtschatdales, Esquimaux, and some other northern people, employ teams of dogs to draw sledges over the frozen surface of snow. They are harnessed in a line, sometimes to the number of eight or ten, and they perform their work with speed, steadiness, and perseverance. Captain Lyon, when he visited the Arctic regions, had nine of these dogs, who dragged 1610 pounds a mile in nine minutes, and worked in this manner during seven or eight hours in a day. Such dogs will draw a heavy sledge to a considerable distance, at the rate of 13 or 14 miles an hour; and they will travel long journeys at half that rate, each of them pulling the weight of 130 pounds.*

271. The elephant was used by the Romans for the purposes of war, as it is still in India, and other oriental countries. His strength is reckoned equivalent to that of six horses, but the quantity of food he consumes is much greater in proportion. An elephant will carry a load of 3000 or 4000 pounds; his ordinary pace is equal to that of a slow-trotting horse; he travels easily 40 or 50 miles a day; and has been known to go 110 miles in that time.

272. The camel is a most valuable beast of burden on the sandy plains on both sides of the Red Sea; for traversing which, the animal might seem to have been expressly created. Some camels are able to carry 10 or 12 hundredweight; others not more than 6 or 7; and with such loads they will walk at the rate of 2½ miles an hour, and travel regularly about 30 miles a day, for many days together, being able to subsist eight or nine days without water, and with a very scanty supply of the coarsest provender.

273. The dromedary is a smaller species of camel, chiefly used for riding, being capable of travelling with greater speed than the larger camel, but not equally proof against exhaustion. The best Arabian camel or dromedary, after three whole days' abstinence

For what purposes have dogs often been employed?
At what speed, and with what loads, can the Arctic dogs travel?
At what speed, and with what load, can the elephant travel?
What circumstances of its constitution adapt the camel for usefulness in the particular climate where it is found to subsist?
For what particular labour is the dromedary adapted?

---

* The exhibition called the Hall of Industry, shows the force of dogs applying their strength on a *flexible inclined plane*.—ED.

from water, shows manifest symptoms of great distress; though it might possibly be able to travel five days without drinking; which, however, can seldom or never be required, as it appears that, in the different routes across the desert of Arabia, there are wells not more at the utmost than 3½ days' journey from each other. Exaggerated statements have been given of the speed of this animal; the most extraordinary performance of which the traveller Burkhardt ever obtained authentic information having been a journey of 115 miles in eleven hours, including two passages across the Nile in a ferry-boat, requiring twenty minutes each. The same traveller conjectured that the animal might have travelled 200 miles in twenty-four hours. A Bedouin Arab has been known to ride express from Cairo to Mecca, 750 miles, upon a dromedary, in five days. Twelve miles an hour is the utmost trotting-pace of the smaller camel; and though it may gallop 9 miles in half an hour, it cannot continue for a longer time that unnatural pace. It ambles easily at the rate of 5½ miles an hour; and if fed properly every evening, or even once in two days, it will continue to travel at that rate five or six days.

274. The lama, or guanaco, is a kind of dwarf camel, which is a native of Peru; and it was the only beast of burden employed by the ancient inhabitants of that country. It is easily tamed, feeds on moss, and being admirably adapted for traversing its usual haunts, the lofty Andes, it is still employed to carry goods. The strongest of these animals will travel, with a load of from 150 to 200 pounds, about fifteen miles a day over the roughest mountains. There is a smaller animal of a similar nature, called the Pacos, which is also now used by the Peruvians in transporting merchandise over the mountains; but which will carry only from 50 to 70 pounds.

275. Oxen have been, in many countries, employed in the labours of husbandry, instead of horses. They are, however, inferior, not only on account of the softness of their hoofs, which renders them, if unshod, unfit for any except field work, but likewise as being comparatively unprofitable. A team of oxen capable of ploughing as much land as a pair of horses will require for support the produce of one-fourth more land, after allowing for the increase of weight and value.

276. In some parts of Europe the goat is made to labour, by treading a wheel to raise ore or water from a mine. They are, in England, sometimes harnessed to miniature carriages for children; and in Holland the children of the rich burghers are thus drawn by goats, gaily caparisoned, and yoked to light chariots. The

What is the greatest speed of the camel?
At what constant rate can it usually travel?
What is the load and speed of the lama of South America?
Why are oxen inferior to horses in the labours of husbandry?
In what manner has the goat been employed as a mechanical agent?
In what region, and for what purpose, is the rein-deer made subservient to the purposes of man?

rein-deer of Lapland is a most serviceable beast of draught in the frozen regions of the north. Two of these deer, harnessed to a sledge for one person, will run 50 or 60 miles on the stretch; and they have been known to travel thus 112 miles in the course of a day.

At what speed can this animal travel?

The foregoing statements and illustrations will, in general, be found sufficient for the class of students for whose use this work is chiefly designed. For the use of teachers and others who may desire to pursue the subject more into detail, and to find rigorous demonstrations of the principles above laid down, we would make the following references to works which may with more or less facility be obtained by the American reader.

Cambridge Mechanics, by Prof. Farrar, p. 13—278.
Fischer's Elements of Natural Philosophy, p. 10—52.
Playfair's Outlines of Natural Philosophy, p. 19—168.
Boucharlat, translated from the French by Professor Courtney
Gregory's Mechanics.
Library of Useful Knowledge, article *Mechanics*, three numbers.
Robinson's Mechanics, edited by Dr. Brewster, in 4 vols.
Young's Mechanics.
Lagrange Mécanique Analytique.
Biot Traité de Physique.
Journal of the Franklin Institute, *passim*.

Many more works might be named, but the above it is believed will constitute a sufficient collection of subsidiary works to aid the teacher in his private investigations under the different heads embraced in the preceding treatise.—Ed.

HYDROSTATICS.

1. As the science of Mechanics treats of the phenomena depending on the properties of weight and mobility in solid bodies, so Hydrostatics relates to the peculiar effects of the weight and mobility of liquids. The term hydrostatics properly denotes the stability of water,* or in a more extensive acceptation, the pressure and equilibrium of liquids at rest. The effects produced by the flowing of water or any other liquid, have sometimes been regarded as appertaining to a distinct department of natural philosophy, named Hydraulics;† and occasionally the whole doctrine of mechanical science as applicable to liquids has been treated of under the designation of Hydrodynamics,‡ which, however, seems to possess no such peculiar property as to warrant its general adoption; and therefore the term Hydrostatics may be retained as denoting the science whose object is to explain the phenomena arising from the influence of gravitation on water and other liquids whether in the state of rest or in that of motion.

2. Liquids differ in some of their distinguishing properties from solids, and in others from gases or aërial fluids; forming an intermediate class of bodies. A solid, by the disintegration of its parts, may be reduced to a state bearing some resemblance to that of a liquid, thus fine sand or any light powder will yield to pressure in every direction, almost as readily as water; but the resemblance is still extremely imperfect. Viscous fluids, as train oil or treacle, approach to the nature of solids; and indeed the distinction between such liquid substances and some of the softer solids, as butter or honey, depends much on their relation to heat, their consistence or relative density varying with the temperature to which they are exposed.

3. As the effect of temperature on different bodies will constitute the subject of a separate treatise, it will be sufficient at present to state that the peculiar degrees of density and tenacity of unorganized substances, constituting the respective states of solidity and fluidity, with their various modifications, seem to be chiefly influenced by heat and pressure; so that a particular substance, as water, may exist under different forms, depending on the circumstances in which it is placed. Thus a certain degree of cold will convert water into a hard solid, as ice or hail, which, when melted by heat, produces a liquid differing in no respect from the water of which it was formed; and this when exposed

To what is the term hydrostatics properly applied?

To what is *hydraulics* sometimes appropriated?

What other term has been used to denote the mechanical properties and effects of liquids?

In what manner may solid substances be made to resemble liquids?

What class of liquids bear an analogy to solid bodies? What circumstances influence the density and tenacity of unorganized substances?

---

* From Υδωρ, water, and στασις, standing. † From Υδωρ, and αυλος, a pipe. ‡ From Υδωρ, and δυναμις, power.

to a sufficiently high temperature, will evaporate or become steam; which may be again condensed or restored to the liquid state by cold. Mercury commonly occurs in the form of a very dense liquid; but it may, like water, be condensed or frozen by exposure to an extremely low temperature, and be made to boil or evaporate by subjecting it to a great degree of heat. The other metals differ from mercury only in remaining solid in higher temperatures than that substance; but they all melt with various degrees of heat, and become sublimed or evaporated when the heat is greatly raised above the melting point.

4. Since the same kind of matter may exist under different states or forms, it follows that liquids must be composed of the same particles as solids, and the difference between a liquid and a solid may be conceived to arise, merely, from peculiar modifications of the cohesive attraction which takes place between the constituent molecules or particles of such bodies respectively. The particles of elastic solids must be capable of a sort of vibratory motion, from sudden pressure, but they will always resume the same position as soon as the vibration ceases, unless it be so violent as to occasion a permanent separation of the particles, when the solid becomes broken or pulverised. Now liquids have their constituent particles, held together like those of solids, by cohesive attraction, but they oscillate on the application of the slightest impulse; and there seems to be such a general relation of all the particles to each other, that when the connexion between any two particles is broken, by shaking or otherwise agitating the mass of which they form a portion, they readily become attracted by any other particles with which they may happen to come in contact, new cohesions take place, and when the disturbing force is removed, the general equilibrium is restored throughout the liquid mass.

5. The cohesive attraction between the particles of liquids is demonstrated by the globular figure which they assume, when no external force interferes with the aggregation of the mass. This appears in the case of mercury thrown in small portions on a china plate, or on any surface which exercises on it no chemical attraction; when the minute portions into which it will become separated, will be found to be perfect spherules, the larger ones only being slightly flattened by the pressure occasioned by their own weight on the plate. Similar spherules, consisting of drops of water,

Through what successive changes of state may bodies occasionally pass? Give some examples of these changes?

Whence arises the difference between a liquid and a solid body?

Of what action are the particles of elastic solids necessarily susceptible?

By what force are the particles of liquids held together?

What constitutes the difference between breaking a solid and separating the parts of a liquid?

How is the cohesive attraction between the particles of a liquid demonstrated?

are formed by dew or rain on the broad leaves of some kinds of vegetables, as those of the common cole-wort or cabbage. If, however, the drops become large, as when two or three run together, they spread out at the edges, sinking down, and becoming flattened, partly through their own weight, and partly owing to the attraction between the water and the surface of the leaf.

6. The general appearance or figure which liquids assume when at rest is the joint effect of the extreme mobility of their constituent particles, of the gravitation of liquid masses, and of their attraction for the solids on which they are sustained. Hence when a liquid in any considerable quantity is poured into a vessel of any shape whatever, it adapts itself exactly to the internal surface of the vessel, the superior or unconfined surface of the liquid forming a horizontal plane, usually raised a little at the sides or border of the vessel, where the liquid is attracted by the containing solid with which it comes in contact.

7. When an immense mass of liquid presents a continued surface, its form will be a portion of a convex sphere; because the collective gravitation of all its particles towards the centre of the earth causes it to partake of the general figure of the terrestrial globe. This, indeed, will be the case with comparatively small bodies of liquid; but when it is considered that the radius of the sphere, of which any such liquid surface formed a part, would be equal to half the diameter of the earth, it must be manifest that the difference between the surface of a small portion of such a sphere and a horizontal plane would be too inconsiderable to be distinguished. Vast collections of water, however, as the open sea, afford decisive indications of superficial curvature, among the most striking of which is the fact that when a vessel first comes in sight its masthead alone is visible, and the lower parts appear successively as it approaches the observer, rising as it were out of the bosom of the deep.

8. Among the properties in which liquids differ most remarkably from gases, is the power of sustaining pressure to a considerable extent, without undergoing any obvious change of volume. Common air, steam, and other elastic fluids, as they are termed, may be compressed by very moderate force, and on its removal they expand to their original dimensions, as may be ascertained by squeezing a blown bladder; but a leather bag or strong bladder filled with water, and secured so that none of the liquid can escape, may be burst by forcible compression, but cannot be made to exhibit any sensible degree of contraction. Such indeed is the

On what three circumstances does the figure assumed by a liquid at rest depend?
What is the external form of a large mass of liquid?
Why is this form taken rather than any other?
What sensible evidence is afforded of the spherical form of the earth?
In what respect do liquids differ essentially from gases?
How was water formerly regarded in respect to compressibility?
On what experiment was this opinion founded?

extraordinary resistance of water, when subjected to pressure on all sides, that it was long regarded as absolutely incompressible. This opinion was partly founded on an experiment made in the sixteenth century, by the members of a scientific society at Florence, called Academia del Cimento. These philosophers conceived the idea of enclosing a quantity of water in a hollow globe of beaten gold, and exposing it to the powerful action of a screw press, when it was found that the water was forced through the pores of the gold ball or case, standing in drops like dew on its exterior surface. But this experiment, can by no means be considered as demonstrating the entire incompressibility of the liquid; for though it obviously displayed vast resistance to the compressing force, it might have undergone the utmost limit of condensation before the exudation took place; and the experiment was unsatisfactory, as affording no means whatever for appreciating the actual volume of the water at the moment when it penetrated the solid envelope. In fact, nothing more could be inferred from such an experiment, but that water is not susceptible of unlimited condensation.

9. The fallacy of the formerly generally received notion of the absolute incompressibility of water was proved by some ingeniously contrived experiments by Mr. Canton, a fellow of the Royal Society of London, in 1761. He showed that water, included in a glass tube with a large bulb or hollow globe at its extremity, expanded and consequently stood higher in the tube when placed under an exhausted receiver than when subjected to the pressure of the atmosphere, and on the contrary was condensed proportionally, by pressure equal to the weight of two atmospheres. He made similar experiments on spirit of wine, olive oil, and mercury, from which it appeared that those liquids undergo condensation, but in different degrees, when subjected to compression. In conducting these experiments proper precautions were adopted to prevent any inaccuracy arising from variation of temperature; and the following table exhibits the results obtained when the barometer stood at 29½ inches and the thermometer at 50 degrees.

10. Spirit of wine underwent compression amounting to 0.000,066 of its bulk.

Olive oil, - - -	0.000,048
Rain water, - -	0.000,046
Sea water, - - -	0.000,040
Mercury, - - -	0.000,003

Hence it appears that mercury is far less compressible than water

What legitimate inference can be drawn from the Florentine experiment?

By whom was the fallacy of the opinion formerly entertained respecting the compressibility of water first demonstrated?

State the manner in which Canton's experiments were conducted?

What other liquids besides water were proved by Canton to be compressible?

11. More recently, experiments on this interesting subject have been instituted by M. Oersted, a philosopher who has greatly distinguished himself by his scientific researches; and the results of his investigations, which appear to have been very carefully conducted, correspond nearly with those of Canton, the contraction of water, under pressure equal to the weight of an additional atmosphere, according to the experiments of Oersted, amounting to 0.000,045.

12. Experiments have been undertaken in England with a view to ascertain the effect produced by subjecting liquids to compressing forces of vast energy, far beyond those employed in the researches of Canton and Oersted. In 1820, an account was laid before the Royal Society of London by Mr. Jacob Perkins, of some experiments from which he inferred that water had suffered a compression of about one per cent. of its bulk by a pressure equal to 100 atmospheres; and in other experiments the compressing force was augmented to 326 atmospheres, which caused a contraction of the liquid to the amount of nearly 3½ per cent. These results were obtained by including water in the cavity of a cannon, fixed vertically in the earth, and driving more water into it with a forcing pump; and corresponding experiments were made by sinking water inclosed in a proper apparatus to a great depth beneath the surface of the sea, and observing the degree of compression it had undergone.* These operations, however, could not be regarded as equally accurate with those previously described; though the deductions from them have been corroborated by the result of subsequent investigation.

13. In 1826 Mr. Perkins made public other experiments on the compression of water, of which also an account appeared in the Philosophical Transactions. The machine he employed was composed of a cylinder of gun-metal, 34 inches in length, and having an internal cavity to which was adapted a steel pump, with a water-tight piston, by means of which water could be injected into the body of the cylinder. A lever apparatus was properly annexed for the purpose of measuring the degree of pressure; and so adjusted that the number of pounds pressing on its piston indicated exactly the number of atmospheres equivalent to the degree of compression.

14. That part of the apparatus in which the liquid is enclosed, the condensation of which is to be measured, is called by the experimentalist a piezometer.† It consists of a strong glass tube, eight inches in length and half an inch in diameter, closed at one

To what results has Oersted been led by his experiments on water?
How many atmospheres of pressure are required to condense water to the amount of one per cent. of its ordinary bulk?

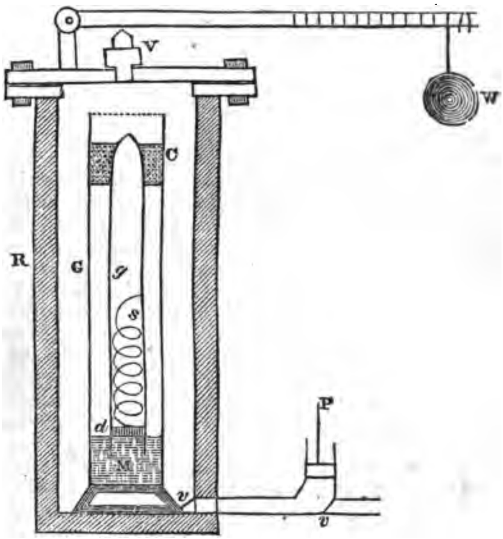
---

* See Philosophical Transactions, 1820, and Abstract of Papers in Philosophical Transactions, vol. ii. p. 134.

† From the Greek Πιεζω, to press, and Μετρον, a measure.

extremity and open at the other. This tube must be carefully filled with water freed from air, and being inverted while the water is prevented from escaping by the application of a thin membrane to its mouth, it must be inserted in a wider tube or glass, the upper part of which is filled with water, and the lower part with mercury; the small tube contains a hair-spring pressing against its interior surface so as to retain its position when forced upward; and this spring is in contact with a steel disk moving freely in the upper tube, and from its inferior weight supported by the surface of the mercury below. A frame of strong wire retains the small tube in its situation; and the piezometer being thus arranged is introduced into the receiver of the compressor, filled with water at a temperature of 50 degrees, when the pump being screwed into its place, any required degree of pressure may be applied. When the experiment was carefully conducted it was found that water, under the influence of a force equal to 2000 atmospheres, was diminished by 1-12 part, as indicated by the situation of the spring.*

15. The nature of Mr. Perkins's mode of compressing water, will



By what part of its original bulk under atmospheric pressure will a force of 2000 atmospheres, or 30,000 lbs. to the square inch, condense a given mass of water?

What is the construction of Perkins's piezometer?

* This curious and interesting experiment is exhibited daily, at the National Gallery of Practical Science, in the Strand, London.

perhaps be more clearly comprehended from the annexed figure, in which R is the metallic cylinder, G the wider glass tube with a quantity of mercury, M at the bottom; *g* is the piezometer dipping into the mercury below and kept steady by the wire cage C near the top; *d* is the steel disk, and *s* the hair-spring to be moved upward when the water in *g* is compressed, and the mercury with the disk *d* rises, and to remain and indicate the degree of compression after the experiment. The use of the force pump P with its two valves, *v*, *v*, and that of the safety valve V, with the lever and weight W serving to determine the force applied, will be readily understood. The apparatus of Oersted substitutes a strong glass receptacle for the metallic one of Perkins; and his piezometer is a nearly capillary tube in which a thread of mercury rises by the compression and forces before it the water with which the whole upper part of the tube, (hermetically sealed at top,) is filled. Oersted employs to compress the liquid instead of the steel pump, a strong thumb-screw inserted into the top of the brass cap with which his glass receptacle is closed. He also encloses a thermometer, not hermetically sealed, to mark the degree of heat, if any, developed by the effect of mechanical compression.

16. Though it is manifest, from the preceding statements, that liquids undergo great compression under certain circumstances, yet the degree of compressibility of such liquids, as water, is so inconsiderable when the compressing force is moderate, that no sensible effect is produced. Hence in all calculations concerning the action of water, at rest or in motion, in ordinary cases, it may be regarded as an incompressible fluid.

17. Liquids in general possess the property of elasticity; but like solids, some of them display that property to a greater extent than others. When a solid disk, as an oyster-shell or a flat stone, is made to strike the surface of water at a small angle, as in the sport which schoolboys call making ducks and drakes, the solid will rebound from the water with considerable force and frequency. So a musket-ball impinging obliquely on water will take a zigzag course, *en ricochet*, as the French express it. Water dashed against a hard surface, as when it is poured against the side of a china basin, or let fall on a plate, shows its elastic force, in flying off in drops in angular directions. Experiments on the elasticity of drops of water, spirit of wine, or any similar liquid, may be made in a shallow wooden box, having its bottom and sides thinly covered with any light insoluble powder; for the drops on being impelled against the side of the box, or even against each other, will rebound like miniature cricket balls or marbles.

Might this instrument be employed with advantage to measure the compression suffered by water in *deep-sea* experiments? Describe the arrangement of apparatus employed by Perkins in the compression of water. How may water be regarded under the influence of moderate changes of pressure? What evidence is afforded of the elasticity of water by the impinging of solid bodies upon its surface? How may we demonstrate the elasticity of drops of water?

18. Mercury is yet more elastic, as might be shown by placing a small quantity of it in a little case made by bending at right angles the sides of a common playing-card; and on inclining it so as to make the metallic fluid strike one of the raised sides of the card, the shining globules would recede with a velocity proportioned to the violence of the shock. The effects thus exhibited appear to be extremely similar to those observed in the case of elastic solids. A globule of mercury impinging on a hard surface becomes slightly flattened, but instantaneously resuming its curved figure, it recoils like a bent spring suddenly liberated. In some hydraulic operations the elasticity of liquids becomes a property of considerable importance, variously augmenting or modifying the efficient force of particular kinds of machinery.

Weight and Pressure of Liquids.

19. Among the absurd doctrines heretofore generally received, but which have been exploded by the light of modern philosophy, must be reckoned that of the non-gravitation of the particles of liquids on each other. That liquids as well as solids possess weight was never denied; since every one must have learnt from experience that a cup or a bucket filled with water would require a greater exertion of force to lift it than when the water was removed. But it was observed that in drawing water from a well, so long as the bucket remained under water very little effort was required to raise it, while as soon as it emerged from the surface of the liquid, the loaded bucket would press downward with a force proportioned to the quantity of water contained in it. This, and the general observation that heavy bodies were easily raised while under water, gave rise to the vague idea that a liquid did not gravitate in its own element, and that therefore a body surrounded by any liquid was destitute of weight.

20. The following experiment sufficiently proves that this is not the case. Let a strong phial, with a stop-cock fitted to it, be exhausted by means of an air-pump, and the stop-cock being turned let it be suspended from one arm of a balance, so that it may be entirely immersed in a vessel of water, weights being placed in the opposite scale of the balance to keep it in equilibrium; then if the stop-cock be opened the water will flow in and fill the phial, which will immediately sink, and to restore the equilibrium the same weight must be added that would counterpoise the water it contains if weighed alone: thus, if the bottle would hold exactly four ounces of water, a weight of four ounces would be required to make the balance stand even as at first.

How are analogous experiments on mercury conducted?
What appears to be the effect of the impact of a drop of mercury upon a hard surface?
What opinion was formerly entertained respecting the gravitation of liquids upon their own mass?
From what circumstance did this idea probably take its rise?
How is its incorrectness conclusively demonstrated?

21. The apparent diminution of the weight of bodies under water is owing to the particles of the liquid mass gravitating equally in every direction; so that the interior portions of any liquid, or of solids immersed in liquids, are subjected to the same degree of pressure on all sides; and therefore a body surrounded by water is partially supported by it, and consequently may be raised through the liquid with greater ease than in the air, a fluid, the relative density of which is so very inconsiderable. Liquids are not less powerfully affected by gravitative attraction than solids, but they exhibit different appearances under its influence, owing to their being constituted differently, so that their particles move freely and almost independently of each other.

22. All the constituent particles of a solid are firmly connected, and they thus act with combined effect in producing pressure or impact; but a liquid yields to force in any direction, and is liable to be separated into small masses, the effect of which is comparatively inconsiderable. A basin of water poured from a great height on a man's head would hardly be felt more than a current of rain; but if the contents of the basin, supposing it to hold a quart, were suddenly changed to a solid mass of ice, it might occasion a fracture of the skull. But though a liquid in falling becomes almost dissipated through the resistance of the atmosphere, it displays great force when it can be made to act in a continuous column. Hence the power of a mill stream in turning large wheels either by weight or pressure; and the tremendous violence of a cataract, sweeping away great stones or other ponderous masses which may present any obstruction to its impetuous course.

23. The effect of a liquid mass when its particles are protected from dispersion, and thus enabled to act in concert, like those of a solid body, may be amusingly illustrated by means of the little instrument called a water-hammer. It consists of a strong glass tube, about twelve inches long, and nine or ten lines in diameter, having three or four inches of water included in it; which being made to boil and form steam by the application of a proper heat, the tube must be hermetically sealed by means of an enameller's lamp and a blow-pipe, so that when it becomes cool, a vacuum will be formed above the water by the condensation of the inclu-

How is the apparent loss of weight in bodies immersed in water to be explained?

To what is the difference attributable between the phenomena exhibited by liquids and those observed in solids, when under the influence of gravitation?

How are the constituent parts of each held together?

What simple experiment would illustrate the influence of a change of form, in modifying the effect of water?

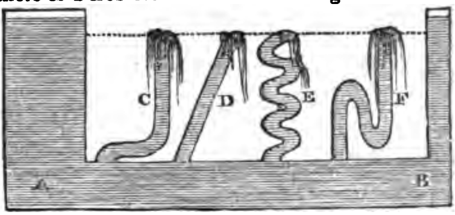
What examples may be cited of great energy displayed by a falling liquid?

By what apparatus may the percussion of a falling mass of liquid be illustrated?

Describe the water-hammer.

ded steam. On shaking such a tube vertically, the water, rising a few inches and sinking suddenly to the bottom of the tube, produces a sound like that arising from the stroke of a small hammer on a hard body, whence the name of this instrument, the action of which depends entirely on the exclusion of the air, so that the water moves in a dense mass.

24. The pressure of liquids extending equally in all directions, a liquid mass will have all parts of its surface at the same level, whatever be the form of the vessel in which it is contained, so long as there is a free communication throughout.



25. In the preceding figure let A B represent a glass vessel closed except at the two raised extremities, and filled with water to a height above the horizontal line; then suppose four differently shaped tubes C, D, E, F, open at both ends, to be inserted in the oblong part of the vessel, with their upper extremities not rising so high as those standing at the sides; it will be found that the liquid will pass laterally into the tube C, ascend directly in D, and circuitously in E, while it both descends and ascends in F, rising equally in all the tubes, and spouting out till the water is reduced in the side tubes to the level of the summits of the internal ones, when the equilibrium being established the liquid will remain at rest. Thus it follows that any number of columns of a liquid, freely communicating, whatever may be their respective diameters and figures will always have the same vertical height.

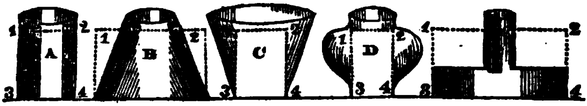
26. Yet though all the particles of a liquid mass will press equally on each other, it must be manifest that the collective weight will be proportioned to the depth beneath the surface, so that the bottom of the containing vessel necessarily sustains the weight of a column having the greatest vertical height of the liquid with an area equal to that of the base itself.

27. If the vessels A, B, C, D, and E, have water poured into them in such quantities that it may stand at the same height in each, the pressures on their bases respectively will be as the several columns marked 1, 2, 3, 4. Hence the amount of the pres-

What consequence results from the equal pressure of liquids, in regard to the height of its surface?

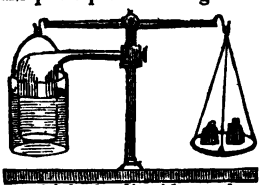
What influence has the figure and size of the parts of containing vessels on the height to which liquids will rise within them respectively?

What measures the pressure exercised by a column of liquid on the bottom of its containing vessel?



sure of any liquid may be ascertained by multiplying the vertical height at which it stands by the extent of surface of its base. Thus suppose the water in the vessel B to stand at the height of four inches, and the area of the base to be eight square inches, the pressure will be equal to thirty-two inches of the fluid; but if the water should stand at the same height in the vessel C, having a base only half the area of the former, the pressure will be but half or only sixteen inches, though the capacity of both vessels may be exactly the same. The diameter of a vertical column communicating with an extended base may be relatively inconsiderable, as in the vessel E, notwithstanding which it will cause the same degree of pressure as a column of the same height with a diameter corresponding to the base throughout.

28. This effect of the vertical pressure of liquids may be variously exhibited, and its results are curious and important. Hence the principle involving the peculiar mode of pressure of liquid masses has been termed the Hydrostatic Paradox. It may be illustrated by the following experiment. Let a cup or wide-mouthed jar, filled with water, be poised by hanging it to the arm of a balance, by loading the opposite scale with the requisite weights; then after marking exactly the height at which the liquid stands, pour out a part of it, and plunge into the midst of the jar a conical block of wood, supporting it with the hand or by means of the apparatus represented in the annexed figure, taking care that the block shall not touch the sides or bottom of the jar. If it be plunged just deep enough to raise the remaining liquid to the same height as at first, the balance will be again exactly equipoised; and the block may be so large as to leave only a thin film or hollow cylinder of the fluid without at all disturbing the equilibrium. It is of no consequence what is the weight or shape of the body introduced, for a piece of cork or a blown bladder held in the jar will produce the same effect, if its bulk be sufficient to raise the water to the required height.*



By what mode of calculation may we ascertain that pressure?

If a vessel representing the frustum of a cone be filled with liquid, and successively placed on its two opposite bases, what will be the relation between the pressures exercised in the two cases?

What is meant by the *hydrostatic paradox?*

What experiment exemplifies the kind of pressure exercised by liquids?

How can we prove that the loss of weight from plunging a body into water is only apparent?

---

* An ingenious apparatus for drawing water from a vessel in which a

29. There is another striking mode of illustrating the effect of liquid pressure, by means of a kind of machine called the Hydrostatic Bellows, a figure of which may be seen in the margin. It

is composed of two flat boards united at the sides by flexible leather, and having a long narrow vertical tube, communicating with the cavity, with a funnel at the top, for the convenience of pouring in water or any other fluid; and a short lateral tube with a stop-cock may be added to discharge the water occasionally. If now water be poured into the long tube it will fill the cavity and consequently separate the boards, and by adding more water the instrument may be made to support any given weight, in proportion to the height of the vertical column. Suppose the boards to be about 320 inches superficial measure, four ounces of water, standing at the height of three feet in the tube, will keep the boards separated when loaded with 416 pounds.

30. Two stout men standing on the upper board, one of them by blowing into the tube may fill the cavity with air instead of water, so as to raise the board on which they stand, and by stopping the pipe with the finger to prevent the air from escaping, they may keep themselves supported.

31. The force of water pressing on an extended surface by means of a small vertical tube may be shown by fixing such a tube in a water-tight cask or other close vessel, which, whatever its strength, might be burst by filling it with liquid, and adding more through the tube, till the weight of the column became too great to be supported by the sides of the cask. The effect depends wholly on the height of the tube, its diameter being immaterial. A hogshead filled with water and exposed to the pressure of a column in a narrow tube, twenty feet high, would burst with great violence.

32. Astonishing effects are sometimes produced by the pressure of water modified in the way already described. As when a shallow body of water is collected in a close cavity under ground,

Describe the construction, and explain the principle, of the hydrostatic bellows?

In what manner might the same principle be applied to maintain a regular blast of air for the blow-pipe?

In what manner do we demonstrate the importance of height of column to the effect of liquid pressure?

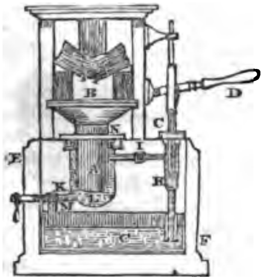
In what manner may the effect of hydrostatic pressure on portions of the earth's surface be manifested?

---

solid has been made to float until the liquid has the same level as at first, and then weighing the quantity drawn out against the solid which had been floating, proves the same general position as the arrangement above described. It moreover shows that the weight lost by the solid, and the upward pressure of the liquid which is the cause of that loss, are both equal to the weight of water so displaced.—Ed.

if a narrow opening be made from a higher surface communicating with the cavity, and it should become filled by rain or snow water, whatever might be the form of the aperture, if it was water-tight, as soon as the communication was effected between the tube-like opening and the cavity, pressure would take place in every direction, in a degree proportioned to the vertical height of the opening and the area of the cavity; in consequence of which the superincumbent mass might be rent from its foundation, and a large building or even a mountain might be overthrown, as by an earthquake.

33. The principle of hydrostatic pressure was discovered, or at least first satisfactorily demonstrated, by the celebrated Pascal, about the middle of the seventeenth century; and he showed how an engine might be constructed, acting through the force of a column of water, by means of which one man pressing on a small piston might counterbalance the efforts of one hundred men brought to bear on the surface of a large piston. Yet notwithstanding the distinct description of what the ingenious discoverer terms "a new machine for multiplying forces to any required extent,"* more than a century and a half elapsed before the idea was fully developed, and applied to practical purposes, by Mr. Bramah, the engineer, in the construction of his hydrostatic press.



34. This machine consists of a solid mass of masonry or strong woodwork, E F, firmly fixed; and connected by uprights with a cross-beam. B represents a strong table, moving vertically in grooves between the uprights, and supported beneath by the piston A, which rises or descends within the hollow cylinder L, and passes through a collar N, fitting so closely as to be water-tight. From the cylinder passes a small tube with a valve opening inwards at I, and D is a lever which works the piston of the small forcing-pump C H, by which water is drawn from the reservoir G, and driven into the cylinder L, so as to force up its piston A. At K is a valve, which being relieved from pressure, by turning the screw which confines it, a passage is opened for the water to flow from the cylinder, through the tube M, into the reservoir G, allowing the piston to descend.

35. The effective force of such a machine must be immensely

Who first demonstrated the principle of hydrostatic pressures according to the height of column?

What application did Pascal propose to make of the principle of pressure according to the area of the base of the containing vessel?

By whom, and at what period, was the idea of Pascal fully realized?

What is the construction of Bramah's press?

* Pascal de l'equilibre des liqueurs, edit. 2, 1664, ch. ii.

great, combining as it does the advantages of solid and liquid pressure. The amount of the latter is to be estimated by the relative diameters of the two pistons; so that if the piston H be half an inch in diameter and the solid cylinder or piston A one foot, the pressure of the water on the base of the piston A will be to the pressure of the piston H on the water below it, as the square of 1 foot or 12 inches, $12 \times 12 = 144$, to the square of ½ an inch, $.5 \times .5 = .25$; that is as 144 square inches, to ¼ of a square inch, or in the ratio of 576 to 1. To this must be added the advantage afforded by the lever handle of the forcing-pump, depending on the relative lengths of its arms; and supposing the power to be thus increased tenfold, the effect of the machine will be augmented in that proportion, or will become as 5760 to 1.

36. As the hydrostatic press acts with a comparatively trifling degree of friction, it may be made to produce an infinitely great amount of pressure; its efficiency in fact being limited only by the measure of the strength of materials employed in its construction. Some idea of the power of this engine may be derived from the statement that with such a press, only the size of a common tea-pot, a person may cut through a thick bar of iron with no more effort than would be required to slice off a piece of pasteboard with a pair of shears. It has been used in making experiments on the tenacity and strength of iron and steel, being applied so as to tear asunder solid rods or bars;* and in packing bales of cotton or trusses of hay, it has been employed to compress them to convenient dimensions for stowage on board ships.

37. The principle of hydrostatic pressure has been ingeniously applied to a purpose of great practical utility by Dr. Arnott, in the contrivance of a hydrostatic bed for invalids. It is so constructed as to keep the body of a person reposing on it, sustained by a mattress on a liquid surface, yielding freely in every direction, and therefore entirely exempted from any irregular pressure: thus the irksomeness, as well as the serious evils caused by confinement to one position for a long time, and the consequent injuries which persons enfeebled by disease sometimes incur, may be wholly prevented.

38. The pressure of water or any other liquid against the bottom of a vessel in which it is contained may be regarded as the common effect of gravity, which acts in the same manner on solid

What method will enable us to estimate the advantage of a Bramah's press of known dimensions?

What advantage has the hydrostatic press over the screw press and similar machines?

What limits the efficiency of this apparatus?

What remarkable applications of the hydrostatic press illustrate its force and usefulness?

What is the construction of Arnott's invalid bed?

In what respects does the pressure of a liquid within a containing vessel differ from that of a solid under the same circumstances?

---

* See Encyclopedia Metropolitana—Mixed Sciences, vol. i. p. 70.

point often becomes an object of importance; since it will indicate the most efficient means for sustaining a floodgate or any similar surface against the pressure of a body of water. The position of the centre of pressure must depend on the figure of the surface and the depth of the head of water. Supposing the surface to be a perpendicular parallelogram, the centre of pressure will be at two-thirds of the distance from the level of the water to the bottom; and if the figure of the surface be an equilateral triangle, at three-fourths of the distance from the vertex to the base.

44. On the principle of the lateral pressure of liquids may be estimated the pressure sustained by solids immersed at any depth beneath a liquid surface. Thus, if it be required to find the pressure which a diver sustains when he has descended in water to the depth of 32 feet, or rather to such a depth that the centre of gravity of his body may be exactly 32 feet beneath the surface of the water; then as the extent of surface of a human body, at a medium, may be estimated at 10 square feet, the product of that number multiplied by 32 will give the quantity of water in cubic feet, the weight of which must be sustained by the diver at the depth just stated. Now as one cubic foot of water weighs 1000 ounces avoirdupois, the weight of 320 cubic feet will be 320,000 ounces or 20,000 pounds.*

45. The equability of the pressure in every direction renders such an immense weight supportable; though it occasions considerable inconvenience to persons learning to dive, from the intense pain caused by the pressure of the water on the drums of the ears, even at the depth of 18 feet below the surface. It appears probable that diving in very deep water, at length, has the effect of rupturing the membrane called the drum of the ear, after which pain in that organ is no longer felt by the diver;† but there must be a limit to the depth to which the most experienced diver can descend, since at a very great depth the compressing force of the liquid mass would be so augmented as to expel entirely the air that had been retained in the cavities of the chest and head,

On what circumstance will its position depend?

At what point in a floodgate in the form of a rectangular parallelogram might a single force on the side opposite to that pressed by the water be applied, so as to resist the whole pressure of the liquid within?

How may we find the amount of pressure upon the body of a diver, when at a given distance below the surface?

Why is not a person crushed by the weight of liquid above him, when placed many feet below the surface of water?

What peculiar sensation is felt at first by persons unaccustomed to deep diving?

What is supposed to take place when the inconvenience at first felt is found to cease?

Why may not a man descend to any depth below the surface of water?

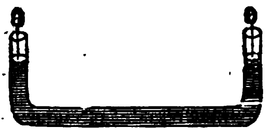
---

* The manner of ascertaining the weight of any body relatively to its bulk will be described in the next section, in treating of specific gravity.

† See Hardy's Travels in the Interior of Mexico. London, 1829.

and contract the bulk of the whole body in such a manner as to render ascent to the surface no longer practicable.

47. The uniform pressure of liquids in every direction, and the consequent equality of action and reaction among the parts of liquid masses cause them to assume a level surface under all circumstances. This property of liquids has been advantageously employed in the construction of instruments for ascertaining the relative heights of any given points, as in taking levels in surveying, and in various operations in which it is requisite to determine the accuracy of a horizontal plane. Such an instrument may consist of a glass tube of considerable length, as represented in the margin, open at both ends, which must be raised or turned upward to the same height; and the tube being filled with water or mercury, when



it is placed in a horizontal position, the liquid will stand at the same level on both sides. Upon the open surfaces of the liquid must be placed floats, each carrying upright sights with cross-wires, which standing at right angles to the length of the instrument, when it is properly adjusted, the intersections of the wires will be situated in a horizontal line; and consequently on looking through the sights at any distant object it can only be seen exactly opposite the intersections of the wires when it happens to be in the same level.

48. The spirit level, an instrument adapted to the same purposes with the preceding, consists of a glass tube, closed at both ends, and filled with alcohol, except a very small space occupied by a bubble of air, which, in whatever situation the tube may be placed, must rise to the highest part of it. When, therefore, the tube is fixed in a horizontal position, the bubble will stand precisely in the centre of the tube and in contact with its surface. Such a level may be used like the water-level, above described, for ascertaining the accuracy of a horizontal plane; or it may be mounted in a frame with moveable sights adapted to a quadrant, by means of which the angular distances of objects may be determined with the utmost degree of correctness.

49. The property which liquids possess of preserving an exact level in different tubes or vessels communicating with each other is of the highest importance, as indicating an obvious mode of conducting water from one situation to another. Thus from a lake or reservoir this useful fluid may be conveyed in pipes or tunnels underneath streets and buildings to any given distance, and supplied to the different quarters of a town or city, at any height not exceeding that of its source. The whole amount of the daily

What is the general construction of liquid levelling instruments?
What is the form and use of the spirit level?
On what principle are we enabled to conduct water under ground, and through irregular tubes?

supply of water to the cities of London and Westminster appears to be nearly 26,000,000 gallons, more than half of which is derived from the Thames; and as most of it is delivered at heights much above the level of the river, it is necessarily raised by artificial pressure by means of steam-engines.

50. Though water and similar liquids may be transferred to any imaginable distance through a series of communicating tubes bent into numerous angles, descending and ascending, and made to issue freely at a height nearly equal to the source; yet it is found in practice that obstruction, arising from the friction of the liquid against the sides of the tubes, especially where they form acute angles, and from the accumulation of bubbles of air in long narrow tubes, may cause great inconvenience; and hence large pipes are more advantageously employed than smaller ones, and aqueducts or open conduits are to be preferred in some situations.

51. In the south of Europe may be seen the remains of stupendous aqueducts constructed by the ancient Romans, forming open canals supported by numerous arches passing across wide valleys, and exhibiting even in decay striking memorials of the architectural skill and industry of those to whom they owe their origin. From these magnificent works on which such immense labour must have been bestowed for the purpose of conducting water on one descending plane, it has been hastily inferred that the ancients were entirely ignorant of the effect of hydrostatic pressure; and of the means of making water rise to the height of its source after passing through a lower level. But this notion is utterly erroneous, for in the great work of the celebrated naturalist, Pliny the elder, it is expressly stated that water will always rise to the height of its source; and he adds that tubes of lead must be used to carry water up an eminence.* Passages to the same effect might be adduced from other ancient writers, containing plain allusions or direct statements relative to the consequences of the pressure and flow of water. Indisputable evidence that the ancients were not ignorant of this principle has been afforded by the researches made among the ruins of Pompeii, where the remains of fountains and baths show that the inhabitants of that city, which was destroyed in the reign of the Emperor Titus, were not unskilled in the means of causing water to ascend through pipes and conduits. The reason why the Romans did not adopt the method of conducting water through large tubes was chiefly because they were unable to construct such tubes as would be

Of what nature are the impediments to the motion of liquids in conduit pipes?

In what manner were the ancients accustomed to conduct water from a distance into their cities?

What evidence have we that the ancient Romans understood the principles of hydrostatic pressure as applicable to subterranean conduits?

* Plinii Hist. Natural. lib. xxxvi. cap. vii. See Leslie's Elem. of Nat. Philos. pp. 411—413.

water-tight when exposed to the pressure of a considerable column of liquid. Their water-pipes were made of lead, earthenware, or wood, and were in many respects inferior to those used in modern times.

52. Some of the most remarkable phenomena of nature are owing to the tendency of liquids to form coherent masses, to become extended over the surfaces of solids, and to flow in any direction till they find a common level. Water is the most abundant of all liquids, and if we trace its operations under the several forms of rain, springs, fountains, running streams, lakes, or rivers, communicating with the extended ocean, the peculiar properties which constitute the distinctive character of liquid bodies will be recognized in the effects which they produce. Some notice has already been taken of the different states of aggregation which water assumes when exposed to certain degrees of temperature, being expanded or converted into vapour by heat, and condensed by cold.* It may be considered as making its first appearance as a liquid in the form of falling rain, which consists of drops of water recently produced by the condensation of aqueous vapours.

53. "The drops of rain vary in their size, perhaps from one twenty-fifth to one-fourth part of an inch in diameter. In parting from the clouds, they precipitate their descent till the increasing resistance opposed by the air becomes equal to their weight, when they continue to fall with a uniform velocity. This velocity is, therefore, in a certain ratio to the diameter of the drops; hence thunder and other showers in which the drops are large pour down faster than a drizzling rain. A drop of the twenty-fifth part of an inch, in falling through the air, would, when it had arrived at its uniform velocity, only acquire a celerity of eleven feet and a half per second; while one of one-fourth of an inch would acquire a velocity of thirty-three feet and a half."†

54. Experimental inquiries have frequently been instituted as to the quantity of rain which had fallen at any particular place during a certain period. An estimate of the amount of aqueous fluid discharged from the atmosphere might be formed from observing the quantity of rain-water descending on the roof of a house or any other building, provided the whole could be collected and measured before any portion of it had been dissipated by evaporation, and an exact measurement could also be obtained of the superficial area of the surface on which the rain had fallen.

Why did not the ancients carry all their aqueducts beneath the surface of the ground?

What limits the velocity of water descending in the form of rain?

To what is the resistance of the air to falling drops of water proportioned?

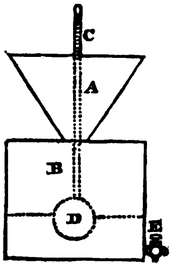
How might an estimate be formed of the amount of water descending annually over the surface of a country?

---

* See Mechanics, 54. † Leslie's Treatise on Heat and Moisture.

There are some situations in which this plan might be executed without much difficulty.

55. But a more generally applicable, though perhaps less satisfactory method of ascertaining the daily, weekly, monthly, or annual fall of rain, in any situation, is by means of an instrument called a pluviameter, or rain-gauge. This instrument has been variously constructed, and the different forms which have been recommended may each have their particular advantages; but the general object of all of them is the collection of rain falling on an area of known extent, as a few square inches, and providing for its accurate measurement. Below is represented a rain-guage which has at least the merit of simplicity, as showing, on inspection, the quantity of rain-water which may have fallen on a certain area during any given time. It consists of a quadrangular-topped funnel, A, the opening of which may be ten inches square, terminating below in a reservoir B. Through the neck or opening between the funnel and the reservoir is inserted the graduated rod C, to which is adjusted the ball D, made of cork or light wood, so that it may float on the surface of the water in the reservoir, and the upper part of the rod being marked with divisions into inches and parts of an inch, will indicate by its ascent the depth of water in the reservoir. The stop-cock E serves to let off the water after its quantity has been noted, or at any stated periods. A more simple instrument consists of a conical vessel about 8 or 9 inches high and 5 inches in diameter, placed in a convenient frame and furnished with a rod, graduated progressively to correspond to the varying size of the cone.



56. According to the observations of Mr. Daniell, the average quantity of rain which falls in the neighbourhood of London, in the course of a year, amounts to 23.1 inches; the greatest quantity falling generally in the month of July, and the least in February; and the whole quantity falling during the first six months being not much more than half that in the last six months of the year.*

57. Leslie has remarked that in general twice as much rain falls on the western as on the eastern side of the island of Great Britain, and that the average quantity may be reckoned at 30 inches. According to this estimate, the whole discharge from the clouds in the course of a year, on every square mile of the surface of Great Britain would at a medium be 1,944,633, or nearly

How is the rain-gauge constructed and applied?
What depth of rain generally falls in London in the course of a year?

* Meteorological Essays and Observations. By J. F. Daniell, F. R. S. 2d edit.

2,000,000 tons. This gives about three thousand tons of water for each English acre, a quantity equal to 630,000 imperial gallons.*

58. It may be questioned whether the very limited extent of any observations which can be made by means of rain-guages affords ground for perfect confidence in the results they afford; and hence wherever experiments can be prosecuted on a larger scale it is desirable that they should be recorded; as the conclusions already obtained might thus be either confirmed or corrected.

59. There is one singular circumstance attending the fall of rain calculated to throw some doubt on the absolute accuracy of the common mode of observation, which is, "that smaller quantities have been observed to be deposited in high than in low situations, even though the difference of altitude should be inconsiderable. Similar observations have been made at the summit, and near the base of hills of no great elevation. Rain-guages placed on both sides of a hill at the bottom, always indicate a greater fall of rain than on the exposed top."*

60. It appears, however, that larger quantities of rain fall on extended tracts of elevated ground than at the level of the sea; but that at stations abruptly elevated above the surface of the earth the amount diminishes with the ascent. The mean annual fall of rain at Geneva, as calculated from observations during thirty-two years, amounts to 30.7 inches; and on the Alps, at the Convent of the Great St. Bernard, the mean of twelve years is 60.05 inches. According to M. Arago, who has traced a progressive decrease in the annual amount of rain from the equator to the poles, not less than 123.5 inches fall in a year on the Malabar coast, in latitude 11½ deg. N.; while in latitnde 60 deg. the quantity is reduced to 17 inches.

61. The water that falls from the clouds as well as that derived from melted snow and similar sources, if the surface with which it comes in contact happens to be loose and porous, will sink into the bowels of the earth, penetrating in any direction till it meets with a stratum of clay, or some other dense and almost impervious substance, which may cause it to accumulate and form subterrane-

How great a weight of water has Leslie supposed to fall on a square mile of the surface of Great Britain.

What is found to be the relative quantity of rain falling in high and low stations?

How are the quantities of rain found to vary on high table lands, and at the level of the sea?

What remarkable example of this variation can be adduced?

What are the relative quantities of rain falling in the torrid and in the temperate zones respectively?

Explain the manner in which water reaching the earth from the clouds is eventually disposed of?

* Leslie on Heat and Moisture; see, also, Proceedings of the British Association at Cambridge, 1833, for a report of experiments made at York.—Ed.

ous lakes or reservoirs, the contents of which occasionally are raised to the surface in various situations by hydrostatic pressure. Thus sometimes in digging wells it is necessary to penetrate to a great depth before water can be obtained, but at length when the source is found the water rises with such rapidity in the shaft that has been opened as scarcely to leave time for the well-sinkers to make their escape from the ascending column.

62. The term Artesian wells has been recently applied, especially in France, to wells formed in the manner just described, by the ascent of water through openings made by boring down and introducing tubes which traverse the superior strata, and communicate with subterraneous springs or reservoirs, from which the water rises through the tubes by hydrostatic pressure, nearly or quite to the surface; constituting in the latter case perpetual fountains, such as occur on the eastern coast of Lincolnshire, England, where they are called Blow Wells. They are also frequent in Artois, in the Netherlands, and hence they have derived the appellation of Artesian wells, from Artesium, the ancient name of that country.*

63. Water collected in subterraneous passages by infiltration sometimes passes below the bed of the sea, and forms a sort of Artesian fountains, which flow at intervals depending on the rising and falling of the tide. A remarkable ebbing and flowing stream of this kind was discovered in 1811, by boring in the harbour of Bridlington in Yorkshire;† and submarine fountains have been met with at the mouth of the Rio los Gartos, in South America, at Xagua, in the Island of Cuba, and elsewhere.‡

64. By means of such underground canals formed by nature, streams of water and even great rivers, after sinking into gulfs and cavities in the earth, make their appearance again at the surface, in some cases far from the spots where they descended.§ Gulfs of this kind, in which rivers and rivulets lose themselves, occur in the Alps of Jura, and other limestone mountains; and where the upper surface consisting of a bed of tenacious clay prevents the absorption of the rain-water by the soil, openings into the more porous strata beneath whether natural or artificial, may

What evidence have we of the existence of extensive collections of water under the surface of the ground?

To what is the term Artesian wells applied?

What is the origin of that term?

In what remarkable situation has the formation of Artesian wells been occasionally prosecuted?

---

* See Notice of a Lecture on Geology, by Dr. Buckland, in the Report of the British Association, vol. i. pp. 100, 101.

† See a Paper by John Storer, M. D. in the Philosophical Transactions, for 1815. Abst. of Papers in Phil. Trans. vol. ii. pp. 6, 7.

‡ Numerous Artesian wells, both salt and fresh water, have been formed in the United States.—Ed.

§ See Humboldt's Travels, vol. ii. p. 312.

be made the means of converting a marshy waste into a fertile plain.*

65. When rain falls on the summits or elevated sides of hills and mountains, if the surface be solid rock or clay, the liquid, by its natural tendency to flow till every part of its exposed surface has attained a common level, collects in rills, which find or form for themselves narrow channels, through which the water descends to the plains below; there the confluence of springs from various sources produce lakes or rivers, which in general ultimately communicate with the ocean, or with some great inland sea, like the Caspian or the Lake of Aral, both which are below the level of the Mediterranean;† and other lakes which have no outlet must be situated in valleys or basin-shaped cavities, either below the sea-level, or surrounded completely by walls of rock or compact earth, which prevent the egress of the liquid mass.

66. Rivers in their passage to the deep sometimes form grand and beautiful cataracts and waterfalls, where the collective stream, after being confined in a narrow channel, bursts abruptly over a precipice with astonishing force, dashing on the lower surface, and rising again in clouds of misty spray. Such are the famous Falls of Niagara, formed by the water of Lake Erie; the Cataract of Tecquendama, on the Rio Bogota, in South America, described by Humboldt; the Fall of the Rhine at Schaffhausen; and the cataracts of the Nile, at Syene, now Assouan, in Upper Egypt.

67. The currents, which have been thus rushing with impetuous force over the same surfaces for successive ages, cannot but have had a considerable effect even on the hardest rocks of which their beds are formed; and hence the heights from which these torrents descend being gradually worn down, alterations take place, and the cataracts must at length lose much of that formidable and impressive appearance they now exhibit. It is owing no doubt to such changes that the descriptions given by ancient travellers and geographers of some of the most remarkable cataracts by no means correspond with their present state.

68. Rivers formed by nature are running streams, whose velocity depends on the inclination of the surface of the country through which they pass. They have in various ages and in dif-

In what instances is water known to have collected in basins below the level of the sea?

What influence are cataracts known to exercise on the rocks over which they descend?

Why are the accounts of ancient travellers not always verified by the present appearance of cataracts?

On what does the velocity of natural streams depend?

* See an account of the draining of the Plain of Palans, near Marseilles, by sinking shafts from the surface into the cavernous strata below, which conveys water through subterraneous channels to the harbour of Mion, near Cassis, forming spouting springs, or Artesian fountains.—Arcana of Science for 1832, pp. 235, 236; from Hericart de Thury.

† See the Report of the British Association at York, p. 239.

ferent parts of the world been made the means of intercourse by inland navigation between distant places. For this purpose, however, they are but imperfectly adapted; since, besides the obstacles arising from rapids and cataracts, there must always be difficulty in ascending the stream of a river proportioned to the rapidity of the descending current. Hence in many countries navigation for the purpose of internal communication is in a great degree confined to the larger rivers and tide-ways, and to the numerous artificial canals which have been constructed chiefly since the middle of the last century; and the smaller natural streams, crossed by wears, mills, and manufactories of various descriptions, may thus be most effectively rendered subservient to the promotion of national industry and wealth.

69. A navigable canal usually consists of several continuous bodies of water, sometimes of considerable longitudinal extent, and each one having a perfectly level surface, the water being at rest. In a country intersected by numerous mountain ridges and valleys, the formation of a long unbroken line of canal must in general be attended with difficulties, and can seldom be effected at all except by erecting massive aqueducts supported on arches, and stretching from one point to another over the lower grounds, and elsewhere by carrying subterraneous galleries or tunnels through intervening hills.

70. Canals, however, generally consist of several longitudinal basins at different levels, and to preserve or rather occasionally to form communications between these, for the passage of vessels, locks are constructed wherever a variation in the level takes place, and thus vessels may be raised or lowered, according to circumstances. Locks are nothing more than small basins, with floodgates at each end, placed across the canal, from side to side, and thus including a portion of its water between them. To transfer a vessel from the higher to the lower level, the water in the intervening lock must be raised, by opening sluices at the bottom, to the height of the upper level, then the floodgates on that side being opened, the vessel is to be drawn into the lock, the gates through which it has passed are to be shut, and the water in the lock suffered to sink through sluices to the level of the lower part of the canal, and the lower floodgates then being opened the vessel may proceed on its passage till it reaches the next lock, where the same process must be repeated. The transfer of a vessel from a lower to a higher level is effected by the contrary operation of raising the water in the lock, instead of sinking it, while the vessel remains inclosed in it.

71. The passage of vessels in either direction through a lock cannot take place without the loss of a considerable quantity of

What circumstance limits the usefulness of rivers for purposes of navigation?

Of what do artificial canals commonly consist?

In what manner is a communication effected from a reach of canal at one level to that at another?

water, which must in each case be allowed to escape from the higher to the lower level of the canal. Where the supply of water therefore is not very copious, and more especially when the application of artificial means is requisite to obtain it, the loss becomes a serious inconvenience, and source of expense. This has led to different schemes for the conveyance of canal-boats from one level to another, without any expenditure of water.

72. One method of effecting this object is by means of a suspension-lock or moveable basin, containing a body of water sufficient to float a canal-boat, and capable of being alternately raised to the higher and depressed to the lower level of two corresponding parts of a canal, separated from each other by floodgates, with a space between them in which the suspended basin might be raised or lowered, so as to take in and discharge the boat. This scheme does not appear to have been put in practice, at least not on an extensive scale; and from the complication of the machinery requisite, it would probably be found liable to insurmountable objections. In some situation, the basin terminates at a certain point, and another basin commencing at a lower level, boats are transferred from one basin to another by inclined planes.

Specific Gravity.

73. The terms Density and Specific Gravity have been repeatedly introduced in the preceding pages; and their general signification has been in some degree elucidated already. It will however be necessary now to explain somewhat more fully the signification of those terms, not only as applicable to liquid bodies, but likewise with reference to solids and gases; and to describe the means by which the specific gravity of any substance may be ascertained.

74. In describing the effects of hydrostatic pressure, we have hitherto considered them as owing to the presence of a single liquid; the illustrations of the principles of the science now under review having been chiefly drawn from the phenomena exhibited by water alone, in several situations and circumstances, as affording results more simple and uniform than those which are observed when different liquids are placed in contact with each other, and when their combined pressure on solids as well as their mutual action must be modified accordingly.

75. It has been sufficiently demonstrated that a single liquid, as water, will always stand at the same height in two or more open

What disadvantage attends the transfer of boats from one level to another by means of locking?

What methods have been proposed or employed to obviate the loss of water in the transfer of boats?

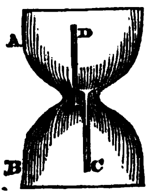
To how many classes of bodies are the terms density and specific gravity applicable?

Whence results the equality of height at which liquids rise in tubes communicating with each other?

tubes freely communicating with each other, whatever may be their peculiar forms or dimensions; and this indeed is a necessary consequence of the common tendency of every liquid to act with equal force in all directions, producing equality of pressure on the solid body or bodies by which it may be encompassed, and extending itself, where unconfined, till every portion of its surface has assumed a common level.

76. When two liquids or any greater number, differing from each other in specific gravity, are placed in contact, as when included in a glass jar or bottle, unless they are capable of uniting to form a chemical compound, it will be perceived that each liquid becomes arranged in a separate and distinct stratum, the heaviest, or that which has the greatest specific gravity, sinking to the bottom of the jar, and presenting a level surface above, on which rests the next heaviest liquid; the others in the same manner taking their places according to their respective degrees of relative or specific gravity. Thus mercury, water, olive-oil, and sulphuric ether, might be poured into the same phial, in which they would form separate layers, standing one above another, in the order in which they have been mentioned; water being much lighter than mercury, oil lighter than water, and ether yet lighter than oil.

77. Many liquids, differing in specific gravity, may be mixed by agitation so as to form a compound; but if the lighter liquid be poured gently on the surface of the heavier, they will for a long time remain distinct, but little action taking place even where the surfaces meet. Every body knows that water may be mixed with port wine or spirits, both which are lighter than that liquid, as may be shown by the following experiments.

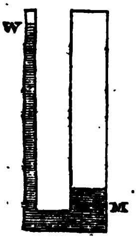


Suppose A B to represent a double-bodied vessel the only communication between the upper and lower portions of which is through the tube C and D; then if the part B be filled with water to the neck, and A with port wine, so as to rise above the tube D, still no mixture or alteration in the state of the liquids will take place, for the lightest occupying the highest situation will retain it undisturbed. But if the lower part be filled with port wine, and the upper with water, the former fluid will ascend through the tube D, and the latter descend through the tube C, till they have entirely changed places. A vessel of this construction, having the upper part transparent, and the lower part opaque, would form an amusing philosophical toy, by means of which might be exhibited an apparent conversion of water into wine. An analogous experiment may be made by taking a

What happens, when two liquids, incapable of chemical union, and of different specific gravities, are put into the same vessel?
With what liquids might this truth be illustrated?
Is the actual mixture of two liquids capable of combining, a certain consequence of placing the one upon the other?
By what arrangement of apparatus might this be exemplified?

small bottle, with a long narrow neck, not more than the sixth of an inch in diameter, which is to be filled with spirit of wine, tinged red, by infusing in it raspings of sanders wood, or yellow, by putting into it a small quantity of saffron; the bottle thus filled with the coloured spirit is then to be placed at the bottom of a deep glass jar of water, when the spirit will be seen to ascend like a red or yellow thread through the water, till the whole has reached the surface.

78. Bodies, differing in specific gravity, and incapable of combination, may be shaken together in a phial, and mixed for a time, but will separate completely on being allowed to remain at rest. Such is the effect exhibited in the following mimic representation of the production of the four elements from chaos. A glass tube, about an inch in diameter, closed at one end, or a deep phial, being nearly filled with equal parts in bulk of coarsely powdered glass, oil of tartar, proof spirit, and naphtha, or spirit of turpentine, the former spirit tinged blue, and the latter red,* the tube or phial must be secured with a cork; and when it is briskly shaken the four imaginary elements will form a confused dull-looking mass, but on setting the phial upright, and suffering it to remain undisturbed for some time, an entire separation will take place between the several portions of the chaotic mixture: the powdered glass at the bottom representing earth; the oil of tartar, floating above it, water; the spirit, with its cerulean tint, occupying the place of air; and the glowing naphtha at the top designed as an emblem of elementary fire.



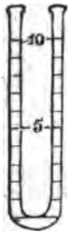
79. When two liquids, varying in specific gravity, are included in a bent tube, as represented in the annexed figure, they will not stand at the same height on both sides of the tube, like a single liquid; but their respective heights will be in the inverse ratio of their specific gravities. Thus, as any given bulk of mercury weighs nearly fourteen times as much as an equal bulk of water, one inch of mercury, M, would equipoise about fourteen inches of water, W, on the opposite side of the bent tube. Neither the form nor the dimensions of the tube are of any importance to the result of this experiment; for as in other cases of hydrostatic pressure, a small quantity of water may be made to counterbalance the larger quantity of the heavier fluid mercury, provided the column of water stands perpendicularly fourteen times as high as the column of mercury.

What happens when two liquids incapable of combination are shaken together?

Describe the apparatus known by the name of the four elements.

What occurs where the bent part of an inverted sypon is occupied by mercury, and one of the branches is afterwards filled with water?

* The blue tint may be communicated to the proof spirit by adding a small portion of tincture of litmus; and the other spirit may be coloured with dragon's blood.



80. On the principle now stated, a ready method might be contrived for ascertaining the relative weights or specific gravities of any two liquids, as oil and water, or water and ether, or spirit of wine. For this purpose it would merely be requisite to procure a glass tube, bent and graduated as represented in the margin; then on pouring into the upright branches, equal quantities by weight of the respective liquids, their relative weights would appear on inspection; being inversely as the heights to which they would rise in the branches of the tube. The accuracy and utility of such an instrument would be augmented by filling the lower portion of the tube with mercury, and the graduated branches being of equal diameter, given weights of any liquids, which would not act chemically on the mercury, would show, by their respective heights on either side, how much greater space an ounce, a dram, or any other quantity of one liquid would take up than an equal quantity of the other; and hence it would appear how far the specific gravity of the latter exceeded that of the former.*

81. As the specific gravity of a liquid is indicated by the relative space which any given portion by weight occupies, so in the same manner the specific gravity of a solid body may be inferred from the bulk of water or any liquid of known specific gravity, which an ounce, a pound, or any similarly ascertained quantity of the solid would displace when plunged in the liquid. On this principle depend the usual methods of determining the specific gravities of bodies, by means of hydrostatic balances, hydrometers, areometers, and oleometers.†

82. The discovery of this fundamental principle of science has been generally ascribed to the Syracusan philosopher, Archimedes, and the circumstances relating to it are thus reported by Vitruvius.‡ Hiero, King of Syracuse, having ordered an artist

How might the principle involved in that experiment be applied to determine the relative weights of different liquids?

What is the relation between the density of a liquid and the space which a given weight of it must occupy?

How may the specific gravity of a solid be found without reducing it to any particular form or bulk?

What instruments are employed to determine relative weights of bodies?

---

* An instrument in which the two open ends of the tube are turned downwards and dipped into separate cups of liquids, and to the bent or upper part of which an exhausting spring is applied to produce a partial vacuum to raise the liquid, is much more convenient in practice. It has long been known in France as the "areometre à pompe." A modification by Dr. Hare is called the litrameter.

† The former of these instruments is so called from the Greek Υδωρ, water, and Μετρον, a measure; and the latter from Αραιος, light, or having comparative levity, and Μετρον. Oleometers test the value of lamp oil.

‡ Architectur. lib. 9. cap. 3.

to make him a golden crown, after it was completed found some cause for suspicion that the goldsmith had imposed on him by mixing with the gold, with which he had probably been furnished from the royal treasury, an inferior kind of metal. The investigation of this matter was referred to Archimedes, who appears to have been unable for some time to contrive any satisfactory method of ascertaining whether the crown consisted of mixed metal or pure gold. At length, on the occasion of his getting into a bath, he observed that the water rose on the sides of the marble basin or reservoir in which he stood, in exact proportion to the bulk of his body beneath the surface of the fluid. At once the idea flashed on his mind that every solid plunged under the surface of water must displace precisely an equal bulk of that liquid; and as solids, bulk for bulk, are some lighter than others, the comparative or relative gravity of two or more solids might be ascertained by immersing equal weights of them in water, and observing the quantity of liquid displaced by each of the solids. Convinced that he could by this means find out whether Hiero's crown had been adulterated, the philosopher is said to have leaped from the bath, in a fit of scientific ecstasy, which rendered him insensible to every thing except the importance of the principle he had discovered, and running naked through the streets, he exclaimed aloud, "Ἕυρηκα—Ἕυρηκα." "I have found it out!—I have found it out!"

83. In order to apply his theory to practice, he procured a mass of gold and another of silver, each having just the same weight with the crown: then, plunging the three metallic bodies successively into a vessel quite filled with water, and having carefully collected and weighed the quantities of the liquid which had been displaced in each case, he ascertained that the crown was, bulk for bulk, lighter than gold, and heavier than silver; and he therefore concluded that it had been alloyed with the latter metal.

84. In comparing the relative or specific gravities of bodies, it is necessary that there should be some standard to which the respective weights may be referred. It might be stated that platina is as heavy again as silver, and that cast iron is not much more than half as heavy as mercury; but it would not be possible from these data to decide whether silver would sink beneath the surface of mercury; for though it is clear that cast iron would float on mercury, yet unless some further information were given, no comparison could be made between the relative gravities of silver and mercury. Supposing, however, it be known that mercury is thirteen times and a half the weight of water, silver ten

What historical account is given of the discovery of this method of determining specific gravities?

What process was performed by Archimedes to detect the amount of alloy in Hiero's crown?

What standard is it customary to assume in speaking of the relative weights of bodies?

What renders any such standard necessary?

times and a half, iron seven times and a half, and platina twenty-one times, it will be obvious that the last-mentioned metal would sink in mercury, while silver as well as iron would remain suspended on it.

85. Tables of the specific gravities of a great multitude of bodies have been constructed, showing their relative weights, expressed in numbers denoting in what ratio they exceed or fall below that of water. The adoption of this fluid as the standard of specific gravity is attended with several advantages, which have induced philosophers in general to consider its density, under certain conditions of temperature and atmospheric pressure, as affording a convenient point of comparison to which may be referred the densities of other bodies, whether solids, liquids, or gases.* The extraordinary power of water to resist compression by mere mechanic force, except under such circumstances as can rarely take place,† is one of the advantages it presents; but in the prosecution of experiments of a delicate nature, the pressure of the atmosphere must be taken into the account in order to ensure accuracy in the results of our calculations. Alternations of temperature, as to heat and cold, also affect the bulk of water so considerably as to render it absolutely necessary that any substances, whose specific gravity we wish to ascertain by experimental comparison with that of water, should have the same temperature with the standard liquid, or that allowance should be made for any unavoidable difference of temperature. Purity of the watery fluid is likewise, as may be supposed, indispensably requisite; rain-water carefully distilled, and thus freed from all foreign impregnation, is therefore to be preferred in the prosecution of experimental inquiries.

86. In the London Philosophical Transactions for 1798, is a memoir by Sir George Shuckburgh Evelyn, containing an account of numerous and important experiments on the specific gravity of water, which have served as the foundation of subsequent researches. He found that a cubic inch of pure distilled water, the barometer standing at 29.74 inches, and Fahrenheit's thermome-

What advantages belong to the standard actually adopted, beyond what are possessed by other substances?

What relation has temperature to the method of determining specific gravities?

What is the weight of a cubic inch of water at mean temperature and pressure?

* The relative density of gases is sometimes estimated by comparison with that of atmospheric air, as the standard: but the ratio of the specific gravity of atmospheric air compared with that of water being known, that of the other gases may be deduced from computation, when their several relations in point of density to atmospheric air have been ascertained; and on the contrary the relations of the other gases to atmospheric air, as the standard of specific gravity, may be computed from a table of specific gravities, including the gases, and referring to water as the common unit of density.—See Treatise on *Pneumatics*.

† See 10—15 of this article.

ter at 66 degrees, weighed 252,587 grains troy. Now it is a well ascertained fact that water attains the utmost degree of density just before it freezes, its bulk being relatively less at 40 deg. of Fahrenheit or 8 deg. above the freezing point, than at any point either higher or lower in the scale.*

87. The difference of the weight of a cubic inch of distilled water at 40 deg. and at 60 deg. is somewhat less than half a grain troy, whence it may be made to appear from calculation that a cubic foot of pure water, at its greatest density, weighs almost exactly 1000 ounces avoirdupois, or 62½ pounds. If, therefore, the specific gravity of water be represented by the number 1000, each of the numbers in the following table will express the corresponding weights of a cubic foot of the several bodies included in it. Thus a cubic foot of pure gold would weigh 19,258 ounces avoirdupois, and an equal bulk of cork but 240 ounces.

88. *Specific Gravities of various Solids, Liquids, and Gases, as compared with Water at 60 Deg.*

Platina, laminated	22,069	Sulphate of Barytes, or Ponderous Spar	4430
purified	19,500	Oriental Ruby	4283
Gold, cast	19,258	Brazilian Ruby	3531
hammered	19,361	Bohemian Garnet	4188
standard, 22 carats	17,486	Oriental Topaz	4010
Mercury, fluid	13,568	Brazilian Topaz	3536
solid	13,610	Diamond	3521
Lead, cast	11,352	Natural Magnet	4800
Silver, cast	10,474	Fluor Spar	3181
hammered	10,510	Parian Marble, white	2837
Bismuth, cast	9822	Carrara Marble, white	2716
Copper, cast	8788	Rock Crystal	2655
Brass, cast	8395	Flint	2594
wire	8544	Sulphate of Lime, or Selenite	2322
Nickel, cast	7807		
Iron, cast	7207		
malleable	7788	Sulphate of Soda, or Glauber Salt	2200
Steel, soft	7833		
tempered	7816	Chloride of Sodium, or Common Salt	2130
Tin, cast	7291		
Zinc, cast	7190	Phosphorus	1770

At what temperature is water at the greatest density?
What is the weight of a cubic foot of water at its greatest density?
What would be the weight in ounces of a cubic foot of platina?
Would a block of silver sink or swim in a bath of mercury? why?
Would a piece of steel sink or swim in melted copper?
What would be the effect of dropping a bar of lead into a pot of melted tin?
How many times more matter in a cubic foot of saltpetre than in a like bulk of water?

* See Treatise on *Pyronomics*.

Nitrate of Potash, or Saltpetre	2000
Sulphur, native . .	2033
Plumbago, or Black Lead	1860
Coal	1270
Sulphuric Acid, or Oil of Vitriol .	1840
Nitric Acid . .	1271
highly concentrated .	1583
Muriatic Acid, liquid, or Spirit of Salt	1194
Sea-Water . .	1030
Ice	930
Alcohol . . .	797
Proof Spirit . .	923
Sulphuric Ether .	734
Naphtha . . .	708
Linseed Oil . .	940
Olive Oil . .	915
Oil of Turpentine .	870
Aniseed . .	986
Lavender . .	894
Cloves . .	1036
Camphor . . .	988
Yellow Amber . .	1078
White Sugar .	1606

Honey . . .	1450
White Wax . .	968
Caoutchouc, or Gum Elastic .	933
Ivory . . .	1917
Isinglass . .	1111
Milk, cow's . .	1032
Butter . . .	942
Mahogany . . .	1063
Lignum Vitæ . .	1333
Dutch Box . .	1328
Ebony . . .	1177
Heart of Oak, 60 years felled .	1170
White Fir . .	569
Willow . . .	585
Sassafras Wood . .	482
Poplar . . .	383
Cork	240
Chlorine, formerly called Oxymuriatic Gas	3.02
Carbonic Acid, or fixed air . . .	1.64
Oxygen Gas . .	1.34
Azotic, or Nitrogen Gas	0.98
Hydrogen Gas . .	0.08
Atmospheric Air . .	1.21

89. If the specific gravity of water be represented by 1 instead of 1000, then that of platina will be 22.069, the last three figures being taken as decimals; the specific gravity of standard gold will be 17.486, that of sea-water 1.030, that of olive oil 0.915; and so on throughout the table, the three right hand figures representing decimal parts, except those denoting the specific gravities of the gases, the numbers of which must be thus altered to indicate the relations of their specific gravities to that of water.

Water - - - -	1.
Chlorine - - -	0.00302
Carbonic Acid - -	0.00164
Oxygen Gas - - -	0.00134
Nitrogen Gas - - -	0.00098

Which would sink most rapidly in water, a piece of flint, or one of native sulphur?

When alcohol and linseed oil are put into the same vessel, which will occupy the higher part?

Determine the same, with regard to water and honey—oil of turpentine and cow's milk—proof spirit and naphtha—sulphuric ether and oil of lavender.

When the specific gravity of water is taken as unity, what must we consider the last three figures of each number in the table?

Atmospheric Air	- -	0.00121
Hydrogen Gas	- -	0.00008

90. From the foregoing table it will appear that almost all bodies will float on the surface of mercury; gold and platina, and their alloys, being the only substances known of higher specific gravity than that metalic fluid, except one or two recently discovered metals of rare occurrence.* Many bodies will float on the surfaces of metal while in fusion: and thus earthy and other substances found in metallic ores rise in the state of scoriæ to the surface of the melted metal in the process of reduction. The lava discharged from volcanos is a very dense fluid, partly metallic; and hence stones of vast bulk and weight are frequently seen swimming on its surface while it remains in the liquid state.

91. Most kinds of wood will float on water, and but few, as fir, willow, and poplar, on rectified spirit. The solution of a solid in any liquid increases its density: thus sea-water is heavier, bulk for bulk, than pure water; and an egg which will sink in the latter will swim in brine. Hence it sometimes happens that a heavy laden vessel, after having sailed in safety across the salt sea, sinks on entering the mouth of a river; owing to the inferior specific gravity of the fresh water.

92. The specific gravity of the human body during life is in most cases nearly the same with that of river water, and coincides more exactly with that of sea-water; so that there are probably but few persons who would not float very near the surface of the sea in calm weather. Corpulent people are, bulk for bulk, lighter than those of sparer habits; for the adipose membrane or fat of animals is inferior in specific gravity to water; whilst lean flesh, unless the blood and other juices are drained from it, is of higher specific gravity than that fluid, and bone is proportionally much heavier than the soft parts of the body. Hence it might be inferred that the power of floating on water does not depend entirely on the relative specific gravity of the solids and liquids which enter into the composition of a human body; and accordingly we

Which of the gaseous bodies has the greatest specific gravity?

How many and which of them are specifically heavier than atmospheric air?

Which is the lightest of gaseous substances?

Why do the impurities of metallic ores rise, when melted, to the surface of the mass?

What is the nature of lava ejected from volcanos?

What effect on the specific gravity of any liquid is produced by dissolving in it a portion of any solid?

To what maritime occurrence is this fact applicable?

What is the relative specific gravity of the human body compared with fresh and with salt water respectively?

* Iridium, a peculiar metallic substance discovered by Mr. Smithson Tennant, in combination with crude platina, has the specific gravity of 18.6; and Tungsten is a rare and difficultly fusible metal, the specific gravity of which is stated to be 17.2.

find that the body of a person destroyed by drowning, or thrown into water immediately after death, will sink far beneath the surface; but after several days have elapsed a body thus treated usually rises to the level of the water, in consequence of its having become specifically lighter than that fluid, from the accumulation of gas within the body, produced by incipient putrefaction. It is then chiefly owing to the air included in the cavities of the body during life, especially that portion contained in the lungs, that a man is enabled to float on the surface of a pond or river.

93. There are, however, some credible accounts extant of persons whose bodies were so much inferior in specific gravity to water, that they could not descend beneath its surface; not possessing that "alacrity in sinking," which may be literally attributed to most individuals. In 1767, there was a priest residing at Naples, named Paulo Moccia, whose extraordinary facility of flotation attracted much public attention. This ecclesiastic could swim on the sea like a duck; when he assumed a perpendicular position, the water stood on a level with the pit of his stomach; and it is stated that when dragged under the water by one or more persons who had dived for that purpose, as soon as he was released, his body would rapidly rise to the surface. It appears that the weight of this gentleman's body was thirty pounds less than that of an equal bulk of water. This peculiarity of conformation doubtless depended partly on his being extremely fat, and having very small bones; besides which, probably his lungs were capable of holding a larger quantity of air than is usual, and there might also have been an accumulation of air in the abdomen, arising from the disease called tympany, or from some other cause.

94. Most very corpulent people, who are at the same time strong and healthy, would perhaps find on trial that their bodies would float on water; and those who do not happen to be endowed with a superabundance of fat might still in almost all cases, with a little application, acquire the habit of floating with facility. The capability of breathing freely and at regular intervals is essentially requisite to enable a person to support himself on the surface of water. The head, and the upper and lower extremities are relatively heavier than the trunk of the human body; and the head especially, from the quantity of bone of which it is composed, is the heaviest part of the whole mass, yet unless the face at least be kept above water respiration cannot be continued. It is therefore of the highest importance that all persons should be

Will a fat or a lean person float with the greater facility in water?

What will generally occur when a human body is thrown into water?

Why does the body of a drowned person rise to the surface after being some days in the water?

What extraordinary instance of specific lightness in the human body is recorded?

On what circumstances did it probably depend?

What operation is it necessary to perform while attempting to float on the surface?

perfectly aware of the precautions necessary for this purpose; so that any one accidentally falling into the water, and being unable to swim, may be instructed how to escape a watery grave.

95. A person suddenly immersed in water, if not absolutely deprived of self-possession by fright, should, on coming to the surface after the first plunge, endeavour to turn on the back, carefully keeping the hands down, with the palms extended towards the bottom of the water, the legs being suffered to sink rather lower than the trunk; the only parts above the surface will then be the face and a small portion of the chest: at each inspiration more of the head and chest will rise above the water, and perhaps those parts will at first be for a moment covered with the aqueous fluid at the interval of expiration of the air. Every thing depends on making no effort to raise or keep out of water any part except the face, and endeavouring to keep the lungs, and consequently the chest as much expanded as possible, without using any irregular exertions in breathing; and it may be proper to caution persons thus circumstanced against struggling or screaming, as worse than useless; for in case any one who might yield assistance should be within call, it would be best to wait till the first alarm had subsided, and then the involuntary bather, conscious of comparative security, might use his voice with due effect, and without increasing the hazard of his situation.

96. But an acquaintance with the art of swimming can alone give a person perfect confidence of safety when by accident immersed in water. It is to be lamented that this is not a more general accomplishment; for it is one which must frequently prove of great utility; and it is much to be desired that it should become a branch of education at schools for boys, as being of higher importance than the more fashionable arts of dancing, fencing, or even gymnastics.

97. It may be questioned whether written instructions alone would enable any one to acquire a facility in swimming; and admitting their utility, it would be inconsistent with the purpose of this work to afford them more than a cursory notice. In swimming, as in floating, the chief object of attention must be to keep the face above water, while the limbs are immersed; but from the different position required, it must be apparent that in swimming, not the face alone, but nearly the whole head must be sustained above the surface. In making a first attempt, the advice of Dr. Franklin may be followed, where he directs the learner to walk into water till he reaches a place where it stands as high as his breast, and dropping into the clear stream an egg; as soon as it has reached the bottom, he is to lean forward, resting on the

What measures should be adopted when one is suddenly immersed in water?

What importance ought to be attached to the art of swimming?

What is the first step towards the acquisition of that art?

How may the learner be made sensible of the buoyant power of the water?

water, and endeavour to take up the egg, when he will become sensible of the upward pressure or resistance of the fluid; and finding that it is not so easy to sink as might have been previously supposed, the young adventurer would acquire confidence in his own efforts, the valuable result of experience.

98. Corks or blown bladders fitted by strings passing under the arms and across the chest, will afford material assistance in supporting the upper part of the body in a proper position; but they perhaps rather tend to retard than facilitate the progress of the learner, by leading him to form a false estimate of the resistance of the water; so that as soon as he makes an experiment without the corks he finds himself obliged to recommence his task, and study it on a different plan which might as well have been adopted at first. If, however, corks or bladders should be used, it is highly necessary that they should be secured from slipping down to the hips, and thus causing the swimmer to fall with the head vertically downwards, and incur the most imminent risk of drowning.

99. As less exertion would be required in the position of floating than in that of swimming, there would perhaps be some advantage in acquiring the power of flotation, as above described, previously to attempting to swim. This having been effected, the learner might, instead of the common expedient of using corks, procure a two-inch pine plank, ten or twelve feet long, and placing it in the water, lay hold of it with one or both hands and push it before him while learning to strike with his legs. But this or any other artificial mode of practice, that may be adopted, should be laid aside as speedily as possible, as the learner cannot too soon make himself acquainted with the full effect of the pressure of the fluid in which he is moving, and with his own strength and power of action; and till such knowledge is attained he will make but slow progress in the art of swimming.

100. The method of communicating buoyancy to solids of greater specific gravity than water, and enabling them to float in that fluid, by inclosing within them air or gas, is susceptible of application to a variety of useful purposes. It has accordingly been adopted in the construction of swimming-girdles, life-preserving belts, and air-jackets, which like the bladders noticed above, are merely bags of different shapes contrived so as to be inflated with air, and worn round the upper part of the body. Life-boats or safety-boats, as they are sometimes called, are rendered buoyant by forming in their sides air-tight cells or lockers, of sufficient dimensions to prevent the boat from sinking even when every other part of it is filled with water. It has recently been proposed to extend this principle to vessels of any size, and thus to prevent

What objection exists to the use of cork jackets and similar expedients to increase the buoyancy of the body when learning to swim.

What use may be made of the swimming board while learning the art?

Explain the construction and use of the girdle employed for the same purpose.

How are life-boats made incapable of sinking?

heavy laden merchant ships or men of war from foundering at sea. The scheme consists in the employment of copper tubes of a cylindrical form, hermetically closed at the ends and sufficiently large and numerous to contain as much atmospheric air as would cause a ship to swim, when in consequence of having sprung a leak it would otherwise sink. It is stated by the inventor of these safety tubes, Mr. Ralph Watson, that an eighty-gun ship, even when immersed from leak, would not require the application of such tubes to a greater extent of displacement of water than would be sufficient to support 240 tons of its immense weight.

101. Fishes, in general, are provided by nature with a peculiar apparatus, which enables them to swim with the utmost facility, and to ascend close to the surface of the water, or descend to a considerable depth beneath it, by means of a membranous bag or bladder containing air, which they can distend or contract, and thus alter their specific gravity according to circumstances. The toad fish it is said distends its stomach by swallowing air, to assist it in swimming, and becomes puffed up like a blown bladder, in the same manner as the globe or balloon fish.

102. An experiment has been previously related exhibiting the effect of the pressure of water upward in supporting a plate of metal, in contact with the lower extremity of an open cylinder, from which it may be inferred that solids of the highest specific gravity, as gold or platina, may be made to float on water or any other liquid, provided the floating body be of such a form that its upper surface may be protected from the pressure of the liquid by a column of air, the depth of which bears a certain proportion to the specific gravity of the solid. It is thus that a china tea-cup, though much heavier than an equal bulk of water, will yet float on that liquid if placed in it with its cavity upwards and empty; but on pouring water into it, the cup will descend in consequence of the air within its cavity being displaced by the heavier fluid; till at length, when so much water has been poured in as to render the cup and water together heavier than a quantity of water equal to the space the cup occupies when immersed to its edge, it will sink to the bottom.

103. A raft will float, because it is absolutely lighter than water, and a life-boat also for the same reason; but vessels in general, from the cock-boat to the largest man of war, owe their buoyancy to their concave form. Hence ships need not be built of fir or any light wood, since not only the heaviest woods might be used but

How are Watson's safety tubes to be applied for the security of vessels at sea?

To what is the power of vertical movement in fishes attributable?

How may the heaviest of metals be made to float on the lightest of liquids?

What quantity of water will it be necessary to pour into a floating basin in order to sink it to the water's edge?

How is the floating of a raft to be explained?

even the heaviest metals, to construct floating vessels; and indeed steam boats made of sheet iron have recently been tried, and found to possess the requisite properties for ploughing the waves with perfect facility and safety.

104. Floating bodies may be employed to raise heavy substances from the bottom of a river, pond, or basin of water. Thus a sufficient number of air-tight casks might be attached by ropes or chains to a large block of granite at the bottom of a river near its entrance into the sea, and the ropes being adjusted to such a length as to keep them strained tightly by the buoyancy of the casks at the lowest ebb of the tide, the block would be raised by the upward pressure of the casks at high water. Perhaps this method of raising or lowering ponderous masses of stone might be advantageously applied to practice in building bridges or piers within the tide-way of a river.

105. The common method of regulating the supply of water conveyed by pipes into a cistern by means of what is called a ball-cock, depends on the action of a hollow globe of such dimensions relatively to the thickness of the metal as to keep it always floating on the top of the water in the cistern. A long wire is connected with the ball at one end, and at the other with a valve or stop-cock, on which it acts as a lever, opening it when the long arm of the lever is allowed to descend by the sinking of the ball attached to that end, when the water falls in the cistern, and on the contrary closing the valve, when, by the rising of the ball with the water, the cistern becomes full, and the lever presses on the valve or cock and keeps it shut, so that the cistern can never be filled beyond the proper height.

106. The power of floating bodies may also be applied in a different manner to the purpose of rendering buoyant other bodies attached to them; and among the various applications of this principle may be noticed the ingenious invention called the water-camel, used in Holland and also in Russia and at Venice, to enable large and heavy laden ships to pass shoals or sand-banks. The method of effecting this object consists of the application of two long narrow vessels adapted to the sides of the ship, and being hollow and water-tight they are filled with water, and then let down, and firmly secured on each side of the ship, after which the water is to be pumped out of them, and the whole mass, consisting of the ship and camel is thus rendered specifically lighter than before, and drawing less water than the ship alone did previously, the shoal or sand bank may be passed without danger of grounding.

How does it differ from that of an iron steamboat?

To what useful purpose may the principle of floatation be applied in connexion with submarine operations?

In what manner is the same principle applied to regulate the access of water to a cistern?

Explain the construction and use of the water-camel?

107. The tendency of a floating body to assume a particular position when partly immersed in a liquid, and to retain or lose that position according to circumstances, may be elucidated by reference to the doctrine of the centre of gravity, as explained with relation to solids.* When a solid body, specifically lighter than water, is placed on its surface, it will sink to a certain depth at which the absolute weight of the body is exactly counterbalanced by the upward pressure of the water. The point at which the entire weight of a body acts with greatest effect must be its centre of gravity; and that point at which the sustaining efforts of the liquid are most effective may be termed the centre of buoyancy, which must evidently coincide with the centre of gravity of the portion of water displaced by the floating body; and if the body be of uniform structure with the centre of gravity of that part of it which is under water. A floating body cannot maintain itself in a state of equilibrium, unless its centre of gravity be situated in a vertical line over its centre of buoyancy, or immediately under that point. In the former case it will be in the state of instable equilibrium, and in the latter in that of stable equilibrium.†

108. Hence the necessity of placing iron bars, stones, or other heavy substances in the hold of a ship by way of ballast when it is not freighted, or is laden with very light merchandize, in order that its centre of gravity may not be elevated too much above its centre of buoyancy. It is not requisite that the centre of gravity should be reduced below the centre of buoyancy, for though such a disposition would contribute to the stability of the vessel, the resistance to its passage through the waves would be so great as to make it sail heavily. In determining the proper situation of those points regard must be had to the shape and dimensions of a vessel as well as to the nature of the cargo or lading, and the manner of stowing it; and on a due attention to these circumstances its security and rate of sailing must in a great measure depend.

109. The methods adopted for ascertaining the specific gravities of bodies are founded on the relation between bulk or dimension, and weight, which may be determined by various operations, according to the nature of the several substances, whether solid, liquid, or gaseous, to which they are applied. The relative den-

What takes place in regard to the centre of gravity of a floating body?

How deep will such a body when specifically lighter than water always sink in the liquid?

What name is given to the point at which the whole buoyancy of the liquid may be conceived to be concentrated?

What will be the relative position of the centre of gravity and of the centre of buoyancy of a body floating at rest on the surface of water?

Why are heavy articles stowed in the hold rather than on the deck of a vessel?

---

* See *Mechanics*, Nos. 125—133. † Ibid. 137—141.

sity of different solids may be discovered by simply weighing a cubic inch of each; but unless the process of measurement and that of weighing are both executed with scrupulous accuracy the result must be uncertain, and the former of these operations at least, must, in many cases, be difficult, and in some impracticable. Hence the method adopted by Archimedes is to be preferred, and it may be improved by merely weighing the subject of the experiment first in air and then in water, and noting the loss of weight that takes place in the latter case, as that must be equal to the weight of the water displaced by the substance under examination.

110. On this principle is constructed the hydrostatic balance, which may be used to determine the specific gravity of liquids, as well as that of solids. For this purpose a globular or egg-shaped mass of glass or crystal must be suspended by a hair or fine silk thread from a hook at the bottom of one of the scales of an accurate balance, and its weight is then to be ascertained first in the air, next in distilled water, and lastly in the fluid whose specific gravity is required; then by deducting the loss of weight of the glass in water from the loss observed when it was weighed in the liquid, the specific gravity of the latter, with reference to that of water, will be obtained. By using a glass globe of such dimensions as to lose 1000 grains in water, its loss of weight in any liquid would at once indicate the specific gravity of that liquid.

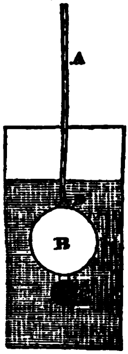
111. Insoluble solids denser than water are easily subjected to experiment; but any insoluble solid body, which is specifically lighter than water, requires, in order that its specific gravity should be ascertained, the addition of some heavier substance, so that the joint mass may be made to sink in water; then its weight in air and in that liquid respectively being determined, the specific gravity of the lighter solid will be the difference between the weight of the heavier body in water alone, and that of the joint mass, deducted from the difference of their weight in air. Solid substances, soluble in water, such as salts, may have their specific gravity ascertained by weighing them in alcohol, or some other liquid which will not dissolve them, and their specific gravity, water, being the standard, may be found by computation; or they may be weighed in water after being defended from its action by coating them thinly with melted bees-wax.

What are some of the methods of determining the specific gravity of bodies?

What is the construction of the hydrostatic balance, and how is it applied to this purpose?

What method is it necessary to adopt in ascertaining the specific gravity of solids lighter than water?

How can we take the specific gravity of solid bodies which are soluble in water?



112. The most usual and convenient method of ascertaining the specific gravities of liquids is by means of a hydrometer. This instrument, as represented in the margin, consists of a hollow glass ball B, with a smaller ball of metal C, appended to it, and which, from its superior weight, serves to keep the instrument in a vertical position, to whatever depth it may be immersed in a liquid. From the large ball rises a cylindrical stem A D, on which are marked divisions into equal parts; and the depth to which the stem will sink in water, or any other liquid fixed on as the standard of specific gravity being known, the depth to which it sinks in a liquid whose specific gravity is required will indicate, by the scale, how much greater or less it is than that of the standard liquid.

Capillary Attraction.

113. Liquids are distinguished by the property of preserving a level surface when at rest, and rising to the same height in any number or variety of communicating tubes; an effect resulting from the joint action of the cohesion of their particles and the influence of universal gravitation. But there are certain circumstances in which liquids may be placed, in consequence of which the phenomena will be remarkably modified, and a portion of a liquid mass may rise far above the common level, and preserve its elevation, as if exempt from the power of gravity. Water may be made to rise perpendicularly to a great height in an exhausted tube; and even mercury, one of the heaviest of fluids, may be seen to be elevated in the same manner in a barometer tube 29 or 30 inches above the level of the liquid in the basin, into which the open end of the tube is plunged. But in these cases, as we shall subsequently show, the influence of gravitation is distinctly perceptible, and the liquids rise in exhausted tubes, in consequence of pneumatic pressure.*

114. There is, however, another case in which liquids rise above their common surface level, not being inclosed in exhausted tubes, but in tubes open at both ends, or between solid plates nearly in contact. This phenomenon is styled *Capillarity*, and is said to be caused by Capillary Attraction.† Instances of the operation of

How are the specific gravities of liquid substances commonly ascertained?

Explain the construction of the hydrometer?

In what manner may water be made to rise above the general level of its mass?

Is the exhaustion of tubes in all cases necessary to produce that effect?

To what phenomenon is the term capillarity applied?

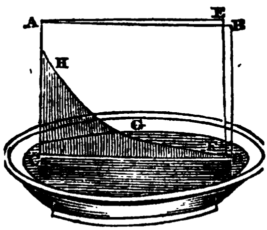
---

* See an account of the Barometer, in Treatise on *Pneumatics*.

† From *capillus*, a hair, or *capillaris*, hair-like, in reference to the small bore of tubes which produce these effects.

this principle are constantly taking place around us, and though highly interesting, they are overlooked by common observers. If a slice of stale bread an inch square, and three or four in length, be held perpendicularly with one end immersed in a small quantity of water or milk, the liquid will ascend through the pores of the bread till it is entirely absorbed, and if there is a sufficient quantity of it, the bread will become saturated with the moisture. In the same manner water or any aqueous fluid will ascend and spread through a lump of sugar or a heap of sand, if the base of either be immersed in the liquid.

115. Tubes of glass having a very small bore, and therefore called capillary or hair-like, if dipped a little way beneath the surface of water, will cause the liquid to ascend to a height bearing a certain relation to the diameter of the tube. If that diameter be 1-50 of an inch, water will rise to 2½ inches; if it be but 1-100 of an inch, it will rise 5 inches; and so on in the inverse ratio of the diameter of the tube. Similar effects may be exhibited by means of two plates of glass, placed as represented in the margin in a shallow vessel of water, so that their edges on one side, A C, may be in contact, and the other, B D and E F, somewhat separated. The liquid will then rise between the plates, standing highest on that side where they most nearly approach, and gradually declining towards the sides that are separated, the upper surface of the elevated portion of the fluid forming the curve F G H, the height of the liquid at any point, as H, being greater in proportion, as it is nearer to the side of the plates A C.



116. It is in consequence of capillary attraction that a sponge imbibes water, blotting paper absorbs ink, or that oil arises amidst the fibres of the cotton-wick of a lamp. These effects are manifestly owing to a common cause, and we learn from experiment that it is only under certain conditions that they take place. Thus, all liquids will not rise to the same height in the same tube, for water will rise higher in a capillary glass tube than alcohol, and neither of these liquids will rise at all in the finest metallic pipe, nor in a glass tube, if the inside of it be greasy. Mercury, on the contrary, will not rise in a clean glass tube, especially if it be wetted; while it becomes elevated, when the inside is lined with a very thin film of bees-wax or tallow.

117. Some remarks have been elsewhere introduced, relative to

From what exhibition of the principle is its name derived?

How may the progressive increase of capillary attraction be experimentally exhibited?

Is the same amount of capillary attraction exhibited by a solid towards all sorts of liquids?

the effect of cohesive attraction on the particles of liquids, causing them to assume a globular figure, and on the modifications produced by the attraction of solids with which the liquids may come in contact.* It is on the joint operation of these causes under particular circumstances that the phenomena of capillarity appear to depend. It is found from observation that when fluids rise in capillary tubes, the surfaces are concave or depressed in the centre; and on the contrary, when the fluids do not rise, they have convex surfaces, or stand highest in the middle. These effects are manifestly owing, in the first case, to the superiority of the attraction between the liquid and the tube over that between the particles of the former; and in the second case, to the inferiority of the former attraction compared with the latter. Hence also if water be poured into a glass tumbler it will rise somewhat at the edges, while mercury poured into the same vessel would be depressed at the edges.†

On what causes do the phenomena of capillary attraction depend?
What surfaces do liquids in tubes ordinarily present?
What causes the diversity in this case?

---

* See No. 5 of this treatise.

† See Journal of the Franklin Institute, vol. xiv. p. 147, for some ingenious experiments on capillary attraction, by Mr. J. W. Draper.—Ed.

The following, among other treatises, may be profitably consulted in regard to this branch of philosophy, and will generally, perhaps, be attainable without much difficulty by the American teacher.

Cambridge Mechanics, by Prof. Farrar, p. 289—368.
Fischer's Elements, p. 83—111.
Playfair's Outlines of Natural Philosophy, vol. i. p. 168—193.
Gregory's Mechanics for Practical Men, Philad. edit. p. 284—301.
Library of Useful Knowledge—Treatise on Hydrostatics.
Robinson's Mechanical Philosophy, vol. ii.
Edinburgh Encyclopedia, article *Hydrodynamics*.
Hydrodynamique, Bossut.
Hydrodynamique, Prony.
Traité de Physique, par Biot, vol. i. chap. 22.
Mecanique Celeste, translated by Bowditch, book 10.

HYDRAULICS.

1 When the equilibrium arising from the weight and consequent pressure of liquids is disturbed, motion will take place; and the laws by which it is regulated are the same with those which govern the motion of solid bodies. The velocity of flowing water, like that of falling bodies, depends on gravitative attraction, and is to be estimated on the same principles; and the phenomena exhibited by jets of water, or other spouting liquids, are analogous to those displayed by solids projected through the air, the effects in both cases depending on the operation of similar causes.

2. Among the circumstances which influence the motions of liquids, one of the most important is the weight of the air, producing atmospheric pressure; and to this force the most powerful and useful machines for raising water chiefly owe their efficiency. Such are the various kinds of pumps, fire-engines, and siphons, which are rather to be considered as pneumatic than as hydraulic machines, resembling in their mode of action the barometer and the common syringe; their construction and effects may therefore be most advantageously investigated and explained in treating of pneumatics. Indeed that branch of hydrostatical science, which relates to the motion of liquids, is so intimately connected with the theory of motion, as applicable to all fluids, whether liquid or gaseous, that in a systematic treatise the subjects could not with propriety be separated.

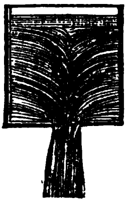
3. At present, we shall confine our attention to the effects of the motion of liquids on different parts of connected masses, or on solids with which they may come in contact; and afterwards briefly notice the construction and mode of action of those machines whose power depends on the weight or pressure of flowing liquids, or on the pressure or impact of liquids on solid bodies.

4. In consequence of the imperfect cohesion of their constituent particles, liquids present some peculiar appearances, when they fall through the influence of gravitation. A continuous solid mass will always remain at rest while its centre of gravity is supported; thus it may be sustained by net-work, or suspended by a line, as securely and steadily as if it were inclosed on all sides; but an unconnected mass, as a heap of sand, can have no common centre of gravity, and therefore to preserve its stability every separate grain must be supported. Water, or any similar liquid, in order to keep it in the state of equilibrium, requires support even to a greater extent than a disintegrated solid, or powder; for such is the peculiar attraction existing between the particles of a liquid,

What laws regulate the motions of liquids?
On what does the velocity of flowing water depend?
What circumstance modifies the motions of liquids?
Under what two general divisions may liquid motions be examined?
What peculiarity is presented by liquids when falling in obedience to gravitation?

that unless the whole mass be supported laterally as well as at the base, it will spread on that side where the pressure is withdrawn till every part has attained a common level. This property, and its effects in producing pressure in liquids at rest, have been already noticed, and those which are exhibited by flowing liquids are now to be developed.

5. When water contained in a deep vessel is suffered to escape from an aperture in the bottom, it flows in a continued stream, formed by the pressure of the liquid acting against that point from which the support has been withdrawn. The combined effect of the hydrostatic pressure, and the cohesion of the particles of the watery fluid causes various movements in the flowing stream, which may be accurately observed by using a glass jar, and mixing with the water some very small pieces of amber, or sealing-wax, the specific gravity of which exceeding that of water but in a trifling degree, they will be carried down with the current, and exhibit its internal motions.



6. The annexed figure will serve to show the manner in which the liquid descends, at first in horizontal strata, and afterwards, when a portion has escaped, the surface becomes depressed in the centre, till at length, when it approaches the bottom, it assumes the form of a funnel, or hollow inverted cone, which it retains till the vessel is nearly emptied. If the aperture be made in the side of the vessel, and close to the bottom, the same appearances may be observed, with the exception of the hollow cone, which in this case does not occur, the liquid remaining level at the surface till it sinks down to the orifice. As the common direction of the particles of the descending liquid is towards a central point, indicated by the course which the floating fragments of sealingwax take towards the aperture, the stream must become compressed, and consequently somewhat contracted at that point. Its situation depends much on the size of the aperture; and when that is very small, and the side of the vessel in which it is pierced extremely thin, the greatest contraction of the jet will take place at the distance of about half the diameter of the orifice beyond it; and at that point the diameter of the liquid vein will be to the diameter of the orifice nearly in the proportion of 5 to 8, whatever be the height of the liquid in the vessel from which it flows. This contraction of the liquid vein may be equally observed when the discharge takes place from an aperture in the side of a vessel, and likewise when the liquid is projected vertically upwards, as in *jets-d'eau.*

What force projects and maintains the continued stream of water flowing from a deep vessel?

How may the interior motions in such a vessel be rendered apparent?

What appearance on the exterior of an orifice results from the interference of the particles of liquid seeking the outlet?

Within what limits does the *contracted vein* approach the diameter of the orifice?

7. The point of greatest contraction in a stream of flowing water, or of any other liquid, must manifestly be also the point where it has the greatest velocity, as it is there that the hydrostatic pressure acts with greatest effect. In estimating the velocity of a liquid issuing from an aperture in the side or the bottom of any vessel, it will be found to depend on the vertical height of the water within the vessel; and in every case it will be equal to the velocity that a body would acquire in falling through a space equal to that height. Hence it cannot be uniform unless the water is supplied as fast as it is discharged, and thus kept always at the same level.

8. Suppose two vessels, one of which is 5 inches in height, and the other 20 inches, to be filled with water, each having a circular orifice at the bottom 1-5 of an inch in diameter, if both be opened, and the vessel kept constantly full by a supply of water above, the taller vessel will discharge about 21 ounces of water in a quarter of a minute, and the shorter vessel about 11 ounces in the same space of time. Thus, estimating the relative velocity of the stream in the two vessels by the quantities discharged by each in a given time, that of the stream from the taller vessel will be to that from the shorter, as 2 to 1, nearly; and the velocities would be exactly in that ratio, but for the effect of friction between the particles of the liquid and the sides of the vessel, and the resistance of the air, which proportionally diminish the discharge from the taller vessel somewhat more than that from the shorter one. Now taking the velocities as 2 to 1, the height of the taller vessel being to that of the shorter as 4 to 1, it will appear that the velocity in either case is as the square root of the height of the column of liquid in the respective vessels; for $1 \times 1 = 1$, and $2 \times 2 = 4$.

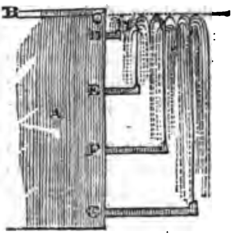
9. It may, therefore, be generally stated, that independently of the irregularities occasioned by friction and other causes, the maximum velocity with which a liquid flows from an aperture in the side or bottom of a vessel will be as the square root of the depth of the vertical column within the vessel. Hence the velocity of a flowing liquid depending, like that of a falling body, on gravitation, it follows that a stream issuing four feet below the surface of a liquid mass will have double the velocity of one issuing at 1 foot below the surface; at the depth of nine feet the velocity will be treble, at 16 feet fourfold, at 25 feet fivefold, and so on in proportion to the depth of the aperture below the surface. It must be recollected that these comparative estimates are to be regarded as results deduced from the influence of gravitation alone, therefore in practice allowance must be made for the effect of friction and atmospheric resistance, and the dimensions and form of the aperture must likewise be attended to in making experiments and calculations.

In what part of a jet will the greatest velocity necessarily be found?
On what circumstance does the velocity of issuing currents depend?
Why does not the rapidity of flowing liquids correspond exactly with the square roots of the heights, or heads of pressure?

10. From the experiments of Bossut it appears that the actual quantity of water discharged from orifices of the same dimensions, under different degrees of pressure, is far less than might be inferred from calculation. The following table* of theoretical and practical discharges through circular orifices one inch in diameter will clearly exemplify this principle.

Height of the liquid above the orifice.	Computed discharge per minute, in cubic inches.	Actual discharge per minute.	Per ct.
1 foot	4427	2812	63,5
5 feet	10123	6277	62,0
10 feet	14317	8860	61,8
15 feet	17533	10821	61,1

11. The phenomena exhibited by spouting liquids when the current is directed vertically upwards, are equally with those of descending currents under the influence of gravitation; and as bodies projected perpendicularly in the air rise to a height equal to that from which they must have descended, to acquire the velocity with which they were propelled,† so liquids spouting from a short pipe directed upwards, rise to a height equal to that of the liquid column by the pressure of which they were ejected. In the marginal figure let A represent a cistern filled with water at the constant height B C, then if four bent pipes D, E, F, G, be inserted at different distances below the surface, the jets will all rise to nearly the same level, that of the line B C. The resistance of the atmosphere and the mutual friction between the particles of the ascending current, both, however, counteract its force, so that it is only when the orifices of the pipes are extremely small that the elevation of the jets becomes considerable relatively to the hydrostatic pressure. Yet water may be made to rise in spouting streams even above the level of the reservoir from which it issues, by introducing a current of air in such a manner that it may be mingled with the stream, and the fluid thus becoming specifically lighter than the water in the reservoir, the latter is more powerfully acted on by the incumbent weight.



What do the experiments of Bossut prove in regard to the discharge of water from orifices under different heads?

Does the difference between the theoretical and the actual discharge increase or diminish by an increase of head?

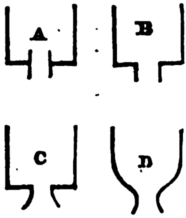
What relation exists between the head of pressure and the height to which a liquid will be projected upwards?

In what manner may a liquid be made to rise in a jet above the level of the source?

* See Encyclop. Metropol.—Mixed Sciences, vol. i. p. 210.

† See treatise on *Mechanics*, No. 91.

12. The concourse of the aërial and aqueous fluids produces musical sounds, somewhat resembling those from the harmonica, but not so soft. That the sounds are caused by the particles of the air striking against those of the water is evident, because, when the flux of the water is stopped, and the air suffered to issue alone, nothing is heard but a hissing noise very different from the preceding.*



13. It has been ascertained from experiment that a greater quantity of water will be discharged in a given time from the side or bottom of a vessel, through a short projecting tube, than from a simple aperture of the same dimensions. The tube, however, must be entirely without the vessel, as in fig. B, for if it is continued inside, as at A, the discharge will be lessened instead of being augmented. Much also depends on the figure of the tube and that of the bottom of the vessel, since more water will flow in the same time through a conical or bell-shaped tube than through a cylindrical one, and a further advantage will be gained by giving a corresponding shape to the bottom of the vessel, as at D. These effects depend on the interruption to the conflux of the aqueous particles by the sides of the rising tube in the vessel A, and the greater facilities afforded for their escape in different degrees by the forms of the apertures in the vessels B, C, and D; and the last of these, coinciding most exactly with the figure of the flowing stream, is best adapted to promote the discharge of the liquid.

14. When pipes, or tubes, of considerable length are used to conduct water from a fountain, the effects will be modified by various circumstances, the quantity discharged depending on the length and dimensions of the pipes, their direction or inclination, and the number and abruptness of the angular bendings which take place in their course.

15. When a stream of water is propelled through a cistern or basin containing water at rest, it will have such an effect on the entire mass as to set it in motion, and cause a great part of it to mix with the current, and make its escape. Owing to this property of flowing liquids, it is possible to drain a lake or marsh by leading a stream descending from a higher level to the border of the lake, when it will sweep through the stagnant water, and

What phenomenon accompanies a jet of mixed air and water issuing from a pipe?

On what circumstances do the effects of short tubes of *adjutage* depend?

What additional causes of resistance are to be considered in long tubes?

What occurs when a stream of water is directed along the surface of a basin of the same liquid?

To what is this effect attributed?

* V. Beudant Traite Elementaire de Physique, 1829, pp. 271, 272.

gradually drawing it into its vortex, carry it off over the opposite bank. Venturi, an Italian philosopher and engineer, made use of this method to drain a marsh near Modena, by conducting through it a rapid descending stream.* This effect is produced by friction between the particles of the liquid, and thus the water in motion communicates its impulse laterally, till the whole mass is affected, and gradually entering the current is carried off.

16. The friction which takes place between the particles of water and those of the air is productive of some curious and interesting phenomena. To this cause is owing the current of air caused by the fall of water from an eminence, of which a remarkable instance is adduced by Venturi, in a cataract which rushes from the glacier of Roche Melon, on the rock of La Novalese, near Mount Cenis.

17. The agitation of the sea by the wind, and the transformation of its surface into a mass of foaming waves and mountain billows during a storm, is another important and striking effect of the friction of air and water. That the formation of waves depends on this cause is convincingly proved by the experiments of Dr. Franklin, who ascertained that by pouring oil on the surface of a pond to the windward, in stormy weather, the ripples with which it was covered might be made to subside; and it appears that this method of calming the waves by pouring oil on their surface has in some instances been found advantageous at sea. From its inferior specific gravity the oil forms a floating film, which defends the surface of the water from contact with the currents of air, and the friction between the wind and waves is vastly diminished, in the same manner as that which takes place between solids is by the application of unctuous matter.

18. The effect of the pressure or impact of flowing liquids on solids immersed in them, is, as in other instances of hydraulic pressure, greatly influenced by circumstances, and therefore the general principles arising from theory must be adopted with considerable limitations when applied to practice. It must be manifest that when a flat solid surface is moved perpendicularly against a liquid, the resistance will always be in a certain proportion to the extent of the solid surface; and when such a plane surface is exposed to the action of a flowing liquid, the effect must be greater or less according to the degree of the velocity of the stream. Hence may be deduced the general rule, that the effect produced by the pressure of flowing water, acting perpendicularly on a flat surface plunged beneath it, is in the compound

To what useful purpose has this experiment been converted?
How is the elevation of waves to be explained?
What experiment is conceived to demonstrate the correctness of this explanation?
In what proportions are solids resisted when moving through liquids?

* See Leslie's Elements of Nat. Philosophy, vol. i. pp. 397, 398; and Nicholson's Journal, 4to. 1798.

ratio of the square of the velocity of the stream and that of the solid surface. If the surface be presented obliquely to the direction of the stream, the effect must be less than when it is perpendicular to the surface of the current; and the diminution of pressure arising from such a cause will be proportioned to the inclination of the solid surface. Its amount in any given case may be calculated on the same principles as the effects of inclined planes in mechanics.

19. When a liquid acts by impact on a solid plane, causing it to turn round an axis, in the manner of the float-boards of a water-wheel, there will be a certain point in that plane, where, if the whole force of the stream could be concentrated, it would produce the same effect as when that force is distributed over the whole surface of the plane. The point thus indicated is the centre of percussion, some notices of which have been introduced elsewhere.*

Hydraulic Machines.

20. The object of hydraulic machinery is chiefly that of raising water from a lower to a higher level, which effect may be produced by hydrostatic pressure or impact, on liquids and solids, either alone, or in conjunction with atmospheric pressure. The construction of those machines whose operation depends on the latter cause must be referred to the treatise on Pneumatics; but there are other machines which may be properly noticed at present as their modes of action admit of satisfactory explanation on the principles of hydrostatic science.

21. These may be distinguished into three classes: namely, machines for raising water by mechanical means only; those which act by the weight, pressure, or impact of water, on solids; and those in which the effect is produced by the reactive force or intermitting action of flowing water.

22. A common draw-well, from which the water is lifted by means of a bucket and windlass, affords an example of a machine of the first class. But the comparatively small quantity of water that can be raised at once by the use of a single bucket confines its employment to domestic or occasional purposes.

23. The chain-pump is a much more efficient engine, though very similar in its mode of action to the preceding. The figure

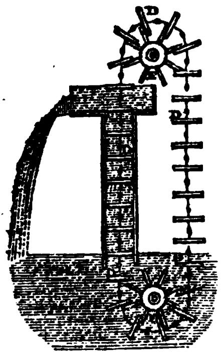
What advantage is possessed by the obliquity of the surface against which the resistance is applied?

At what point in a float-board may the whole action or reaction of a liquid be conceived to be applied?

On how many different principles are machines for raising water constructed?

Into how many classes are those machines divided, which depend for their efficiency entirely on hydrostatic laws?

*** See *Mechanics*, No. 123. See Col. Beaufoy's experiments on Hydraulic action, in which a vast variety of forms, velocities, and modes of action are detailed.—Ed.**



in the margin represents it as consisting of a number of plates or flat disks of wood, D D D D, attached horizontally to an endless chain, and passing round two wheels, E and F, by turning which the chain and plates are carried through a water-tight cylinder, the lower end of which is plunged beneath the surface of water, and its internal dimensions are exactly adapted to receive the plates, which successively entering the tube when drawn up by the revolving chain, form so many buckets filled with water, which they carry up and discharge into a cistern above, or when used as they commonly are on ship-board, into a pipe that may discharge it again into the sea. The machine may be set in motion by a winch, or other means applied to turn the upper wheel. The chain-pump will act with greater effect when the cylinder can be placed obliquely than when its direction is exactly vertical.

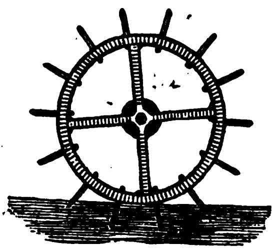
24. The rope pump is a less efficient modification of the chain-pump or bucket-engine. It is composed of wheels, one under water and the other above, having on their peripheries several grooves, through which pass endless ropes of very loosely spun wool or horse hair; and the upper wheel being made to revolve with great velocity, the water which adheres to the coarse ropes may be raised and discharged above by pressure. The water is here attached to the rope by simple cohesive or capillary attraction.

25. The Persian wheel, which is used to raise water not only in Persia but also in Egypt and other eastern countries, consists of a large wheel, to the nave of which are suspended a number ot buckets, in such a manner that in the revolutions of the wheel they successively dip into a pond or stream of water over which the wheel moves, and the buckets thus being filled ascend with their load till each in turn reaches the summit of the circuit, where there is a contrivance for tilting each bucket, so that it may discharge its contents into a cistern or reservoir, and it then descends with the revolving wheel to be filled again. Such a wheel may be put in motion by any mechanical means; or if it be employed to raise water from a running stream, float-boards may be added to make it revolve like an under-shot wheel.

Explain the action of the chain-pump.
In what position will the chain-pump act to most advantage?
By what species of mechanical action is water raised on a rope pump?
Explain the construction of the Persian wheel.

26. The cochlion or screw of Archimedes, derives its designation from a prevalent opinion that it was the invention of the Syracusan sage. But it is not mentioned by Vitruvius among the discoveries of Archimedes, and there is some ground for believing that it was, before his time, used in Egypt to raise and carry off the superfluous water left in the low grounds after the inundations of the Nile; so that the question as to its origin remains undecided. Its form, as represented in the margin, is that of a helix (as the name partly implies,) consisting of a flexible tube like a hollow corkscrew wound round a solid cylinder, which may be made to revolve by turning a winch, or by attached wheel-work. When it is placed in an oblique position, with the lower opening of the screw immersed in a cistern, or any other body of water, the liquid will enter below, as the orifice dips beneath it in each revolution, and be carried up and discharged above; the peculiar form of the machine facilitating the elevation of the water.

27. The most important machines belonging to the second class are different modifications of water-wheels. They are respectively termed undershot wheels, overshot wheels, and breast wheels.

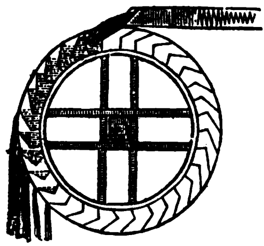


The undershot wheel is said to be of earlier origin than the others; and it is likewise the most common. It consists, as is shown in the annexed figure, of a wheel on the periphery of which are fixed a number of flat boards at equal distances, and set at right angles to the plane of the wheel. They are called float-boards; and the wheel being so placed as for its lowest point to be immersed in flowing water, it is set in motion by the impact of the water on the boards as they successively dip into it. As a wheel of this kind will revolve in any stream which furnishes a current of sufficient power, it may be used where the descent of the water is by far too trifling to turn a breast wheel, much less an overshot wheel.

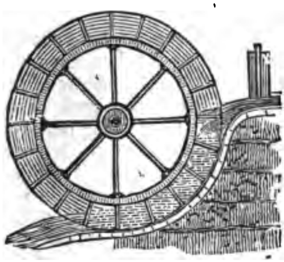
28. If all the float-boards are vertical to the centre of the wheel,

To whom is the invention of the cochlion commonly ascribed?
Into how many classes are vertical water-wheels divided?
What name is given to that part of an undershot wheel which receives the impact of the water?
In what situations is the peculiar advantage of this kind of wheel to be obtained?

as in the figure, the wheel will work equally well in either direction, and one of that construction may therefore be advantageously used in the tide-way of a river, as it will revolve either with the flowing or the ebbing tide. But in any other situation a wheel is to be preferred in which the float-boards incline towards the current, and thus the effect of the stroke is increased; but it appears from experiment that the best position is when the inclination of the float-boards is but inconsiderable.



29. The overshot wheel differs from the foregoing in the manner in which it is acted on by water, receiving its impulse not from the impact only, but from the weight of water. This kind of wheel, as may be conceived from the figure in the margin, can only be used where a considerable fall of water can be obtained. On its periphery are fixed a number of cavities called buckets, being closed on both sides, but having openings, so that the water, conducted by a level trough of the same breadth with the wheel, may fill each bucket in succession, as it reaches that point in the circuit of the wheel at which the weight of the water can begin to act on its circumference. From the peculiar form of the buckets they retain the water partially till they have descended to near the lowest point of the circuit, and having discharged their contents into the tail-stream, they ascend on the opposite side to be filled as before. As the overshot wheel requires the greatest fall of water to make it act, so is it likewise the most powerful with reference to the effect produced, by the momentum of flowing water.

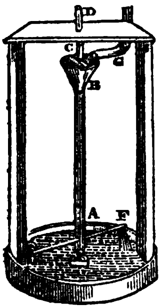


30. The breast wheel is a sort of machine having an intermediate character compared with the undershot and overshot wheel. It has float-boards like the former, but they are converted into buckets somewhat after the manner of those in the chain pump, as they move in a cavity adapted to the circumference of the wheel, as shown in the margin. The water passes through this cavity, enter-

How are the floats of an undershot wheel to be set with respect to the centre?
Describe the construction and action of an overshot wheel.
What relation has the power of the overshot wheel to that of other wheels using the same quantity and fall of water?
What is the construction of the breast wheel?
In what points does it resemble the other two forms of water-wheels?

ing it nearly on a level with the axis of the wheel. In this case the liquid acts chiefly by its weight; and the machine, though less efficient than the overshot wheel, is more so than the other. It is, therefore, only used where the fall of water happens to be peculiarly adapted for the purpose.

31. Among the hydraulic machines belonging to the third class, which derive their power from the reaction of flowing water, is one called Barker's Mill, as having been invented by Dr. Barker, towards the close of the seventeenth century. This engine, as represented in the annexed figure, consists of a hollow cylindrical metal pipe, A B, of considerable height, and terminating above in a funnel-shaped cavity. The pipe is supported in a vertical position, by resting below on a pointed steel pivot, turning freely in a brass box, adapted to receive it; and the upper part has a cylindrical steel axis, C D, passing through a board, supported by uprights at the sides. The hollow tube, A B, communicates with a cross tube, E F, closed at the extremities, but having adjustible orifices at the opposite sides, near each end of the cross tube. A pipe, G, above, communicates with a supply of water, which it discharges into the funnel at the top of the vertical pipe B; and the supply must be so regulated that the pipe may be kept constantly filled with water without running over; while the orifices in the cross-pipe at E and F will deliver the water with a force proportioned to the height of the column in the tube A B, and the apertures being in opposite directions, the spouting currents will communicate a rotary motion to the vertical tube and its axis C D, to which may be attached a toothed wheel connected with any other machinery.



32. The action of this machine does not, as sometimes stated, depend on the resistance of the atmosphere to the jets from the cross-pipe; but is wholly owing to the hydrostatic pressure of the column of water in the vertical tube, which exerting great force on the interior of the horizontal tube, and that force being removed from the points whence the water issues, the pressure or reaction on the corresponding points on the opposite parts of the interior of the tube tends to make it revolve, the action of both jets producing motion in the same direction. Hence it is often called the reaction wheel. The theoretical investigation of its peculiar properties and mode of action, has engaged the attention of the celebrated mathematicians, Leonard Euler and John Bernoulli,

By what mechanical property does the water produce its effect on this wheel?

On what principle is Barker's mill constructed?

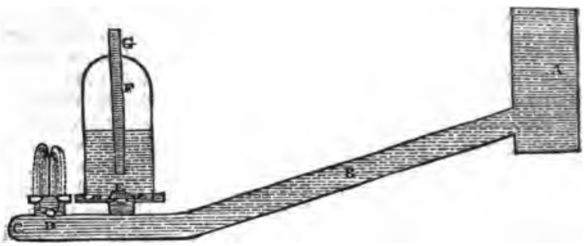
Is the presence of the air necessary to the action of this machine?

On what part of the revolving arms is the moving force really exerted?

both of whom represent it as exhibiting a method of employing the force of water as a moving power, superior to any other.

33. Among machines whose effects depend on the force of flowing water may be included the Hydraulic Ram, invented, or rather improved by Joseph Montgolfier, distinguished for his share in in the invention of the air-balloon. The hydraulic ram operates chiefly from the momentum of a current of water, suddenly stopped in its course, and made to act in another direction; and as it produces a kind of intermitting motion, owing to the alternate retreat and access of the stream, accompanied with a noise arising from the shock, its action has been compared to the butting of rams; and hence the name of the machine.

34. Several historical facts, in regard to the employment of the percussive force of liquids to elevate portions of their own nass, are cited by writers on this subject, prior to the invention of Montgolfier's *Belier hydraulique.* The fixing of pipes to convey water from one level to another, could scarcely fail to render apparent the immense power momentarily exerted when a column of water descending with considerable velocity is suddenly arrested. A most striking example of this was exhibited (Dec. 1834) at the Philadelphia water works, in which, by a little derangement in the action of the valves of the force pump, the column of water from the basin 100 feet high, was suddenly met by the machine with a force which burst the air vessel with an explosion like that of artillery, tearing asunder the cast iron at a part where the diameter of the vessel was three feet, and the thickness of the metal full an inch and a half of perfectly sound casting. Several inch bolts of wrought iron which had confined the upper part of the vessel were likewise torn away.



35. The essential parts of the hydraulic ram, as exhibited by Montgolfier, are represented in the marginal figure. A, is a head of water, connected with the tube or tunnel B, closed at the extremity C, but having an aperture at D, to which is adapted a valve formed by a ball of porcelain or copper, hollow, so as to be not

On what principle is the hydraulic ram constructed?
What remarkable effects of the percussion of a liquid column have been observed?
Explain the several parts of the machine invented by Montgolfier.

more than as heavy again as an equal volume of water, and supported near the orifice by a sort of muzzle or cage. F, is a reservoir of air, with an opening from the tunnel B, and a valve E fitted to it, but lifting upward, and prevented from displacement by a muzzle over it. From near the bottom of the air-vessel F proceeds a pipe G, which may be continued to any given height to which it is requisite that the water should be raised. The tube B, is called the body of the ram; the tube G, the tube of ascension; D the stoppage valve, and E the ascension valve.

36. Now the former valve being open and the latter shut when the water begins to run, it at first escapes through the stoppage valve D, but soon acquiring a momentum, from the accelerating velocity of its fall, it drives the ball D against the opening and stops the passage in that direction; the reflected stream then strikes up the valve E, and water enters into the air-vessel F, through the ascension valve: the ball D, as soon as it is relieved from pressure, falls into its muzzle, and makes way for the water again to escape through the stoppage valve, while the other valve closes through its weight and the reaction of the compressed air in the reservoir. The renewed momentum of the stream presently shuts the stoppage valve, and lifting the ascension valve, more water enters the air vessel, and as soon as the orifice of the pipe G becomes covered, the pressure of the air drives the water upward; for that which has been admitted through the ascension valve cannot return, and more being added at each stroke of the engine, it may be gradually raised to an indefinite height.

37. The absolute effect produced must, in any given case, depend on the fall of water to supply the engine, and the diameter and lengths of the tubes. Montgolfier erected a water ram in his garden, with an artificial fall of water of 7½ feet, by which water was raised to the height of 50 feet, in tubes two inches in diameter: the water expended in four minutes was 554 pints, that elevated 52 pints. Comparing the *power expended*, ($554 \times 7.5 = 4155$,) with the effect obtained in this case, ($52 \times 50 = 2700$,) we get the result $2700 \div 4155 = ,65$, or the effect is sixty-five per cent. of the power, while with the best forms of overshot wheels the effect sometimes exceeds 85 per cent. In another machine, with a fall of about 34 feet, water was raised seven times that height, and the stoppage valve closed one hundred and four times in a minute. Improvements were made on the original construction of the hydraulic ram by the son of the inventor, who obtained, in England, a patent for his construction.

Why does not the stoppage valve remain permanently in contact with its seat when once elevated by the force of the current?

On what does the absolute effect of the hydraulic ram depend?

What proportion did Montgolfier find between the *power expended* and the *effect produced* in the elevation of water?

The subject of hydraulics embraces two different objects.—The first, a theoretical view of the nature of the forces exerted by water in motion, and the peculiar phenomena accompanying its movement, whether in open channels, closed pipes, or the organs intended to receive and employ its mechanical efficiency; and the second regards it as a branch of engineering. Teachers will find the two departments often blended together, and the topics belonging to both promiscuously treated. But in some recent publications they have been very properly distinguished, and the science of the matter, with its various theoretical developements, arranged under appropriate heads. In this manual, the object of which is to treat chiefly of the sciences, the former class of treatises deserves particular mention.

Theoretical calculations are to be found in Cambridge Mechanics, pp. 369—417.

Gregory's Mathematics for Practical Men, pp. 302—329.

Treatise of Mechanics, by the same author, 2 vols. 8vo. 1826.

Venturi's Experimental Inquiry, translated by Nicholson.

Lectures on Natural Philosophy, by Dr. Young.

Belidor's Architecture Hydraulique.

Prony's Nouvelle Architecture Hydraulique.

Dubuat's Principes d'Hydraulique.

Traité Elémentaire d'Hydrodynamique, par Bossut.

The volume of the transactions of the British Association at Cambridge, contains an able report by Mr. Rennie, on hydraulics, as a branch of engineering, which has been republished in the Journal of the Franklin Institute for January and February, 1835.

For an account of experiments on water power the reader may consult Smeaton's Reports, Evan's Millwright's Guide, Banks on Mills, and Journal of the Franklin Institute, (report of committee on water-wheels.)

PNEUMATICS.

1. The object of that branch of physical science which has been denominated Pneumatics,* or Aërology,† is to explain and illustrate those phenomena which arise from the weight, pressure, or motion of common air or other fluids possessing the same general properties. The distinction between liquids and those more elastic fluids called air, gas, vapour, or steam, depends in a great degree on occasional causes, especially on temperature and pressure. Those effects which are to be attributed to the operation of heat and cold, or diversity of temperature, are on several accounts of sufficient importance to be made the subject of detached investigation, comprehending a review of the relations of heat to all natural bodies, whether solids, liquids, or gases; and tracing the general influence of temperature in the production of those peculiar forms of matter. Therefore, though it will be impossible to explain the phenomena of atmospheric pressure, and its effects on solids and liquids, without adverting to the influence of temperature, a more extended survey of that important subject must be referred to the subsequent treatise on that branch of science which has been termed, Pyronomics, or the laws of heat.

2. There are two kinds of aëriform bodies; namely, those which are always in the gaseous state, under common circumstances of temperature and pressure, thence named permanent gases or airs; and those which become gases chiefly at high temperature, and which therefore may be styled non-permanent gases or vapours. Common air, or atmospheric gas, affords an obvious specimen of a permanent elastic fluid, and steam or vapour of water of a non-permanent elastic fluid.

3. These different species of gases possess many properties in common; and there is reason to believe that those gases which have till recently been regarded as capable of existing only in the form of permanently elastic fluids, might be reduced to the liquid state by subjecting them to extremely low temperature and very powerful pressure.

4. Mr. Faraday has effected the condensation to the state of a liquid of the gas called carbonic acid or fixed air, as well as several other gases previously considered as permanently elastic

What is the object of the science of pneumatics?

On what rests the distinction between liquids and gaseous bodies?

What imponderable agent is necessarily involved in the phenomena of atmospheric action?

How many kinds of aëriform bodies are found in nature?

What constitute their distinguishing properties?

What has Faraday proved in regard to the state of carbonic acid and other gaseous bodies?

---

* From the Greek Πνευμα, breath, or air; or Πνευματικος, aërial.

† From Αηρ, air; and Λογος, a discourse, or treatise.

fluids, by the combined operation of pressure and low temperature.* And Mr. Perkins, whose experiments on the compressibility of water have been already described, extended his operations to gaseous bodies, and from his statements it appears that he succeeded in reducing atmospheric air to the state of a limpid liquid, by a pressure equal to the weight of twelve hundred atmospheres.† Should the observations of those gentlemen be confirmed and extended to all those now called permanent gases, it will be evident that their existence in the liquid or gaseous form depends entirely on their relations to temperature and pressure, the various airs and vapours being all susceptible of condensation under different circumstances.

5. Airs and vapours, or permanent and non-permanent elastic fluids, however, though they may be considered as forming but one class of bodies, yet from the vast diversity of their relations to heat, admit of being applied to very different purposes; and hence, in treating of their physical properties, the distinction between them must be carefully kept in view. It will, therefore, be conducive to perspicuity to notice in this treatise the properties of the permanent gases, such as atmospheric air; leaving the circumstances which constitute the discriminating characteristics of the non-permanent gases, and especially of steam or the vapour of water, to be more fully investigated in the division of this work, appropriated to the doctrine of Heat.

General Properties of Air.

6. Common or atmospheric air is an invisible or perfectly transparent fluid, the ultimate particles of which appear to be destitute of cohesion; and hence air has a disposition not only to sink down, and spread out laterally like liquids, when unconfined, but it is also equally capable of expansion upwards; so that any portion of this fluid will speedily become dissipated and lost, unless it be inclosed within a solid air-tight vessel or other receptacle, such as a bladder, or retained in an open vessel by the pressure of a liquid on its surface.

7. That air is porous in a very high degree appears from its readily yielding to pressure; but like all material bodies it possesses the property of impenetrability, for though a considerable bulk of this fluid may be forced into a comparatively small space, there must be a limit beyond which the utmost pressure will cease to have any effect. The resistance of air to pressure may be

What effect did Perkins obtain by subjecting air to the pressure of 1200 atmospheres?

To what conclusions are we conducted by these experiments on gaseous bodies?

What are the most striking sensible properties of atmospheric air?

What appears to be the mutual relation of its particles to each other?

* See Abstracts of Papers in Philos. Trans., vol. ii. p. 192.

† Idem, p. 290.

demonstrated by means of a syringe of any kind with a solid piston; for if the pipe or lower opening be firmly closed after the piston has been drawn up so as to fill the barrel with air, it will be found impossible to thrust down the piston again completely while the pipe remains obstructed.

8. Let a tall narrow-mouthed glass jar or bottle be half filled with water A, and a funnel C, with a long tube, be inserted in the mouth of the bottle, as represented in the margin, and firmly secured at D, by luting or by passing it through a cork, in such a manner that the included air at B cannot escape between the funnel and the mouth of the bottle. Then water being poured into the funnel, little or none of it would pass into the bottle; for if the funnel had a tube several feet, or even yards in length, so as to give the advantage of strong hydrostatic pressure, though in that case the air at B would be compressed into somewhat smaller space, yet no imaginable force would fill the bottle, which of course would burst under a certain degree of pressure.

9. Another property of air is compressibility, in which it differs most essentially from liquids. It has been elsewhere stated that water undergoes no apparent diminution of bulk from pressure unless vast force is applied to it; and other liquids in different degrees resist compression, though readily dilated by heat and contracted by cold. But airs and gases, though, as we have just shown, manifestly endowed with impenetrability, yet display a facility of contraction and expansion under the influence of pressure, which is completely independent of temperature. They are, however, most powerfully affected by changes of temperature also; their bulk increasing or diminishing with the degree of heat to which they are exposed.

10. That the particles of air can be compressed, or driven by external force closer to each other than they were before that force was applied, must be apparent from the experiments adduced to prove the impenetrability of air; for while those experiments show that the particles of the compressed fluid cannot be destroyed, but will, when exposed to the utmost force, still occupy a certain space, yet it appears that contraction always takes place under the influence of pressure to a certain extent; and hence may be inferred another property of air already noticed, namely its porosity.

11. The compressibility of air may be experimentally illustrated by means of a strong glass tube closed at one end, like a barometer tube, and having fitted to it a piston, consisting of a strong iron wire or rod, with moistened leather fixed to one end, so that it may move up and down in the tube quite air-tight. Then, the

How is air proved to possess the property of impenetrability?
In what manner is impenetrability manifested in filling a bottle with liquid?
How do gases differ from liquids in regard to compressibility?
How may the compressibility of air be experimentally illustrated?

tube being full of air, the piston is to be adapted to the open end, and if it be cautiously pressed down, the air may be reduced to about one-half of its original bulk, without using much force, and by stronger pressure the fluid may be yet further condensed, but at length the resistance will be such as to preclude the possibility of any greater compression.

12. The most remarkable among the properties of air is elasticity, depending on its expansive power, in consequence of which, when its dimensions have been reduced by pressure, it immediately recovers its bulk on the cessation of the compressing force. Thus, if the piston of a common syringe is pushed down while the air is prevented from escaping by the pipe, as soon as the pressure is withdrawn the piston will be raised by the expansion of the included air. To this property of air or gas is owing the force with which a pellet of wet paper is driven from a school-boy's popgun; and this insignificant little engine acts on the same principle with the air-gun and other philosophical instruments, which will be subsequently noticed.

13. Gravity or weight is another very important property of air, which it possesses in common with solids and liquids. Common air, as being comparatively lighter than water, will when set free below the surface of that liquid, rise through it, in the form of transparent bubbles. This is an effect of hydrostatic pressure, in consequence of which bodies of inferior specific gravity to water when immersed in it are pressed towards its surface; and thus it happens that a cork, a drop of olive oil, or a bubble of air or gas will float on the surface of water, and when forcibly pressed beneath it, rise again to the top as soon as the force that kept it down ceases to act.

14. The weight of air may be ascertained in the same manner as that of liquids or solids, by the common operation of weighing it with a balance. But in consequence of its extreme expansibility, some peculiar precautions are necessary in performing this operation, even when no great nicety is required. These, however, will be subsequently noticed; and it will be sufficient at present to state that by means of a large bottle with a stop-cock and a syringe adapted to it, the weight of a given quantity of air may be discovered. For suppose the stop-cock to be left open and the bottle weighed in that state, when of course it will be full of air, then the weight of the bottle and the included air having been noted, the air must be drawn out, as completely as possible, by screwing the syringe on to the stop-cock, and working the piston; the stop-cock is then to be turned so as to close the bottle, which on being weighed again, after being unscrewed from the syringe, will be found to have lost a portion of its weight equal to that of the quantity of air which it would hold.

What effect, resulting from elasticity, follows the compression of air?
What familiar facts illustrate this position?
What causes the rise of bubbles of air through a mass of liquid?
How is the *weight* of air demonstrated?

15. A cubic foot of air weighs about 523 grains; and consequently a cubic inch will weigh somewhat more than .3 of a grain, therefore if the bottle would hold three pints, its capacity, solid measure, would be rather more than 100 cubic inches, so that if it could be perfectly exhausted, it ought to weigh $.3 \times 100 = 30$ grains more when weighed with the stop-cock open, than it does after the air has been extracted from it. By using an air-pump instead of a syringe, a bottle with a stop-cock may be so nearly exhausted of air, as to leave behind no quantity sufficient to interfere in the slightest degree with the result of this experiment.

Different Kinds of Airs or Gases.

16. Common air, which forms the atmosphere surrounding on all sides the earth which we inhabit, was long supposed not only to be a simple elementary body, but even after its mechanical properties had been investigated, and great progress had been made in the study of the laws of nature, very erroneous ideas were retained concerning the composition of air, and it was imagined that all elastic fluids were essentially the same. It is now known that atmospheric air is a compound, consisting of two different species of air or gas, one of which, called oxygen gas, and sometimes vital air, is necessary to the support of animal life; and the other, named nitrogen or azotic gas, when inspired alone, is injurious to animals. Both these gases are capable of entering into combination with many other bodies of very different kinds, and producing compounds, some of which are usually in the solid or liquid state, and others in the form of permanent gases. There are likewise other gaseous bodies besides oxygen and nitrogen which have never been decomposed, and are therefore considered as simple forms of matter; and these, together with the various compound gases, constitute a very numerous class of bodies, which possess different degrees of elasticity and weight, and by their consequent pressure on solids and liquids, produce equilibrium or motion; and hence they are capable of being applied to various important purposes.

17. The peculiar nature and effects of the combinations of the gases with each other and with solid and liquid substances can only be ascertained by the application of the principles of chemical science; but the action of the gases or airs, so far as it depends

What is the weight of a cubic foot of air?

About how many grains less will a three-pint bottle weigh when exhausted than when filled with air?

What opinion prevailed among the early philosophers in regard to the nature of air?

How were all gaseous bodies regarded?

Of what materials is atmospheric air composed?

What analogy have oxygen and nitrogen with other gaseous bodies?

What differences exist in the mechanical properties of the gases?

How far does the examination of gaseous bodies belong to the science of pneumatics?

on their mechanical properties, forms the appropriate subject of Pneumatics.

18. Though atmospheric or common air, as being by far the most abundant and generally diffused of all elastic fluids, is therefore usually employed as the medium of pneumatic pressure, yet since the recent researches of men of science have made us acquainted with the variety of those fluids and their several properties, it appears that some of them may be adapted to the purposes of art with greater advantage than others, and atmospheric air is no longer the only kind of gas made use of as a moving power.

19. The discovery of elastic fluids much lighter than the atmosphere has given origin to the art of Aërostation, or soaring through the air in an inflated balloon; the explosion of gunpowder, and the projectile force of balls, shells, and other missiles discharged from artillery, depends on the elasticity of a peculiar kind of air formed by the deflagration of nitre, sulphur and charcoal, composing gunpowder; and the combustion or burning together in close vessels of oxygen gas with another kind of gas called hydrogen forms water, which, being a liquid, nearly the whole space taken up by the gases previously to their combustion becomes a vacuum, and thus pressure may be produced, and a moving power obtained.

20. The application of the vapour of water to cause motion by the alternate expansion and condensation of steam affords an example of the advantageous adaptation of a non-permanent gas to the most important purposes; and if convenient means can be discovered for the liquefaction of common air and other gases by pressure and reduced temperature, as appears probable from the researches of Mr. Faraday and others, it may be expected that machines will be invented as far superior in some respects to the steam-engines now used, as *they* are to those which were constructed in the early part of the last century.

21. As the mechanical effects of the different gases when they act by pressure must depend on their relative specific gravities, it is of importance that those should be accurately ascertained. The following table will show the respective weights of equal quantities by measure of several elastic fluids, including those which are of the greatest importance, on account of their frequent occurrence and the valuable purposes to which they have been applied.

	Weight of 100 cubic inches.	Specific gravity.
Atmospheric air - -	30.5 grains - -	1.
Oxygen Gas - - -	33.8 -	1.111
Nitrogen Gas - - -	29.25	0.972
Nitrous Oxide - - -	46.5 - -	1.527

To what mechanical purposes have the gases other than common air been applied?

By what species of force is motion impressed on projectiles?

How does the alternate formation and condensation of non-permanent vapour afford a mechanical agent?

How much do 100 cubic inches of common air weigh? How much the same bulk of oxygen? of nitrogen? nitrous oxide? hydrogen? car-

Hydrogen Gas - - -	2.12	- - - 0.069
Carbonic Acid - -	46.5	- - - 1.529
Chlorine Gas - - -	76.3	- - - 2.500
Subcarburetted Hydrogen Gas*	16.9	- - - 0.555
Carburetted Hydrogen Gas*	29.6	- - - 0.972
Steam - - - -	18.8	- - - 0.519

22. From this table it may be perceived that gaseous bodies differ greatly from each other in specific gravity; chlorine being 2½ times the weight of common air, and hydrogen only about 7-100 the weight of that fluid, so that common air is nearly 15 times the weight of hydrogen. Steam has but little more than half the weight of atmospheric air, and hence it rises through the air, in the same manner that a piece of deal or cork rises in water.

Elasticity of Air.

23. The most obvious and effective property of air is its elasticity, to which, with its gravity or weight, are to be attributed the phenomena of equilibrium, or motion in bodies under the influence of pneumatic pressure. In addition, therefore, to what has been already stated concerning these properties, a more detailed investigation of their nature and action will be requisite in order to the fuller elucidation of that branch of science now under our notice.

24. The elasticity of air appears from its resistance to pressure. The application of a heavy weight, or any external force to a woolpack or a bag filled with twisted horsehair would cause the pack or bag to give way, and become more or less contracted, but on the removal of the force it would expand to nearly its original dimensions.† What thus takes place is manifestly owing to the

bonic acid? chlorine? subcarburetted hydrogen? carburetted hydrogen? steam?

What substance is generally assumed as a standard of comparison in stating the specific gravities of the gases?

What are the several specific gravities of the gases compared with that substance as unity?

How many times heavier is common air than hydrogen gas?

How much lighter is common steam than atmospheric air?

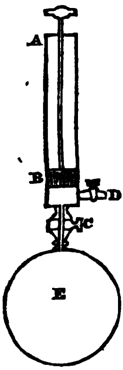
What property of air is most important in reference to its mechanical agency?

---

* The gases procured from the distillation of coal and from oil consist principally of subcarburetted hydrogen, or light inflammable air, and carburetted hydrogen, or heavy inflammable air. As these gases, which are now generally used for lighting streets and shops, are frequently mixed with other gases, the specific gravity must vary, in different specimens, with the degree of purity. Coal-gas, after it has been purified is found varying in specific gravity, from .450 to .700; while oil-gas, which contains a larger proportion of carburetted hydrogen, is much heavier, and therefore yields more light in proportion to its bulk.

† The manner in which elastic bodies act is strikingly illustrated by the novel application of spiral springs of iron wire in the construction of elastic chairs and beds. Dr. Paris, who notices this invention in his

form and texture of the included substances; the particles of which are separated by numerous interstices, and therefore readily yield to the force applied at the surface, which drives them nearer together without destroying their elasticity, or disposition to regain their previous situation, and hence they recede from each other, when the force which made them approach is withdrawn. A bladder filled with air may thus be compressed by squeezing it with the hands, and it will swell out again as soon as it is relieved from the pressure, owing to its particles being endowed with a power of repulsion; for in proportion as they are left at liberty they exhibit a tendency to expand in every direction, so that their absolute dispersion through boundless space can only be prevented by the influence of pressure.

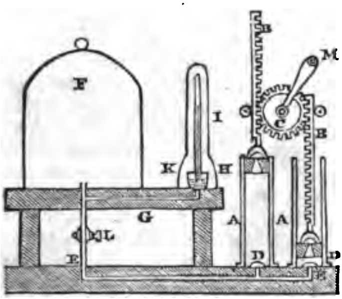


25. The elasticity of the air is most convincingly demonstrated by the operation of the machine called an air-pump, the construction of which is similar in principle to that of the syringe.. By adapting two stop-cocks to a common syringe, and forming by means of them a communication with a vessel of convenient shape and dimensions, a rude and imperfect kind of air-pump might be contrived, by means of which air included in the vessel might be considerably rarefied or condensed. The effect thus produced will appear from the annexed figure, in which A B represents a syringe with a solid piston, C a cock, which when open, leaves a communication between the barrel of the syringe and the glass globe E; and D another cock which opens a communication with the external air. If now we suppose the piston to be at the bottom of the barrel, and the cock D shut, then on drawing the piston up to A, a part of the air in the globe will rush into the barrel, and the whole mass of the included air will become expanded; the cock C is then to be closed and the cock D opened, when the piston being pressed to the bottom of the barrel, the air it contained will be expelled through the open cock; this is next to be shut, and the cock C opened, and on drawing up the piston again, the air in the globe will become further rarefied; and these operations, the alternate opening and shutting of the cocks, and raising and depressing the piston, may be continued till a high degree of rarefication is produced. This apparatus is called an exhausting syringe.

Whence does this property become apparent?
What familiar illustration shows the nature of this action?
How is the dispersion of air through the regions of space prevented?
What machine demonstrates most satisfactorily the elasticity of air?
Explain the simplest form of this machine.

"Philosophy in Sport made Science in Earnest," says, "Down itself cannot be more gentle nor springy; and such beds never require to be shaken or *made*."

26. The same apparatus may be employed to effect the condensation of the inclosed air, by drawing up the piston with the cock C shut, and D open, and thrusting down with C open, and D shut; for by continuing this process, air would be made to enter by the cock D, and be afterwards forced into the globe E. The apparatus now takes the name of a condensing syringe; though valves which open and shut by the mere pressure and expansion of the included air are usually substituted for the stop-cocks. Valves are more convenient than stop-cocks, as requiring less labour and attention on the part of the operator; but a much higher degree of exhaustion can be effected by means of a syringe furnished with the latter than by using the common exhausting syringe with valves; yet these are generally adopted in the construction of exhausting and condensing syringes and air-pumps, as being much less expensive than stop-cocks, and more easily kept in proper order.



27. The air-pump, as might be inferred from its appellation, is a machine for extracting air out of a close vessel, and thus producing within it a degree of rarefaction nearly approaching to a vacuum; it being impossible, as we shall subsequently show, to form a perfect vacuum, by this or any other apparatus; though the exhaustion may be carried so far that the remaining air will not at all interfere with the results of our experiments.

28. The figure in the margin exhibits a section of an air-pump, from which it may be perceived that it essentially consists of two exhausting syringes, so arranged that they can be worked alternately. The syringes are marked A A, and their pistons are moved up and down within the barrels, by the racks or toothed rods B B, adapted to corresponding teeth on the periphery of the wheel C, having a winch or handle M, by which it may be turned so as to raise and depress either piston successively. Each of the pistons is furnished with a valve by which the air escapes as the piston descends, and there are other valves D D, at the bottom of each barrel, which become closed by either piston in its descent, but when it is drawn up, open a passage into the tube E E, communicating with the cavity of the glass bell F, called a re-

What purpose is served by the stop-cocks or valves of an exhausting syringe?

Is the air-pump adequate to produce perfect exhaustion within a containing vessel?

In what manner is motion usually communicated to the pistons of an air-pump?

ceiver. From the tube E passes off another tube G, the extremity of which opens into the bell-shaped tube K, within which is a small basin H, containing mercury, and the small tube I, closed at the upper end only, has its lower end plunged beneath the surface of the mercury. At L is a stop-cock, which when closed cuts off the communication between the receiver and the syringes, and which must therefore be opened while the machine is put in action. Another stop-cock, not shown in the figure, closes a passage through which the external air may be admitted under the receiver, when the result of an experiment has been ascertained.

29. There is so little difference in the mode of action of the air-pump and the exhausting syringe before described that the effect of the former will be readily understood. Either syringe in turn, by the elevation of its piston, and the consequent closure of the piston-valve and opening of the valve D, draws a portion of air from the receiver F, through the tube E E; and the alternate depression of each piston, by the elasticity of the air inclosed in the barrel, shuts the valve D, and prevents the air from returning into the receiver, at the same time that it opens the valve of the descending piston, and finds a passage into the upper part of the barrel, whence it is expelled by the piston in its next ascent. Thus, the reciprocal action of the syringes, by means of the rack-work, may be continued, till the requisite degree of rarefaction be produced in the air within the receiver. The only part of the apparatus requiring further explanation is the air-gauge, consisting of the tubes K and I, and the basin of mercury H, with which the latter tube is connected.

30. The air within the tube K, by its pressure on the surface of the mercury in the basin, will keep that portion of the same fluid in the tube I raised to a height exactly proportioned to the density of the included air, which must be the same with that in the receiver, in consequence of the communication by the tube G; and thus the height at which the mercury stands in the small tube I will serve as a gauge or measure of the elasticity and weight of the included air, being always in the inverse ratio of the rarefaction which has taken place.

31. It may be proper to add that the edge of the receiver must be ground perfectly smooth and level throughout its circumference that it may fit closely to the brass plate of the air-pump on which it rests; and that it may prevent the entrance of the air more effectually, it must be smeared with grease, or, as is more usual, set on a collar of oiled leather, and thus the junction of the receiver with the surface below it will be rendered impervious to the air.

What is the purpose of the mercurial apparatus connected with the air-pump?

What closes the lower valve of the pump on the descent of the piston within the barrel?

What ratio is preserved between the height of mercury in the gauge and the degree of rarefaction in the receiver?

What practical precautions are usually necessary to preserve the rarefaction obtained by the action of the air-pump?

32. A multitude of experiments, serving to demonstrate the elasticity as well as the weight of air, may be satisfactorily performed by means of this machine, which was originally invented by Otho Guericke, a German philosopher, in the latter part of the seventeenth century, and having been rendered more effective by the skill and science of Boyle and Hooke, it subsequently underwent numerous improvements, some of the most important of which we owe to the ingenuity of Smeaton, the celebrated engineer, of Dr. Prince of Salem, in Massachusetts, and Dr. Hare of Philadelphia.* But the principle and general plan of this philosophical instrument, under the various forms in which it has been constructed, correspond with the descriptive statement already laid before the reader.

33. The elastic force of atmospheric air may be rendered obvious by placing under the receiver of an air-pump a bladder, which has been about half filled with air and firmly tied at the neck so as to prevent it from escaping; for on exhausting the receiver gradually, the bladder will be seen to swell, from the expansion of the air within it; and if the exhaustion be continued long enough, the bladder will burst, from the elastic force of the air it contained, no longer counterbalanced by pressure on the external surface.

34. A square or flat glass phial, filled with air, well corked and fastened with wire, if placed under the receiver, will crack from the expansion of the air within it, as soon as the pressure is withdrawn from its surface by the exhaustion of the receiver. A phial of the usual shape would resist force applied internally or externally, much better than one with flat sides, in consequence of its arched figure; hence the globular or hemispherical shape of the receiver, renders it best adapted for its purpose.

35. Shrivelled apples, prunes, or raisins, with their skins unbroken, when placed under a receiver, on the air being exhausted, will become plump from the elasticity of the air included in those fruits; and thus a bunch of dried raisins may be made to assume the appearance of a fine cluster of grapes, and a similar apparent renovation may be effected on the apples and prunes; but on readmitting the air into the receiver the fruits would all resume the wrinkles which betray their age.

36. If a large glass globe with an open mouth have a piece of

By whom and at what period was the air-pump invented?

Who have contributed towards its improvement?

How is the elasticity of the air proved by the experiment of the flaccid bladder?

What will occur when a thin flat or square phial is placed under a receiver, and the air exhausted while the phial remains corked?

How may shrivelled fruit be temporarily restored to a plump appearance?

Explain the experiment of the *glass globe and bladder*.

---

* See Journal of the Franklin Institute, vol. xii. p. 303.

bladder tied over it, so securely that the air within it cannot escape while the bladder remains whole, and it be set under a receiver, while the air is being withdrawn from it, that within the globe will expand by its elastic force, and raise the bladder to a convex shape, distending it more and more as the exhaustion increases, till at length the bladder will be ruptured, and the air in the globe will expand itself through the receiver.

37. Let a small syringe, having a weight fastened to the handle of the piston be closed with a cork at the end, tied down with a piece of bladder, so that on pulling up the piston the air could not enter; then let it be suspended in an inverted position with the weight downward, under the receiver of an air-pump; upon extracting part of the air from the receiver, the weight at the handle will draw down the piston, and on readmitting the air the piston will rise again. In this case the partial exhaustion of the receiver lessens the elasticity of the included air so considerably that it is unable to support the weight; and on letting in the air again, it will recover its elastic force and raise the piston with the attached weight, in the same manner as it would be raised by the pressure of the external air.

38. A very amusing exhibition of the effect produced by the elasticity of the air may be made by means of the apparatus represented in the margin. Hollow glass figures, about an inch and a half in length, resembling men or women, must be procured, each having a hole in one foot, and the glass must be of such thickness that the figures will float near the surface of water when they are filled with common air. They are then to be immersed in a tall glass jar nearly filled with water, and covered on the top with a strong bladder, fastened air-tight. If the bladder now be pressed inwards with the finger, the water being almost *incompressible*, and the air quite the reverse, that contained in the little images will yield to the compressing force, and becoming contracted, water will enter, and the images thus becoming specifically heavier than they were at first will descend towards the bottom of the jar; on the pressure above being removed, the air in each image recovering its elastic force, will expel the water, and the images will rise as before. By forcing a little water into one or two of the figures before they are placed in the jar, they may easily be made to float at different heights; and thus their motions may be greatly varied, by regulating the pressure on the bladder. These diminutive images have been

How may the *syringe and weight* be made to exhibit the alternate expansion and contraction of air?

Describe the pneumatic toy called the bottle of imps.

In what manner may the *imps* be made to rise from the bottom of water, and how is the experiment to be explained?

whimsically called bottle-imps; and their agility must appear wonderful enough to those who are ignorant of the cause of it.*

39. The elasticity of the air may be further illustrated by placing an open jar containing a single glass figure, and filled with water, under the receiver of an air-pump, only the figure must be just heavy enough to sink to the bottom of the jar under the usual pressure of the atmosphere. Then on exhausting the receiver, and thus diminishing the elasticity and consequent pressure of the included air, the density of the water remaining the same, the figure will gradually rise, as the air becomes more rarified, till it reaches the surface of the water, where it will float, till the air is again admitted into the receiver, on which it will descend to the bottom of the jar.

40. Abundant proof of the compressibility and elasticity of the air may be drawn from the consideration of the mode of action of the common domestic utensil, a pair of bellows. This will at once appear on attending to the effect of the valve or leathern flap. This valve rises when the boards are separated, and the air enters through the hole in the lower board, which on pressing together the boards again becomes closed by the falling of the valve, and the air having no other vent, makes its exit through the pipe in a dense current.

41. The double bellows, used by blacksmiths and other artisans, differs from the machine just described in having an intermediate board, which is fixed, while the others are moveable, so that it consists of two air-chambers instead of one; and a hole in the middle board, with a valve, suffers the air which has been drawn into the lower chamber through the hole below to pass into the upper chamber, where it becomes condensed by the pressure of a weight fixed to the upper board, and is discharged in a continued stream through a pipe connected with the upper chamber. The lower board is moveable, and when it sinks by its own weight, the valve opens, and shutting again when the board is raised by means of a lever or some other contrivance, the air is prevented from escaping by the valve-hole, and is therefore forced into the upper chamber.

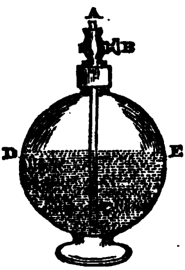
42. A kind of bellows or blowing machine, constructed entirely of wood, was invented at Bamberg in Bohemia about 1620, and was thence called the Bamberg bellows. It consists of two boxes, in the form of cylindrical sectors; one fitting into the other so as not to prevent it from being moved up and down, but without suf-

How is the common hand bellows constructed?
How is a constant stream of air maintained by the double bellows?
Of what does the Bamberg bellows consist?

* French writers on natural philosophy usually exhibit a single figure in describing the counterpart of this experiment. To this little enamelled figure, *petite figure d'email*, they give the name of *Ludion*.—V. Sigaud de la Fond Elem. de Phys., vol. iii. p. 162. Beudant Traite Elem. de Phys., p. 306.

fering the air to escape between the sides of the boxes. It is needless to describe it more fully, as the manner in which it acts may be easily conceived from what has been stated above. Various modifications of this machine have been adopted in establishments for smelting metals, and other purposes connected with the arts and manufactures.

43. The effect of air acting by its elastic force on the surface of water may be variously exhibited in the formation of *jets d'eau*, or spouting fountains. Let a strong decanter be filled to about half its height with water, and a glass tube of small bore be passed into it nearly to the bottom, and fixed air-tight, going through a hole drilled in a cork, with a piece of bladder tied over it and round the tube. This bottle is then to be placed under a tall receiver, on the plate of an air-pump; and on the receiver being exhausted, the air within the bottle will expand, and pressing on the surface of the water, cause it to issue from the top of the tube in a jet, the height of which will be proportioned to the degree of rarefaction of the air under the receiver.



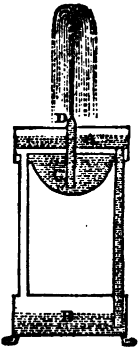
44. Compressed air may be made to produce a similar effect, which may be thus displayed: a strong bottle somewhat more than half filled with water, as represented in the marginal figure, by the line D E, must have a tube A C fitting into its neck, and capable of being opened or closed at pleasure, by turning the stop-cock B. A condensing syringe* being adapted to the tube at A, and the stop-cock opened, air is to be forced into the bottle, which rising through the water, will by its density press strongly on the surface of that liquid; then after turning the stop-cock the syringe is to be removed, and a small jet-pipe being fitted to the tube A, the stop-cock is to be opened, and the elasticity of the condensed air in the bottle will drive up the liquid in a jet, the height of which will gradually diminish, as the included air, by its expansion, approaches nearer and nearer to the density of the external air.

45. A small phial, with a well fitted cork, having a little tube or a stem of a tobacco-pipe passed through it, and reaching nearly to the bottom of the phial, partly filled with water, will, on blowing strongly into the bottle through the pipe, exhibit effects precisely analogous to those of the apparatus just described.

46. The machine called Hero's Fountain, resembles in principle those noticed above, differing from them only in the manner in which the compression and consequently increased elasticity of the air is produced. This is effected by means of a column

Explain the construction of the fountain in vacuo.
How is the force of air applied in the *compressed air fountain*?
In what respect does Hero's fountain differ from the preceding?

* See above, No. 26.



of water, as will appear from inspection of the annexed figure, representing one of the numerous forms in which such spouting fountains have been constructed. It consists of an open vessel A, from which a tube passes downward to the vessel B, from the opposite side of which another tube forms a communication with a close cavity over the basin C, having a jet-pipe extended almost to the bottom, and open above to the air. Water having been introduced into the basin C, more water is to be poured into the vessel A, till it runs down the tube, and fills the lower part of the vessel B, and compressing the air in it, and in the other tube and cavity above it, the water in the basin C, will, by the elastic force of the condensed air, be driven in a jet from the aperture at D; and by adding water to that in the vessel A, the enclosed air may be so compressed as to expel nearly all the water from the basin C. The principle on which Hero's Fountain acts has been heretofore adopted in Germany, in forming machines to raise water from mines; but they have been laid aside since the progress of science has led to the construction of far more powerful and efficient engines adapted to the same purpose.

47. A familiar example of the elastic pressure of the air occurs in the frothing of bottled ale, porter, cider, and the sparkling or creaming of champaigne wine, when uncorked and poured into an open vessel; the air which those liquors contain, on being released from its confinement in the bottle, escaping in numerous bubbles covering the surface of the liquor. Ginger beer contains a quantity of air or gas, formed by a chemical process, and such is its elastic force, that if the ginger beer has been properly prepared, the included air will drive out the cork with a loud report, as soon as the string with which it is tied down is cut through. Hence also the bursting of bottles filled with cider, perry, and other liquors considerably impregnated with air, when well corked and secured with wire.

48. What is called soda water is manufactured by compressing carbonic acid into water by mechanical means; and it therefore can scarcely be preserved except in strong bottles of a peculiar form, from which it spouts with violence through the elasticity of the condensed gas, as soon as the cork is removed. Air readily combines with water, though not to any great extent, under the usual pressure of the atmosphere. This will be evident on placing a glass of water under the receiver of an air-pump; for on exhausting the receiver the air will issue in a multitude of small bubbles from the surface of the water.

To what purposes has this fountain been applied in mining operations?
In what familiar operations is the elastic force of gaseous matter escaping from a liquid made conspicuous?
What is the nature of the preparation called *soda water*?

49. It has been already stated that a perfect vacuum cannot be obtained, even by means of an air-pump of the best construction. The impossibility of completely exhausting the receiver of an air-pump; so far as it is not owing to the imperfection of the machinery, depends on the identical property of the aërial fluid which causes the air-pump to act: for the elasticity of air is always in the direct ratio of its density; so that when half the air is extracted from any vessel, the remaining half will expand to fill the whole space, its density and elasticity being diminished in the same proportion. Thus if half the air could be exhausted from a receiver by the first stroke of the piston, and one-half of what was left by the next stroke, the quantity removed by every subsequent stroke must manifestly be but one-half of that removed by the stroke immediately preceding it: in fact, there must always be a remainder, however trifling it must at length become. It will be evident that though an indefinitely small quantity of air must thus remain after working an air-pump for any imaginable period of time, yet that quantity would soon become so extremely inconsiderable as to have nearly the effect of a complete vacuum.

50. Suppose the proportion of capacity between the barrel of an air-pump and the receiver to be such, that one-fourth part of the air would pass from the latter into the barrel at each stroke of its piston, then the quantity remaining in the receiver after the fifth stroke would be less than one-fourth of the original quantity; and as the decrease would go on in a geometrical progression, thirty strokes of the piston would leave in the receiver only 1-3096 of the quantity it contained at first. Hence it will appear that if the receiver be not less than the barrel, the smaller the difference between the size of the receiver and that of the barrel, the more rapidly must the rarefaction of the included air take place; and though with a small receiver the air may be highly rarefied in a short time, it cannot be entirely withdrawn.

51. It must also be observed that the extent to which the rarefaction can be effected will be limited by the operation of the rarefied air on the valves at the bottom of the barrels; for as the elasticity of the air remaining in the receiver is the cause of the opening of those valves, they will at length cease to act, when the exhaustion has been carried so far that the expanded air has not elastic force enough to overcome the very small degree of resistance caused by the weight and friction of the valves.

52. Another obstacle to the rarefaction beyond a certain limit will arise from the resistance to the opening of the piston-valves

Why cannot a perfect vacuum be obtained by means of the air-pump?

What would be the rate of exhaustion if the barrel had one half of the capacity of the receiver?

State some other relation between the bulks of the cylinder and receiver, and compute the degree of exhaustion after a certain number of operations.

What influence has the nature of the lower valve on the extent of rarefaction?

When must the rarefaction necessarily cease?

during the descending stroke, owing to the want of sufficient elasticity in the highly rarefied air to overcome the pressure of the atmosphere on those valves. Various improvements have been made in the construction of air-pumps, which have considerably lessened the imperfections in these machines now stated,* and though from the essential properties of air the formation of an absolute vacuum in the manner described must be impracticable, yet the ingenuity of modern artists has enabled us to produce within a receiver any degree of exhaustion requisite for the most delicate and interesting experiments.

Weight of the Air.

53. The phenomena depending on the influence of gravitation on air, and its consequent gravity or weight, are of equal importance with those arising from its elasticity; and the subject therefore demands a more extended investigation than has been already afforded to it.

54. Direct evidence of the weight or ponderosity of air may be easily obtained by means of an air-pump. For by ascertaining the weight of a bottle of known capacity before and after it has been exhausted of the air contained in it, the loss of weight after exhaustion would show the gravitating force of the air which had been extracted from it, and if the experiment be accurately performed it would appear that a cubic foot of air would weigh 523 grains. The same quantity by measure of water would weigh 1000 ounces avoirdupois; hence it must follow that water has about 840 times the weight of air, bulk for bulk; and this result corresponds sufficiently with the estimate of the specific gravity of atmospheric air compared with that of water, as stated in the table of specific gravities, in the treatise on Hydrostatics.†

55. As air then has a determinate weight like all other ponderable kinds of matter, it must produce pressure in the same manner as other heavy bodies, and that in proportion to its mass and specific gravity. The weight of 1000 cubic inches of atmospheric air must, from what is stated above, be greater than that of a single cubic inch of water, and consequently if the pressure of such a mass of air could be made to act on a small surface, it would produce a greater effect than the pressure of a cubic inch of

What other obstacle to rarefaction exists in the construction of the air-pump?

In what manner may the air-pump be employed to ascertain the weight of the air?

By what number of times does the weight of water exceed that of air?

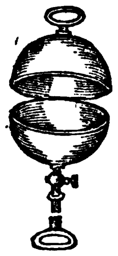
---

* Such is the object of Dr. Prince's improvement, who makes use of a subsidiary piston to take off the pressure above the main pistons, after the exhaustion is nearly completed.—Ed.

† See *Hydrostatics*, No. 88.

water. Now the most direct mode of causing the pressure of a given bulk of air to act by its gravity on a surface of a certain extent would be, by forming a cylindrical or square column of air, the base of which should be exactly of the extent required. This could not be conveniently effected by artificial means, except in columns the height of which was but inconsiderable; but in the atmosphere around us nature presents a mass of air of great altitude, the vertical pressure of which on any given space may be ascertained by direct experiment.

56. A receiver, or any other air-tight vessel, placed on the plate of an air-pump, would become fixed to it by the exhaustion of the included air, in consequence of the atmospheric pressure on its surface. Some idea of the amount of this compressing force may be obtained by placing the palm of the hand over the top of a glass cylinder open at both ends, the lower opening resting on the plate of an air-pump, and the upper opening being covered by the hand so closely as to prevent the air from entering in that direction, the cylinder being partially exhausted the weight of the atmosphere pressing on the back of the hand would not only be sensibly felt, but would also be found to be so considerable before complete exhaustion had been effected, as soon to occasion pain and inconvenience. Reckoning the weight of the atmosphere upon every square inch of surface, to be fifteen pounds, the pressure on the hand placed over an exhausted receiver, the top of which it would just cover, would be equal to about sixty pounds.



57. A more exact estimate of the weight of the atmosphere may be formed by attending to the result of an experiment to show its effect on the surface of two hollow hemispheres, from which the air has been extracted by means of an air-pump or exhausting syringe. These hemispheres, constructed of brass, should be furnished with handles, or hooks, by means of which they may be suspended; one of which may be fixed, but the other should be removable. In the tubular neck to which this handle is screwed is a stop-cock, which being opened, and the handle removed, the hemisphere is to be screwed on the pump-plate, or on to an exhausting syringe; and the other hemisphere having been fitted to it, a vacuum is to be formed in the interior by working the pump. The stop-cock must then be turned so as to prevent the re-entrance of air, and on unscrewing the brass globe, and refixing the handle, it will be found that the hemispheres composing it are firmly united by the pressure of the external air. Suppose the diameter of the globe to

How might we conceive the pressure of a given bulk of air acting by its weight alone to be exercised?

With what illustration of this subject does nature furnish us?

What causes the adhesion of an exhausted receiver to the plate of an air-pump?

How is the correctness of this explanation made apparent?

be 6 inches, the surface of a section through the centre would be about 28 inches square; and hence the pressure of the air upon one square inch being known, the force requisite to separate the hemispheres, supposing the exhaustion to be nearly complete, might easily be computed.

58. This is usually termed the Magdeburg experiment, it having been originally contrived by Otho Guericke, of Magdeburg the inventor of the air-pump; and it appears to have led him to that important discovery. For the manner in which he originally conducted the experiment was by filling the space included between the hemispheres, when pressed together, with water to expel the air, and then pumping out the water, while the air was prevented from re-entering by turning a stop-cock. Having thus ascertained the fact of the existence of atmospheric pressure to a great degree, he proceeded to the invention of the air-pump, by means of which the exhaustion of the joined hemispheres could be much more readily and conveniently effected than by the operose process he had at first adopted. This ingenious philosopher operated with two copper hemispheres, nearly a Magdeburg ell* in diameter; and the amount of pressure on such an extent of surface was so great, that when the interior cavity had been exhausted, the separation of the hemispheres could not be effected by the strength of twenty-four horses, twelve being harnessed together on each side, and dragging in opposite directions.

59. That the weight of the atmosphere is always proportioned to the vertical height of the column of air pressing on any extent of surface, may be demonstrated by means of a glass tube bent as represented in the margin, and open at both ends. The diameter of the tube being the same throughout, if mercury be poured into it, it will rise to the same height, D C, in either part of the tube. Then let the extremity, A, be closed by placing over it a piece of moistened bladder, firmly secured by melted resin or sealingwax; and the mercury pressed on by the air above it, of the common density of the atmosphere, would always remain at the same height, D; but the column of mercury in the other part of the tube having its surface exposed, would rise or sink with the variation in density of the atmosphere. Thus if such a tube were carried to the top of any high tower or mountain, the column of air would be shortened by a space equal to the height of the situation and the mercury, in some degree re-

Describe the manner of proving the pressure of air acting by its weight on the Magdeburg hemispheres.

How did Guericke at first produce the vacuum in his hemispheres?

What account is given of the size and efficacy of his apparatus?

In what manner can we prove what pressure the air exercises on the exterior surfaces of bodies?

---

* See Winkler's Elements of Nat. Philosophy, Eng. Tr., 1757, vol. i. p. 131.

lieved from pressure, would rise in the space C B. On the contrary, if the tube could be removed into a deep mine, the mercury on the open side would sink below C, being pressed by a loftier column of air than when at the surface, where the height of the mercury was first noted.

60. Such an instrument as that just described would be a species of barometer,* since it would indicate the varying weight of the atmosphere. But the instrument to which the appellation of barometer has been given is differently constructed, and better adapted to afford a correct estimate of the amount of atmospheric pressure at different times, or under varying circumstances.

61. The invention of this valuable instrument appears to be justly attributed to Torricelli, professor of mathematics at Florence, in the earlier part of the seventeenth century. He was the pupil of the celebrated Galileo, who seems to have been the first among modern philosophers who had any idea that air possessed the property of weight; though he was not aware of the mode of its operation in producing atmospheric pressure, and the numerous phenomena constantly resulting from it.

62. It had been accidentally observed that in raising water by means of a pump, the height to which it could be drawn in what is called the suction-pipe never much exceeded 33 feet; since when the piston of a pump was elevated more than about that height above the surface of the water in the pump-well, the liquid no longer followed the piston. The drawing up of the piston of course forms a vacuum in the pipe below it, and the consequent rising of the water into the void space was accounted for, or rather attempted to be explained, by the philosophers of the sixteenth century, by the hypothetical principle that "Nature abhors a vacuum," and therefore causes the water to ascend in order to prevent the vacuum from taking place.

63. The dogma of Nature's abhorrence of a vacuum is a complete absurdity; and the phrase was invented, like many others, some of which are still current, to conceal the ignorance of those who pretended to universal knowledge. It was, however, generally adopted at the period just mentioned; and till it was discovered that, when a vacuum was actually formed in the suction-pipe of a pump, water would not rise to fill it much above 33 feet, no one seems to have thought of questioning the propriety of the current opinion on the subject.

What is the nature and purpose of the barometer?
Who was the inventor of that instrument?
Who first conceived the idea that air possesses weight?
By what expression did ancient philosophers explain the rising of water in a common pump?
In what light are we to view this expression?

---

* This term signifies a measure of weight, from the Greek Βαρος, a weight, and Μετρον, a measure. The instrument described in the text would bear a nearer relation to Adie's sympiezometer than to the common barometer.—Ed.

64. Some engineers at Florence finding themselves foiled in an attempt to raise water by a pump from a well of greater depth than usual, applied to Galileo for advice as to the means of raising water to a greater height than 33 feet, or at least for an explanation of the cause of a phenomenon which they could not reconcile with the generally received hypothesis concerning the ascent of water in the suction-pipe of a pump. Galileo is said to have told the inquirers that "Nature's abhorrence of a vacuum did not extend to distances greater than 33 feet, and therefore that at that point her efforts ceased." It has been questioned whether the philosopher really expressed himself in this manner, though the story has often been repeated; and it may at all events be concluded that if he gave such an answer to those who applied to him, he could hardly have considered it as a satisfactory solution of the difficulty which had been started. Accordingly in his writings he attempts to account for the phenomenon on other principles, but the real cause of it seems to have eluded his penetration.

65. Probably the discussions to which this circumstance gave rise suggested to Torricelli the idea that the ascent of water in the suction-pipe of a pump was caused solely by the pressure of the atmosphere on the water in the well, and that as the weight of the atmosphere at the earth's surface could never vary to any great extent, it therefore never greatly exceeded what would be sufficient to raise a column of water in a vacuum to the height of 33 feet. The happy thought occurred to him of verifying his conjecture by making an experiment with a fluid much heavier than water, as he perceived that if the ascent of water depended on atmospheric pressure, the same pressure on the heavier fluid would raise a column of it to a proportionally inferior height. With this view he fixed on mercury, as the heaviest fluid known, at common temperatures; and having procured a glass tube, open at one end, he filled it with mercury, the specific gravity of which compared with that of water was as 13½ to 1; then immersing the open end of the tube in a small jar of mercury, and suffering a communication to take place between the mercury in the tube and that in the jar, he observed that the fluid sunk till it stood in the tube just 30 inches above the level of that in the jar below. This experiment was so far completely satisfactory; for as 13½ : 1 : : 33 feet : 2½ feet = 30 inches; thus the weight of the atmosphere pressing on any given surface was found to be equal to that of a column of water of the same extent at the base and 33 feet in height, or of a similar column of mercury only 30 inches in height.

What is said to have been the reply of Galileo to inquiries on this subject?

Did that philosopher understand the true cause of the rise of fluids into an exhausted tube?

To whom do we owe the true explanation of this subject?

In what manner did Torricelli demonstrate the correctness of his views in regard to the pressure of the air?

66. The barometer now in general use as a weather-glass is nothing more than a tube of proper length filled with mercury, and either dipped at the open end in a small cup of the same fluid, or else having the open end curved upwards, so that the mercury may be exposed to the pressure of the atmosphere: a scale of inches also is adapted to the upper part of the tube, extending from 27 to 32 inches, that it may appear by inspection at what height the mercury stands under the pressure of the atmosphere at any particular time. This useful instrument was at first called the Torricellian tube, from the name of the discoverer of the principle on which its action depends; but it subsequently received the designation of a barometer, now universally adopted.

67. After the effect of atmospheric weight and consequent pressure had been ascertained by the decisive experiments of Torricelli, the subject was further investigated in France, chiefly by the distinguished philosopher Pascal, and by Father Mersenne, in 1647. The former reflecting on the effects of atmospheric pressure, it occurred to him that the weight of the column of air, depending on its vertical height, must be greatest in low situations, and decrease in ascending an eminence. To try this principle by the test of experiment, he requested a friend who resided in Auvergne, to ascertain the relative heights of a barometrical column at the bottom, and afterwards at the top of the Puy de Dome, a high mountain, situated in that province of France. The effect took place as Pascal had anticipated; and he himself subsequently made corresponding observations on a barometer, removed from the level of the street in Paris to the summit of a lofty church-tower.

68. As a philosophical instrument, the barometer is highly useful, not only for the purpose of ascertaining the daily and hourly variations which are taking place in the atmosphere in any given situation, arising from causes connected with the science of meteorology, and for other purposes of a similar nature; but likewise as affording means for accurately estimating the heights of mountains, or in fact of any places whatever above the level of the sea. For either of these purposes, however, it is necessary that a barometer should be very carefully and accurately constructed; and in making observations by means of it, especially in the measurement of heights, various precautions are required, and the effect of temperature in particular must be taken into the account in making any calculations.

69. It must hence be obvious, that as a weather glass, the utility of such instruments as are commonly used must be extremely

Describe the manner of constructing the barometer.
By what name was this instrument formerly known?
What application of the barometer was made by Pascal?
In what manner was his principle verified?
To what particular purposes is the barometer applied in meteorology?
What particularly requires attention in the measurement of heights by the barometer?

limited; for as the height of the mercury at any time must depend partly on the elevation of the place of observation above the level of the sea, no correct judgment can be formed relative to the density of the atmosphere, as affecting the state of the weather without reference to the situation of the instrument at the time of making the observation; and a series of observations at any given place would be required in order to enable a person to form a probable opinion of the change of weather to be expected after the rising or falling of the mercury.

70. One source of imperfection in the instrument, which renders it difficult to determine the extent of those slight variations in the height of the mercurial column which are yet interesting to the meteorological observer, has led to some peculiarities of construction, by means of which the scale of observation might be enlarged, and minute changes in the height of the mercury be rendered obvious. One method of effecting this purpose is by means of what is called a wheel barometer, the external appearance of which few persons can be unacquainted with, as such instruments are generally preferred for domestic use.

70. The construction of the wheel-barometer may be thus described, with reference to the figure in the margin. It consists of a tube, A B C, hermetically sealed at A, and open at C; and of such a length that the distance from C to A may be about 32 inches. The tube must be entirely filled with mercury, which on placing it in a vertical position will subside in the part A B, till the difference of the levels E and F will be equal to the height of a column of mercury which will balance the weight of the atmosphere, so that any change of pressure will have an equal effect on the mercury at E and F, and thus through whatever space the fluid may rise at E, it will be depressed to the same extent at F. Upon the surface of the mercury at F floats a small ball of iron, suspended by a strong thread over a pulley P, and to the other end of the thread is attached the weight W, not so heavy as the floating ball. The axis of the pulley passes through the centre of a large graduated circle G, and carries an index H, which revolves as the pulley turns round. The weight W being just heavy enough to counterbalance the iron ball and overcome the friction of the pulley, the iron ball rises and falls freely, as the surface of the mercury on which it floats is elevated or depressed by the weight of the air. Now if the circumference of the wheel P be 2 inches, then one entire revolution will corre-

Why is the barometer, as commonly constructed, ill adapted to the purposes of indicating the state of weather?

How has it been found practicable to enlarge the scale of barometric variations, so as to read slight differences?

Give a description of the wheel-barometer.

What is the purpose of the weight suspended on the exterior end of the cord?

spond to an alteration of level amounting to 2 inches at F, and therefore to an alteration of 4 inches in the height of the barometric column. And as the graduated circle may conveniently be 40 inches in circumference, 10 inches of that circle will correspond to 1 inch of the column, and 1 inch of the circle to 1-10 of an inch of the column; so that variations, amounting to much less than the tenth of an inch will be distinctly perceptible.

72. As already stated, the utility of the barometer as a weather-glass must depend on certain circumstances, with reference to the situation of the observer; and not the least attention ought to be paid to the words "rain," "fair," "changeable," &c., frequently engraved on the plate of a barometer, as they will be found to afford no certain indications of the correspondence between the heights marked and the state of the weather.

73. General rules for calculating changes in the weather from the barometer can seldom be adapted to all situations; and therefore those who may be desirous of obtaining the means for forming a correct judgment, as to subsequent alterations in the state of the atmosphere, from the indications of the degree of atmospheric pressure at any time afforded by the barometer, must devote much attention to the subject; without which, written rules would only mislead the observer, and long application to the practical study of the instrument would render rules unnecessary. One circumstance, however, may be worth mentioning, which is, that changes of weather are indicated not so much by the actual height of the barometrical column, as by its variation of height, and the manner in which that variation takes place.

74. Among the methods which have been adopted to obtain the most accurate estimates of the effect of atmospheric pressure may be noticed the compound barometer, in which water is added to the mercury in the tube, and the mean height of the barometrical column being thus augmented, the variations which arise from the varying weight of the air will be more considerable than in a common barometer, and therefore may be more distinctly observed. Such instruments, however, are liable to certain defects and disadvantages, which render them inferior upon the whole to those of the usual construction.

75. A barometrical column, composed of water alone, from its extreme sensibility to changes of atmospheric pressure, must afford much greater facility for noticing the more minute alterations which are found to be constantly occurring than the mercurial barometer. But a water barometer must necessarily be a most unwieldy machine, and consequently could be adopted in but few situations, even where the expense and inconvenience attending its construction might be of little importance.

What reliance is to be placed on the prognostics of weather sometimes found on the scales of barometers?

What circumstance, in regard to changes of weather, deserves particular attention? What advantage is possessed by the column composed of water and mercury?

76. M. Pascal, whose philosophical researches have been already noticed, made some interesting experiments at Rouen, in Normandy, in which he, by means of glass tubes, 40 feet in length, ascertained the effect of the pressure of the atmosphere on water, and also on wine; and he found that when mercury stood in the common barometer at the height of 2 French feet 3½ inches, water was raised in one of his tubes to the height of about 31 1-9 feet, and wine to that of 31⅗. Thus, though the difference of specific gravity in these two liquids must have been but inconsiderable, yet it occasioned a sensible difference in the manner in which they were affected by atmospheric pressure. The experiment on water was repeated by Roger Cotes, professor of philosophy at Cambridge, England, in the beginning of the last century; but in both cases the object was merely that of a temporary exhibition for the purpose of distinctly demonstrating the operation of aërial gravity and pressure.

77. A permanent water-barometer, however, has been erected by order of the Royal Society of London, in the hall of entrance to their apartments, the tube extending upwards in the well of a winding staircase. It consists of a glass tube 40 feet in length, and 1 inch in diameter at the lower end, nearly cylindrical throughout, being only a little narrower at the upper extremity than it is below. This instrument is well adapted to show the various periodical alterations, or as they have been termed, oscillations of the atmospherical column, and some observations, with tables formed from them, have already been laid before the Royal Society, by Mr. Daniell. It has been noticed, that the rise and fall of the column of water in this barometer precedes, by one hour, the corresponding changes in a mercurial barometer; and it is stated that in windy weather the water is in perpetual motion, its fluctuations in the tube having been compared to the breathing of an animal.*

78. It has been already observed, that the elasticity of the air is always in the direct ratio of its density; or in other words, that the greater the density of any portion of air, the greater will be the degree of elastic force which it is capable of exerting. The best modern air-pumps are so constructed as to serve for the condensation as well as the rarefaction of air; but for the former purpose, a condensing syringe may likewise be employed; and either method may be adopted in making experiments on the elasticity of compressed air.

79. Among the most interesting applications of the force of air

What relation did Pascal find between the heights of columns of wine and of water equivalent to the weight of the atmosphere?

In what peculiar manner is the water barometer found to be affected?

What advantage does it possess over the *mercurial barometer*, in regard to the indication of diurnal fluctuations?

In what ways may the artificial condensation of air be effected?

* Arcana of Science, 1833, pp. 263, 264.

in a state of high condensation is that of projecting by such means bullets or other missiles from an air gun. It is somewhat remarkable, that this instrument appears to have been in use before the discovery of the air-pump or the barometer; for it is mentioned in a work entitled "Elémens d'Artillerie," written by David Rivaut, who was preceptor to Louis XIII. of France, and he ascribes the invention to Marin of Lisieux, in Normandy, who presented an air-gun to Henry IV. It is also stated, that an air-gun was preserved in the armory of Schmettau, on which was the date 1474. But these instruments were far inferior to modern air-guns, from which they must have differed considerably in the mode of construction.

80. The air-gun, like the common gun or musket, consists partly of a long metal tube adapted to receive a ball, but the breech end of the tube or barrel has an opening to admit condensed air behind the ball, which, acting by its elastic force, propels it with a velocity, proportioned to the degree of condensation of the air. Though the effect is produced in the manner just described in all air guns, yet the mechanism or arrangement by which the admission of the air is regulated varies in different instruments. Some of them are furnished with a syringe for compressing the air, included within the butt of the gun, and there is an exterior tube surrounding the barrel, so that the air is forced into the space between the tubes, and the ball having been introduced into the barrel which it fits closely, a valve is opened by pressing on a knob or trigger, and the air rushes from the cavity formed by the outer tube into the chamber behind the ball, which it expels from the barrel, continuing to act upon it by its expansive force till the ball has passed from the mouth of the air-gun. Other instruments have but one tube, for the reception of the ball; and the air is compressed by a condensing syringe into a strong brass or copper globe, which when filled, can be detached from the syringe, and screwed to the butt of the gun, and by a contrivance similar to that already described, a bullet can be discharged, by drawing a trigger. The butt may be made to hold a magazine of balls, which can be admitted one at a time into the chamber, and a portion of the condensed air escaping on opening the valve, several balls may be projected from the air-gun in succession, but in this case, as each discharge will diminish the density and elasticity of the remaining air, the velocity and effective force of the balls will also progressively decrease.

81. From what has been stated relative to the density and elasticity of air, it will follow, that all bodies on the surface of the

What are some of the important applications of condensation?
What are the essential parts of the air-gun?
To what is the velocity of the ball proportioned?
What two different arrangements of parts are occasionally applied for retaining the condensed air?
Can this instrument propel, with equal velocities, several balls in succession, without renewing the charge of air?

earth, sustain a pressure from the superincumbent atmosphere equal to the weight of a column of water, about 34 feet in height, with a base corresponding in extent to that of the body or bodies pressed upon. This pressure may be estimated at from 14 to 15 pounds on every square inch of surface, being the weight of a column of mercury 30 inches high, and 1 inch square at the base.

82. Hence it must be evident that every human being constantly has pressing on the body in every direction a weight equal to 15 times as many pounds as there are square inches on the surface of that body. Suppose then the surface of a man's body to measure 2000 square inches, the force of the atmosphere pressing on that surface would be equal to 30,000 pounds. It may appear unaccountable that so vast a pressure should be perpetually in operation, without our being sensible of the weight or experiencing any inconvenience from it. This however is owing to the uniform manner in which the force acts in all directions, so that the body is supported by the pressure on one side against the equal pressure on that which is opposite; and it is only when the equilibrium is destroyed by removing the force in one direction, that its effects become perceptible, as is shown by an experiment previously described, in which the hand is exposed to atmospheric pressure by placing it over a partially exhausted receiver. All the cavities of the body also are either filled with air or with denser fluids, so that they resist compression from the external air as perfectly as the firmest solids.

83. Some idea of the weight of the whole atmosphere, encompassing the earth on every side, may be formed from a calculation which has been made to determine what must be the diameter of a sphere of lead, the weight of which would be equal to that of the entire atmosphere; and from which it appears that the sphere must have a diameter nearly 60 miles in length; which would correspond in weight with a mass of water sufficient to cover the whole surface of the earth to the height of 34 feet.

84. It is an interesting matter of speculation to what height the atmosphere extends from the surface of the earth. If the density of the atmospheric column were uniform, its vertical height might be readily calculated; for as water is nearly 850 times heavier than air of the common density, and a column of water 34 feet high is equivalent to an atmospherical column having a base of the same extent, it is evident that the height of such a column of air of uniform density must be 850 times 34 feet, or $850 \times 34 = 28,900$

What amount of atmospheric pressure is sustained by all bodies on the surface of the earth?

What pressure is applied to the body of a person of ordinary size?

How is the body enabled to sustain this pressure without inconvenience?

What would be the diameter of a sphere of lead equal in weight to the whole atmosphere of our globe?

To how thick a stratum of water over the whole globe would this be equivalent?

How may we calculate the height of an atmosphere of uniform density. equal in weight to that of the earth?

=5 miles 833 yards and 1 foot, or nearly 5½ miles. But the density of the air varies at different distances from the surface of the earth, in consequence of its elasticity.

85. Air may be conceived to consist of innumerable strata or layers, forming a concentric shell, surrounding the solid globe we inhabit; and the lowest stratum being compressed by the whole weight of the superincumbent mass, must necessarily be more dense than the next above it, and the density decreasing in proportion to the increase of height or distance from the earth's surface, no definite limit can be assigned to the extent of the atmosphere.

86. Cotes, in his Hydrostatical Lectures, has stated the relative density of the atmosphere at different heights, as deduced from a comparison of the specific gravity of air at the common level of the earth's surface with that of air at a certain elevation as ascertained by means of the barometer. Thus the rarity of the air being four times greater at the altitude of seven miles than at the surface, and the rarity of the air augmenting in a geometrical progression, while the altitude increases in an arithmetical progression, it will follow that at the height of 14 miles the atmosphere would be 16 times rarer than at the surface, at 21 miles 64 times rarer, at 28 miles 256 times, at 35 miles 1024 times, at 70 miles about a million of times, at 210 miles a million of millions of millions of times, supposing air to be capable of indefinite expansion. Hence, also, at the altitude of 500 miles, if the air could continue to expand at the same rate, a cubic inch of the common density would be dilated through a greater space than a sphere equal in diameter to the orbit of Saturn.* This, however, is a purely hypothetical estimate, for it is founded on the presumed infinite divisibility of matter.

87. The observations of Dr. Wollaston, "On the Finite Extent of the Atmosphere,"† tend to prove that air consists of ultimate indivisible particles; and the expansion of a medium composed of such particles must cease at a certain point where the force of gravity acting downwards, upon a single particle, would be equal to the resistance arising from the elastic or repulsive force of the medium. At such an altitude, therefore, the elasticity of the atmosphere would be completely extinguished, and thus a physi-

How may we conceive the atmosphere to be arranged upon the surface of the globe?

What limit can be assigned to the height of the atmosphere?

State the calculated progressive rarefication of air as dependent on elevation.

On what supposed property of air is this calculation founded?

What views did Dr. Wollaston advance on this subject?

What equality of forces would limit the expansion of air?

---

* See Cotes's Hydrostatical and Pneumatical Lectures. Sec. edit. Cambridge, 1747, p. 124.

† Abstracts of Papers in the Philos. Trans., vol. ii. pp. 160—162.

cal limit might be assigned beyond which it could not possibly extend.

88. In making calculations relative to the density of the air at different heights, or forming rules for the determination of the correspondence between atmospheric altitude and pressure, for practical purposes, such as the measuring of eminences by means of the barometer, several circumstances must be taken into the account. Thus it is not only necessary that the exact height of the mercurial column at different levels should be ascertained, but due regard must also be had to the influence of temperature, the effect of vapour suspended in the air, and the latitude of the eminence whose height is to be determined. The indefatigable spirit of research of modern experimental philosophers and mathematicians has triumphed over these difficulties so far as to have furnished us with general principles and formulæ, by the application of which to the results of carefully conducted experiments, the perpendicular heights of the principal mountains in every part of the world have been discovered.

89. From calculations founded on the barometical formula contrived by the celebrated mathematician, Laplace, and adapted to the estimation of heights, it appears that at the elevation of 52,986 metres, French measure, or 173,795 English feet,* the rarity of the air as equal to the utmost degree of rarefaction which can be obtained in the exhausted receiver of an air-pump. This manifestly connot be the extreme altitude of the atmospheric column, nor is it possible to decide that point with certainty. But it appears from the observations of astronomers on the duration of twilight and the magnitude of the shadow of the earth by which the moon is eclipsed, that the rays of light from the sun are affected by the medium through which they pass at the distance of from 40 to 50 miles from the earth's surface;† and therefore it may be reasonably inferred that the atmosphere extends to the altitude of at least 45 miles above the level of the sea.

90. The pressure of the air arising from the joint effect of elasticity and weight is the cause of a great number of phenomena constantly taking place around us, and immediately depending on the operations of nature or art. It is thus that the effect of the instrument called a sucker, used by schoolboys, is to be explained. It consists of a disk of moistened leather, with a string by which it may be suspended with any weight attached to it

What three circumstances are to be taken into account in measuring heights by barometric observations?

At what height has Laplace calculated that air will have as great a rarity as it is possible to produce by the air-pump?

What height of our atmosphere is deduced from the observations of astronomers on the duration of twilight, and the magnitude of shadows in eclipses of the moon?

---

* A French metre is 39.37 inches English measure, or 3.28 feet.

† See Treatise on *Optics*.

and as its smooth moist surface may be pressed so closely against the flat side of a stone or other body, that the air cannot enter between them, the weight of the atmosphere, pressing on the upper surface of the leather, makes it adhere so strongly that a stone of weight proportioned to the extent of the disk of leather may be raised by lifting the string. If the sucker could act with full effect, a disk an inch square would support the weight of 14 pounds; but the practical effect of the instrument must be variable, even supposing that it was accurately constructed.

91. Whenever surfaces are brought into such close contact that the air cannot insinuate itself between them, they will be pressed together with a force corresponding to the extent of the surface of contact. Hence glass-grinders and polishers of marble find that the substances on which they are operating by friction, when reduced to a state of extreme smoothness, become united by atmosperic pressure so firmly that great exertion is required to separate them, and the circumstance is the cause of considerable inconvenience.

92. The adhesion of snails, periwinkles, limpets, and some other crustaceous animals, to rocks and stones, is effected on the same principle. The surfaces of their shells at the opening are capable of being exactly fitted to any plane surface; these animals have the power of producing a vacuum within their shells when thus fixed, and the atmosphere consequently presses on them with a force proportioned to the extent of exterior surface. It is thus, too, that a common house-fly is enabled to run with great facility up a perpendicular pane of glass, or on the under side of a horizontal plane, as the ceiling of a room. The feet of the insect are provided with cavities, the sides of which being adapted to the surface of glass, &c., by some internal mechanism the cavities are exhausted, and the pressure of the atmosphere on the minute surface of the feet supports the insect against the power of gravitation. That such small animals may be thus sustained will probably appear less extraordinary than that a similar power of running up a perpendicular plane should be possessed by a much larger creature.

93. But Sir Everard Home, who, by means of microscopical observations explained the structure of the fly's foot, as connected with its mode of progression on walls and windows, also investigated the anatomy of the foot of the lacerta gecko, a kind of lizard, found in the island of Java, which walks up and down the smoothly-polished walls of the Javanese houses, pursuing the flies on which it feeds, and it runs upwards to its retreat in the

How is atmospheric pressure illustrated in the stone-sucker?

What facts do marble masons experience connected with the same principle?

What facts in natural history prove the application of atmospheric pressure to the position and locomotion of animals?

What enables flies and other insects to walk upon upright surfaces and ceilings?

How are the feet of the gecko formed?

roofs of houses, though its weight is sometimes 5¾ ounces. It has on each foot five toes, and on the under side of each of these are sixteen transverse slits, with serrated edges, and pouches between them, by means of which the animal is enabled to form a vacuum within the cavities, produced by the application of the loose membranes, surrounding the under surface of the toes, to a wall or any other smooth plane.* Nature has provided animals of far superior bulk to this lizard with a similar organization, and for the same purpose.

94. Sir E. Home, from an examination of a specimen of the amphibious marine animal, called by naturalists the walrus, from the Arctic regions, discovered that there is an analogy in structure between the hind foot of the walrus and the foot of the fly; so that this large clumsily-shaped animal is enabled to proceed upon the smooth surface of ice against gravity, by the adhesion of the feet, owing to atmospheric pressure.†

95. Those who are but slightly acquainted with natural history can hardly be ignorant of the faculty belonging to the fish called remora, which fixes itself firmly to the side of a ship or to that of a larger fish, as a shark; and thus it travels without the exertion of swimming from one part of the ocean to another. It has a sort of sucker on its head, by the application of which it becomes attached, the pressure of the surrounding water having the same effect in this case as that of the air in those previously noticed.

96. Among the experiments which have been devised to demonstrate the elastic pressure and weight of the atmosphere, the following are well adapted to the purpose.

I.

97. Take a quart bottle and drill several holes in the bottom, then set it in a wide-mouthed jug, and having filled it quite full of water, cork it securely. On lifting it from the jug it will be found to hold water notwithstanding the perforations, the pressure of the atmosphere preventing its escape; as will appear on taking out the cork, when the water, being equally pressed above and below, will run out through the holes till the bottle is emptied.

II.

95. A wine-glass filled with water may be held with the mouth downwards without spilling a drop. The means by which this seemingly marvellous effect is produced are extremely simple. It

What advantage does the walrus enjoy in consequence of the peculiar structure of its feet?

By what apparatus is the remora enabled to adhere to the sides of a vessel or those of a larger fish?

In what manner may a vessel, the bottom of which is perforated, be still made to hold water?

* See Abstracts of Papers in Philos. Trans. from 1800 to 1830, vol. ii. p. 38.

† Idem, p. 213.

is merely necessary to place a piece of paper on the surface of the water with which it must be every where in contact, and also with the rim of the glass, which is then to be inverted; and as the air cannot get in to act on the liquid above, its pressure is exerted against the under surface alone.

III.

99. A tumbler or goblet may be filled with water, and the surface being covered as before with paper, which may be held up with the palm of the hand, while it is suddenly inverted, then placing it on the surface of a smooth table, the paper is to be withdrawn, and the water will remain suspended in the glass; which will adhere closely to the table from the pressure of the atmosphere. Any one may now be safely challenged to lift the glass vertically without spilling every drop of the water; for it would require some exertion to move the glass at all upwards, and as soon as it was elevated on one side, the included water would sink down and escape.

100. It is in consequence of the unrestrained pressure of the atmosphere that liquor will not flow from a cask after it has been tapped or pierced, unless another opening be made as a vent-hole in the upper part of the cask: for till this is done the force of the air pressing on the mouth of the tap, having nothing to counterbalance it, would support a column of liquor, if the cask was air-tight, the height of which would be proportioned to the specific gravity of the liquor. When, however, the air is enabled to act through the vent-hole above, the pressure below is counterbalanced, and the liquor descends and runs through the tap by the effect of its own weight. The operation of the same principle may be observed in using a tea-pot; for there is always a small hole in the lid through which the air enters, and without which the liquid would not flow from the spout, if the lid fitted close, as it ought.

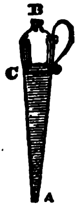
101. Many circumstances of frequent occurrence may be traced to the influence of atmospheric pressure acting irregularly. The stoppage of a supply of water from wells and fountains during a frost is sometimes owing to this cause; for the frost does not extend far beneath the surface of the earth, but it consolidates it so as to prevent the access of air to the channels of water from which fountains and wells are fed, and thus the atmosphere pressing only on the open well prevents the water from entering it as usual, till a thaw takes place, and the ground again becoming pervious to the air, it acts on the feeding springs, and the water rises in the well.

How is the paradox of the inverted glass of water to be explained?

How may a full goblet be inverted upon a table without spilling its contents?

How is atmospheric pressure concerned in the discharge of liquid from a cask, urn, or other close vessel?

In what manner can you account for the occasional failure of springs in severely cold weather?



102. The instrument, called in French Tâte-liqueur, or Chantepleur, and that used in filling essence-bottles, act on the principle of atmospheric pressure. Their construction and effect will be readily apprehended from inspection of the annexed figure, which represents a small conical tube, A B, open at both ends; and when in this state the lower orifice is plunged beneath the surface of any liquid, a portion of it will enter at A, and fill that part of the tube A C, which is immersed in the liquid; if then the upper extremity B be closed air-tight by placing the thumb over it, the tube may be lifted out of the liquid, and the pressure of the air below will prevent it from escaping, till the thumb is removed, and the air thus allowed to act on the surface of the liquid at C. The length of the tube to raise water in this manner might obviously be extended to more than 30 feet; as the height of the liquid column which the atmosphere would keep suspended would be greater or less according to its specific gravity. Such instruments of a moderate length are conveniently applicable to the purpose of withdrawing a small quantity of any liquor through the bung-hole of a cask.

103. The Siphon* affords another illustration of the principle under discussion. It is employed for the purpose of decanting or drawing off liquors, and is variously constructed. If an open tube of small diameter, bent into the shape of the letter U, be filled with water, and the curved side turned upward, the liquid will be suspended by the pressure of the air on the open extremities, while the tube is held in such a position that the columns of liquid in both legs shall be exactly of the same height; but if the tube be inclined at one side more than the other, so as to destroy the equilibrium, the water will run down and escape through that end which is at the lowest level. So if a common siphon, or bent tube with one side longer than the other be filled with water, and inverted or held with the open ends downward, the atmospheric pressure acting equally on both sides, and the liquid columns being unequal, the water will escape through the longest leg, falling in virtue of its own specific gravity. But if, when such a siphon is filled, its shortest leg be plunged beneath the surface of water, not only will the liquid all run out of the longest leg, but it will also rise in the shorter, and be discharged from the other in a continued stream, till it sinks below the open end of the shorter leg.

104. If the siphon be used without previously filling it with

How may we apply the pressure of air to the purpose of raising small quantities of liquor from a cask?

To what length might a tube for this purpose be extended?

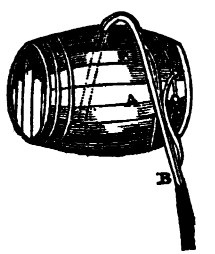
What is the construction and use of the siphon?

What principle besides that of atmospheric pressure is concerned in producing the continued action of the siphon?

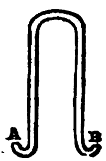
Why will not the siphon act without previously filling both legs of the tube?

* From the Greek Σιφων, a tube.

the liquid to be decanted, though the liquid will rise in the shorter leg, it will not ascend beyond its own level, so as to pass over the bend of the tube, and escape, unless the air be drawn out of the longer leg. Hence the utility of that kind of siphon represented in the margin, the peculiarity of which entirely consists in the addition of the tube C, open at the upper end, and communicating below with the longer leg of the siphon B. The shorter leg A then being plunged into the bung-hole of a cask, or into any other vessel containing liquor, the opening B is to be stopped with the hand, or otherwise, and by suction at C, the liquor may be made to pass over the bend and fill the leg B, when being suffered to escape, it continues to flow, as long as the extremity A is immersed in it. Large siphons of this sort, made of copper, and furnished with a stop-cock, just above the opening B, may often be seen in action; being used by the distillers and liquor-merchants to draw off spirits.



105. The Wirtemberg Siphon, shown in the following figure, when once filled with liquid, will remain so, and hence may be hung up in that state ready for use. One leg A being plunged into a vessel of the liquid to be drawn off, it will escape through the open extremity B, in consequence of the additional pressure of the liquid in the vessel at A; thus it will appear that this siphon acts somewhat differently from those of the common construction, though it is applicable to similar purposes.



106. Tantalus's Cup, or the Magical Goblet, is an amusing philosophical toy, which consists of a cup with a cavity at the sides or bottom, or both, with which the longer leg of a siphon communicates; so that when water is poured into the cup high enough to overcome the pressure of the air on the end opening into the cavity, the liquid will sink in the cup, and run into the cavity; and thus it can never rise so high as the mouth of the figure within which the siphon is concealed; and the classical fable of Tantalus is realized. There must be an aperture near the rim of the cup to admit air into the cavity, or rather to suffer it to escape, and by closing it with the finger, the cup may be filled to the brim; but as soon as it is unclosed the water will sink as before. If a hollow handle, communicating with the lateral cavity, be fitted to the cup, the hole may be so placed at the inner side of the handle as to escape notice; and the effect will appear astonishing to those unacquainted with the theory of atmospheric pressure.

To what practical purpose is the siphon frequently applied?
What advantage is possessed by the Wirtemberg siphon?
In what manner is the cup of Tantalus constructed?

107. Intermitting fountains, or periodical springs, are found in some places, and from the capricious and apparently unaccountable irregularity of such streams they have been regarded as miraculous, in dark ages, and have given rise to abundance of superstitions among the common people. There is a remarkable spring of this kind called Laywell, near Torbay, in Devonshire, England, and the peculiarity of this and other intermitting fountains, may be satisfactorily shown to arise from the operation of siphons formed by nature, communicating with subterraneous reservoirs.*

108. The siphon may be made available for the purpose of conveying water over the side of a pond or reservoir into another, provided the latter is on the same or a lower level than the former. It was thus very ingeniously applied by a French engineer, M. Garipuy, in 1776, to discharge the surplus quantity of water from the canal of Languedoc, when it had been raised above the proper level by the influx of water at the mouth of the river Garonne during a storm.

109. Whenever water is conveyed by pipes from a higher to a lower level, over an intervening eminence, the principle on which the siphon acts must be adopted; and thus water may be made to pass over any height not much exceeding 30 feet. It is thus conducted from Lochend to Leith, near Edinburgh, through pipes, the intermediate ground being 8 or 10 feet above the fountain head. It is necessary that the water should be driven in the first instance beyond the most elevated part of the pipe by a forcing-pump, and it then continues to flow by the influence of atmospheric pressure. But as air, always loosely combined with flowing water, will be gradually extricated from it at the bend or highest part of the pipe, it will at length there accumulate so as to stop the flux of the water. When this happens, the forcing-pump must be worked to renew the current.

110. From what has been stated with regard to the siphon, it follows that it can only be used for transferring liquids from higher to lower levels; therefore when water or any other liquid is to be raised by means of atmospheric pressure, some kind of pump must be employed. Pumps are variously constructed. The marginal figure below, (111,) represents the common suction pump, which is nothing more than a syringe so contrived that the water

With what natural phenomena are the principles of the siphon connected?

From what source do intermitting springs derive their supply of water?

For what hydraulic operations may the siphon be employed?

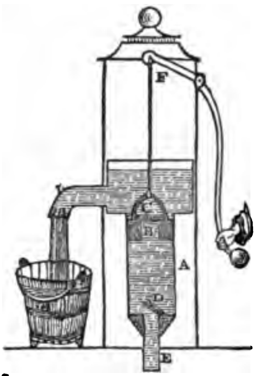
How high may water be made to pass over a barrier?

In what manner is the siphon trunk for such purposes usually filled?

---

* For an account of Laywell, see Philos. Trans., No. 424; see also Nos. 119, 189, 192, and 384. There is an interesting paper on the noted intermitting spring at Giggleswick, in Yorkshire, by Mr. Gough, of Kendal, in Nicholson's Journal of Natural Philosophy, 8vo.

drawn into it passes through the piston by means of a valve, and is discharged above it, instead of being again forced out below The invention of this instrument is attributed by Vitruvius to Ctesibius or Ctesebes, an Athenian engineer, who lived at Alexandria, in Egypt, about the middle of the second century before the Christian era; and the construction of syringes, fire-engines, and other machines acting on similar principles is described by his scholar Hero, in a treatise on Pneumatics, still extant.



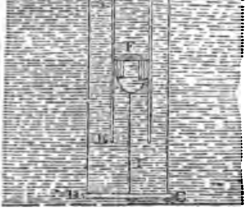
111. The suction-pump consists of two hollow cylindric pipes A and E, the latter of which usually terminates below in a perforated ball, through which the water in the well enters freely into the suction-pipe; and at its other extremity is a valve D, opening upwards, and affording a communication, when open, with the upper pipe A. In this pipe, constituting the barrel or body of the pump, the piston B moves air-tight vertically, and by its valve C opening upwards, it permits the water to pass above it and be discharged at the spout. Now suppose the piston to be at the bottom of the barrel in contact with the valve D, on lifting the former by depressing the lever handle of the pump, connected with the piston-rod at F, the valve C will be closed by the pressure of the air above, and a vacuum being thus formed in the barrel, the same pressure on the surface of the water in the well, will drive it up the suction-pipe, and raising the valve D, the water will enter the exhausted barrel, whence by depressing the piston, the valve D will be shut, and that at B rising, the water will pass upwards and be discharged through the spout. The first effect of working such a pump must be to form a partial vacuum in the barrel of the pump, and the upper part of the pipe E, and it will be only after the whole of the included air has been expelled through the piston-valve, and replaced by water in the pipes, that the liquid begins to flow, the atmospheric pressure below taking full effect, while the equivalent pressure above is counteracted by the manual force applied to the handle of the pump.

112. The suction-pump cannot raise water beyond the extent of action of atmospheric pressure, the utmost limit of which will be about 34 feet; so that the height of the valve D above the level

Describe the construction and operation of the common pump.
To whom is its invention attributed?
By whom were syringes and fire-engines first described?
What closes the upper valve of the suction pump before it has become immersed in water?
What is the first operation which takes place within the barrel of the pump?

of the water in the well must never exceed that distance; and unless the pump be accurately constructed, so that the piston in its descent fits close to the bottom of the barrel, so as to form a perfect vacuum in its ascent, the water will not rise to the extreme height in the suction-pump. It must appear somewhat paradoxical, that though this will be the effect when the pump is in the best working order, the valves and pipes being air-tight, yet a pump, the suction-pipe of which has been damaged, so that a small quantity of air can enter, will raise water nearly as high again as a good pump.

113. A tinman of Seville, in Spain, ignorant of the principles of science, undertook to construct a suction-pump to raise water from a well 60 feet deep: when the machine was finished, he was confounded at discovering that it had no power to raise water at all, and enraged at his disappointment, while some one was working the pump he struck the suction-pipe with a hammer or axe, so forcibly as to crack it, when to his surprise and delight the water almost immediately began to flow, and he found that he had thus attained his purpose. This happened about 1766, when M. Lecat, a celebrated surgeon, then at Rouen, in Normandy, being informed of it, made a similar experiment on a pump in his garden, by boring a small hole in the suction-pipe, 10 feet above the level of the water in the cistern, and having adapted to it a stop-cock, he found that when it was open the water could be discharged at the height of 55 feet, instead of from 30 to 34 as before.* The circumstance admits of an obvious explanation, the effect being analogous to that exhibited by *jets-d'eau*, when air is mingled with the acending column of liquid.† Thus in the case of the pump, the air presses in through the slit or aperture in the suction-pipe, and becoming mixed with the water in its ascent, forms a compound fluid, far lighter than water alone, and therefore acted upon by atmospheric pressure more readily, and thus it produces the phenomenon described. However, as there are other and more efficacious methods of raising water to great heights, the contrivance just noticed is not to be recommended.

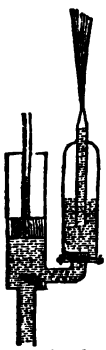


114. The Lifting-pump, as represented in the margin, acts in much the same manner as the preceding, but the machinery is reversed. It consists of a hollow cylinder or barrel A B, in which is fixed the valve G, a little below the level of the water in the well or reservoir. A piston F with a valve opening upwards, fits into the lower part of the barrel, in

* V. Sigaud de la Fond Elem. de Phys., t. iii. pp. 238, 239.
† See *Hydraulics*, No. 11.

which it is moved vertically by means of the frame B C D E, connected with the piston-rod I. Now when the piston is at the bottom of the barrel, the pressure of the atmosphere on the surface of the water in the well will open the piston valve; and the water will rise to the same height within the barrel as without; and on lifting the piston, its valve F will close, and the water above it will be driven by the opening of the valve G, into the upper part of the barrel: then the piston being depressed again, the valve F will open to admit more water into the lower part of the barrel, while that above will be prevented from returning by the closing of the valve G; and thus by continued working of the piston, the water will rise in the barrel till it escapes by the spout.

115. In both the suction-pump and the lifting-pump, the water will be discharged by jets, unless a kind of reservoir is made by the enlargement of the barrel above the spout, in which case it may be made to flow in a continuous stream.



116. The forcing-pump is another form of this useful machine, combining in a great degree the properties of those already described. It is composed of a hollow cylinder, the lower end of which dips into the water in the well; just above the valve, in the upper part of this cylinder, a lateral pipe branches off, having at a short distance from its origin another valve, both valves opening upwards; and in the upper part of the cylinder or barrel is a solid piston or plunger, moving air-tight vertically. Now if the piston be depressed to the lower valve, and then raised, that will open, while the valve in the lateral pipe remains closed, and the pressure of the atmosphere on the water in the well will cause it to rise a little and expel a part of the air through the first valve; the piston then being lowered that valve will close, and the air above it be expelled through the other valve; thus every elevation of the piston will make the water rise higher in the cylinder till it has expelled all the air, and it will consequently, at the next lifting of the piston, pass above the first valve, and the piston being again lowered, as the liquid cannot descend, the valve being closed, it will be forced into the lateral pipe, through its valve, and as it is prevented from returning again by that valve,

What is the greatest height to which water may be drawn up by a well constructed pump of this form?

In what manner was it discovered that a mixture of air and water may, by the action of a pump, be raised higher than 34 feet?

How is this action explained?

Of what does the lifting-pump consist?

Is the lifting-pump limited to any particular height to which it can raise the liquid column?

In what manner is a constant stream maintained either in the lifting or the suction-pump?

Describe the form and action of the forcing-pump.

Which of the preceding pumps constitutes a part of this?

it will continue to ascend with every down-stroke of the piston, and may thus be raised to any height required

117. In a pump of this kind, the stream will be intermitting, unless there be a cistern above the spout, to form a head of water which may act by hydrostatic pressure; or the same object may be more effectually attained by closing the force-pipe, so that a portion of condensed air may press on the surface of the water after it has passed the valve, and an open tube, fitting air-tight, entering the chamber, and having its lower extremity, plunged beneath the surface of the water, that liquid will be driven up it by the pressure of the included air, and form a *jet-d'eau*, or flow in a regular stream, according to the disposition of the spout or mouthpiece.

118. The fire-engine is a modification of the forcing-pump, consisting essentially of two working barrels, like an air-pump, but fitted with solid pistons, and valves corresponding with those of the forcing-pump; and thus water is drawn from any reservoir or other source of supply, and propelled into a strong air-chamber, from the upper part of which passes a tube, having its inferior extremity dipped under the surface of the water, which is thus driven through it by the pressure of the condensed air. The tube just mentioned may be connected with the part that enters the air-chamber by a universal joint, and thus its extremity may be conveniently turned to throw water in any direction; or as more usual, it may have fitted to it a flexible leathern pipe or hose, by means of which the stream may be conducted to any spot where it may be made to act with the greatest effect.

AEROSTATICS.

119. The laws which regulate the ascent and descent of floating bodies have been generally elucidated in treating of specific gravity, as connected with the science of Hydrostatics. It was there demonstrated that liquids differing in density when placed in contact would assume an arrangement depending on their relative weights or densities, the heaviest always sinking to the bottom of the containing vessel, and the others floating at heights corresponding to those weights.* Solids, immersed in liquids, in the same manner either sink or float according as they may be heavier or lighter than the medium in which they are placed. Thus if a vessel were partly filled with mercury, and water standing above

What device maintains a constant efflux in the forcing-pump?
What are the essential parts of the fire-engine?
What device enables the fireman to direct the stream in any direction, according to circumstances?

---

* See *Hydrostatics*, No. 76.

it, then on dropping into it a piece of iron, the solid metal would be seen to fall through the upper stratum of the liquid mass, and stop at the surface of the lower stratum, as consisting of a metallic fluid more dense than the solid metal.

120. An analogous effect might be exhibited with gases of different densities. If a quantity of carbonic acid or fixed air were to be poured into a large glass jar, so as to fill the lower half of it, the upper part of the jar would be occupied by atmospheric air, as the lighter of the two fluids; and any bodies of specific gravity intermediate to these gases, as soap bubbles, being let loose over the jar would fall through the upper stratum of gas, and be arrested by the lower, on the surface of which they would float, just as a cork would float on water.

121. A great number of substances of various kinds are suspended in the atmosphere within a moderate distance from the surface of the earth; some of them, in consequence of their extreme minuteness, belonging to the class so picturesquely described by Shakspeare as "the motes that people the sunbeam." These floating corpuscules appear to be numerous in proportion to the heat of the air; and hence they are much less frequent in winter than in summer.

122. "We are ignorant of the precise nature of this fine powder. Perhaps it may be a mixture of inert matter extremely divided, with the exquisitely small germs of various species of organized bodies, as the eggs of insects, the seeds of plants, and likewise the fecundating powder from the stamens of flowers. It is in fact known from the observations of naturalists, that under many circumstances, animalcules and minute vegetables of different species become developed, though it is impossible to perceive the germs from which they are derived. It is certain, also, that flowers furnished with pistils only, (as those of the date palm,) are fecundated, and bear fruit, though the plants furnished with stamens are found at considerable distances, and even separated from the others by vast tracts of sea. All these observations tend to confirm the hypothesis of the transmission of germs and fecundating powders by means of the atmosphere. Indeed we take nature in the fact, as it were, under many circumstances; thus plumose or tufted seeds are frequently observed flying in the air, as those of the lettuce, the dandelion, and others, with which children sometimes amuse themselves. And it may be perceived that the seeds of many species of vegetables are furnished with delicate membranes or wings; as, for instance, those of the fir

What analogy exists between the phenomena of liquids and those of gases, when different kinds are poured into the same vessel?

Give examples of that analogy.

In what manner is the floating dust of the atmosphere seen in warm sunny weather to be accounted for?

Is the ascension of those substances from the earth rendered probable by any known facts in natural history?

What seems to be the design of the thin membranes and delicate gossamer with which the seeds of certain plants are furnished?

the elm, &c., which seem formed expressly in order that the wind may raise them, so that they may be transported in all directions, and thus contribute to the propagation of the species to which they belong.

123. "Relatively to the fecundating powders, it may be reremarked, that in forests of pines and firs, at the period of flowering, the ground is covered for several days with an extremely fine light powder, which becomes raised in the air by the winds in prodigious quantities, and conveyed to distant places, where the descending clouds have been often mistaken for showers of sulphur. Also during the season of the flowering of wheat, the fecundating dust, or pollen, may be seen floating over the fields like a thick mist."*

124. The modern art of aërostation, or as it has been more correctly styled aëronautics, depends on the application of the principle of specific gravity to the action of gases on solid bodies, and the consequent motion of the latter through the atmosphere. After the invention of the air-pump, when the mechanical properties of the air had been experimentally demonstrated, the feasibility of contriving a machine for the purpose of navigating the atmospheric regions became a favourite subject of speculation among men of science.

125. Bishop Wilkins, a distinguished mathematician, and one of the earliest members of the Royal Society of London, was so far convinced that a method of travelling through the air might be discovered, that he hazarded the opinion that the time would come when a man about to take a journey would call for his wings as familiarly as he might now for his boots. But the idea of taking advantage of the principle of specific gravity to form a flying-engine, that should rise in consequence of its being lighter than an equal bulk of air, appears to have been first published, if not conceived, by Francis Lana, an ingenious Jesuit. The scheme he proposed was that of attaching to a car four hollow globes of copper, which were to be exhausted by means of an air-pump; and which he imagined would have sufficient ascending power to elevate the car and the aëronautic adventurer. It seems to have been merely a theoretical project, which must have failed in the attempt to execute it; for neither globes of copper nor any other substance known could be manufactured in such a manner as to be at once buoyant, from the thinness of the sides, and strong enough to resist atmospheric pressure.

What remarkable appearance is often exhibited by the surface of t earth in the flowering season of pines, firs, &c.?

How early, and by what occurrences, were men induced to attemp' aërial navigation?

What appears to have been the earliest conception of this subject, and how did it differ from the idea of Lana?

Why was the project of the latter impracticable?

* Beudant Traite Elem. de Physique, p. 3C , 335.

126. Nearly a century had elapsed after the publication of the abortive plan just noticed, when the discovery of hydrogen gas, or inflammable air, by Cavendish, about 1766, and of its remarkable inferiority of density compared with common air, revived the speculations of philosophers on the subject of aëronautics. Dr. Black, of Edinburgh, soon after ascertained, by experiment, that a thin bladder filled with hydrogen gas would rise to the ceiling of a lofty room, and remain suspended till it was taken down; and several years subsequently the subject was further investigated by Cavallo, a Portuguese gentleman, residing in England, who was a fellow of the Royal Society.

127. It was, however, in France that the invention of the air-balloon took place. Two brothers, Joseph and Stephen Montgolfier, paper-makers, at Annonay, constructed a large square bag of fine silk, and caused it to ascend in an inclosed chamber, and afterwards in the open air, by heating the air within it by means of burning paper. After several preliminary experiments, a balloon was constructed at Paris, consisting of an elliptical bag, 74 feet in length, and 48 in breadth, with an aperture below, near which was suspended an iron grate for burning wood and straw, and a boat or car attached for the reception of aërial travellers; and in this machine the first ascent was made, in October, 1783, by Pilatre de Rozier, superintendent of the Royal Museum. Other experiments of the same kind followed, with balloons rendered buoyant by the admission of heated air.

128. But this method of aërostation was liable to inconveniences and imperfections, which rendered it less eligible than that of employing balloons inflated with hydrogen gas, the chief objection to which arose from the expense attending it. This, however, was obviated by means of a public subscription; and December 1, 1783, M. Charles, professor of natural philosophy, at Paris, and his companion M. Robert, ascended from the gardens of the Tuilleries, by means of a balloon filled with hydrogen or inflammable air. The success of this undertaking demonstrated the superiority of this mode of construction; and it was consequently adopted by many other experimentalists, both in France and elsewhere. Lunardi, an Italian, was the first aëronaut who exhibited in England; and among those who distinguished themselves by their enterprising spirit, or philosophical researches, amidst the fields of air, may be noticed the names of Blanchard, Garnerin, Zambeccari, Dr. Jeffries, W. Windham Sadler, and Gay-Lussac, the last-mentioned of whom, in 1804, ascended from

How long was Lana's scheme published before the discovery of hydrogen gas?

What experiment by Dr. Black is probably the earliest form of balloon ascension?

In what manner did the Montgolfiers effect the elevation of their silk bag?

What is related of the form and size of the first balloon with which an aëronautic expedition was made by Rozier?

Why was not hydrogen adopted by the earliest aëronauts?

Who were among that number?

Paris, furnished with instruments for making meteorological observations; and from the descent of the mercury in his barometer, he inferred that he had, when at his utmost elevation, attained the height of about 23,000 feet above the level of Paris; and this appears to be the greatest distance from the surface of the earth to which any person has hitherto risen by means of an air-balloon.

129. Several accidents have occurred to aëronauts in the prosecutions of their adventures, and some have lost their lives; as Pilatre de Rozier, who, after repeated successful ascents, was killed, together with M. Romain, in consequence of the balloon taking fire in which they had attempted to pass from France to England, in June, 1785; Madame Blanchard, the wife of the aëronaut, mentioned above; and W. W. Sadler, who, after having made thirty atmospheric voyages, in one of which he crossed the Irish Channel, was precipitated from his balloon, owing to the car striking against a chimney, at the height of about forty yards from the earth. Notwithstanding these and other fatal disasters, aëronautic expeditions have been so frequently undertaken, that most persons must have had opportunities for witnessing them; but though several useful purposes to which air-balloons might be applied have been suggested, the difficulty of managing them has hitherto prevented their adoption except as objects of display.

130. The air-balloon consists of a light bag of thin silk, of a globular or elliptic shape, and rendered air-tight by a coating of varnish, made by dissolving gum-elastic in spirits of turpentine. When thus prepared, it must be distended with some elastic fluid, lighter than common air; and it will thence acquire an ascending power equal to the difference between its weight, including the attached car and its contents, and that of the bulk of atmospheric air which it displaces. Suppose the diameter of the silk globe to be 20 feet, its circumference will be about 63 feet, its superficial measure about 1257 square feet, and its contents, solid measure, 4190 cubic feet; then if it be filled with gas having only ¼ of the specific gravity of common air, and admitting that a cubic foot of the latter would weigh 1½ oz., and that 1 square foot of taffeta or thin silk would weigh 1 oz.:—

The weight of atmospheric air displaced will be	6285 oz.
The weight of gas in the balloon - - -	1571¼
The weight of the taffeta - - - -	1257
	2828¼
	3456¾

To what height did Gay-Lussac ascend?
To what purpose have balloons been hitherto applied?
Of what does the air-balloon consist?
What would be the ascensional force of an unloaded balloon of silk 20 feet in diameter filled with hydrogen of a specific gravity ¼ that of common air? Calculate on similar principles the force of a balloon 30 feet in diameter?

131. Hence the inflated balloon would weigh 3456 oz., or 216 pounds less than an equal bulk of common air; and therefore such a balloon, with a car and its contents attached, weighing 200 pounds, would have an ascending force equal to 16 pounds. But if it were filled with pure hydrogen gas, having a specific gravity but 1-13 that of common air, its power of ascension would manifestly be augmented in a high degree.

132. Aëronauts in general were accustomed to use inflammable air, procured by dissolving pieces of iron or zinc in sulphuric acid diluted with water; a tedious, troublesome, and inconvenient operation, which was never found to produce gas approaching to the specific gravity just mentioned. Hence Mr. Green, who has distinguished himself by the number of his aërial expeditions, amounting to about one hundred, determined to make a trial of coal gas. From some preliminary experiments he ascertained that the ascending force of a balloon three feet in diameter, when inflated with gas from coal, was equal to 11 oz.; and that when filled with hydrogen gas procured in the usual way, its force was not more than 15 oz. He therefore, in his ascents in the neighbourhood of London, availed himself of the convenience of procuring gas from the coal-gas companies, which he found to be sufficiently adapted for his purpose.

133. The accidents which occurred to some of the earlier aëronauts suggested the idea of contriving a method of descending independent of the balloon, if circumstances should render it desirable. The first experiments for this purpose were made by Le Normand, in 1783; and Blanchard subsequently constructed a machine resembling a large expanded umbrella, called a parachute, which he let fall from a height of 6000 feet above the earth, with a dog in a basket suspended from it. A whirlwind arrested its descent and swept it above the clouds; but it soon approached the balloon again, when the dog recognized his master, showing his uneasiness and alarm by barking; another current of air then carried him out of sight, and he ultimately landed in safety, though not till after the descent of the balloon. Garnerin, who used a parachute 25 feet in diameter, with a basket attached to it, descended from the air by this means, several times, both in France and in England; and on one occasion from the perpendicular elevation of 8000 feet.

134. On the principle of the parachute depends the buoyancy of numerous light bodies presenting an extended surface to the air; and thus a little canopy made by attaching four strings to the angles of a sheet of paper with a light weight in the place of a car, if dropped from an eminence will descend but slowly to the ground.

What has recently been substituted for hydrogen in the inflation of balloons?

What relative ascensional forces will be given to balloons by coal-gas and hydrogen respectively?

What is the form and what the object of the parachute?

What accounts are given of the use of this apparatus?

Some experiments founded on the observation of such facts, made in Germany, may here be noticed. Zacharia of Rosleben, conceiving the possibility of forming a flying boat, constructed, by way of trial, a case of light wood covered with linen, in the shape of a flat obtuse-angled keel, 5½ feet in diameter, and ½ a foot deep, weighing 14½ pounds. On the 17th of September, 1822, this machine was launched from a scaffold on the race-course of Wendelstein, the scaffold being 27 feet high, and standing on a rock 100 feet above the surrounding plain; so that the perpendicular height was 127 feet; and the boat flew to the distance of 153 feet. A second flying boat 7¼ feet in diameter, ½ a foot deep, and 25 pounds in weight, which was launched from the scaffold on the same day, took a somewhat more elevated path, and landed after a flight of 158 feet. These experiments appear to have been expensive, and the result was not sufficiently flattering to induce the projector to repeat them.*

135. Attempts have been made at different periods to construct wings for active flight through the air; but they have all proved abortive. The celebrated historian, William of Malmesbury, in his account of the conquest of England by the Normans, mentions an alleged prediction of that event, by Elmer, or Oliver, a Benedictine monk of Malmesbury, in consequence of the appearance of a comet, in 1060. This monk appears to have been a learned and ingenious man, who was skilled in mathematics. But his claim to notice at present is grounded on his being the earliest English aëronaut on record; though his speculation was not only unsuccessful but unfortunate. For the historian informs us that Elmer, having affixed wings to his hands and his feet, ascended a lofty tower, whence he took his flight, and was borne upon the air for the space of a furlong; but owing to the violence of the wind or his own mismanagement through fright, he fell to the ground, and broke both his legs.†

136. The famous Roger Bacon, who died towards the end of the thirteenth century, in his treatise on the Secret Works of Nature and Art, expressly asserts the possibility of constructing machines in which a man sitting might move through the air, by means of wings, like a bird flying.‡ In the fifteenth century,

What success has attended the various attempts which have been made to employ aërial boats?

How early do attempts of this kind appear to have engaged the serious attention of speculative men?

What success attended the flights of Elmer, Dante, and Degen?

---

* Elements of Natural Philosophy. By Prof. Vieth, of Anhalt-Dessau, (German.) Leipsic, 1823. p. 208.

† Gul. Malmesbur. de Gestis Regum Anglorum, lib. ii. cap. 13.

‡ "Possunt etiam fieri instrumenta volandi ut homo, sedens in medio instrumenti, revolvens aliquod ingenium, per quod alæ artificialiter compositæ aërem verberent, ad modum avis volantis."—Epistola Fratris R. Baconis de Secretis Operibus Naturæ et Artis. Hamburg. 1572. p. 37.

John Baptist Dante, a mathematician of Perugia in Italy, excited the astonishment of his contemporaries by his aëronautic exploits. But his career was unfortunate; for we are told that after he had repeatedly crossed the lake of Thrasymene through the air, he took his flight from an eminence in his native city, when his machinery becoming deranged, he fell on the roof of a church, and fractured his thigh. The Journal des Sçavans, December 12, 1678, contains a description of a flying-engine contrived by a locksmith of Sablé, in the county of Maine, in France, by means of which the inventor descended from a second floor window, and proposed to fly from a height over a river. Professor Vieth says, that the latest experiments on the art of flying were made by a watchmaker at Vienna, named Degen; but they seem to have led to no practical results of importance.*

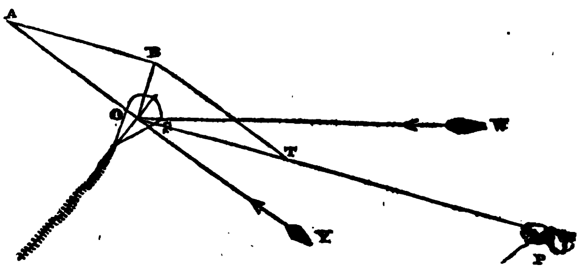
137. The ascent of sky-rockets affords an interesting object of philosophical speculation, and the phenomenon has been variously accounted for by men of science. The rocket consists of a cylindrical case or cartouch of thick paper filled with a composition of gunpowder, charcoal, steel filings, and other inflammable matter; with a head technically styled "the pot," at the upper extremity; and a light stick, to which the rocket is affixed laterally. Its flight, like that of other projectiles, depends on the sudden expansion of compressed air, formed by combustion. The cause of the ascent of the rocket is, that whereas it would, if it were not for the aperture below, be equally pressed on all sides within by the expanding gas, and would remain at rest, but this pressure, like that of steam in a boiler, will often on a small portion of its inner surface greatly exceed the weight of the containing vessel. In such cases, the opening of an aperture sufficiently large, will project the container in the direction *opposite* to that in which the opening takes place. It will be perceived that from this account of the effect, the operation would be the same in vacuo as in the open air. In fact the effect is no more due to the impinging of the escaping gas against the air below, as Dr. Hutton and others have supposed, than the effect of effluent water in Barker's mill is to be attributed to the same cause. Several steam-boilers which have exploded in the United States have gone off through the air like rockets, having first formed a rent in such a part as to allow the issuing steam to urge the enormous mass forward by its elastic action. One occurrence of this kind at Pittsburg was, at the time, de scribed as having been accompanied by a train of light; as if the issuing stream had been an inflammable mixture. A revolving

Of what does the sky-rocket consist?
On what does its flight depend?
What causes the rocket to ascend when the contents are inflamed?
What analogous effects on a larger scale have sometimes been witnessed?
By what method is the rapid developement of gases obtained in the rocket?

* Elem. of Nat. Philos., p. 209.

apparatus, like a Barker's mill, only adapted to the action of air instead of water, may be set in motion by condensed air; but will revolve with rather more velocity if placed in the receiver of an air-pump, and, after exhaustion, set in motion by allowing the external air to find an entrance through the revolving arms. Dr. Hutton justly remarks that the rocket would not rise unless the elastic fluid were produced in abundance; and hence the necessity for piercing in the centre of the rocket a conical hole, and thus the composition when inflamed burns in concentric strata, of much greater extent than the circular disk to which the combustion must otherwise be confined, and the expansive gas is formed in quantities sufficient to produce the required effect.

138. Among the amusements of schoolboys there are few more susceptible of application to useful or curious purposes than that of flying paper-kites. By means of such a machine, which he constructed by stretching a silk handkerchief over a wooden frame, Dr. Franklin demonstrated the identity of lightning with the electric fluid;* the paper-kite has been employed to convey a line to the shore from a vessel wrecked on a rocky coast;† and a few years ago, a Mr. Pocock, of London, made repeated experiments, by means of which he ascertained the possibility of travelling in a carriage drawn by two paper-kites, supported at a moderate elevation, and impelled by the wind. The elevation of the paper-kite in the usual manner, with a line attached to a loop on the under-side of the machine, is satisfactorily elucidated by Dr. Paris, who has shown that the ascent of the kite affords an example of the composition of forces, the mode of action of which is exhibited in the following diagram.



139. The kite is here represented rising from the ground, the line W denoting the direction and force of the wind, which falling on an oblique surface, will be resolved into two forces, namely,

To what useful purposes has the kite been occasionally converted? On what principle is its ascent to be explained?

* See Treatise on *Electricity*.

† See Transactions of the London Society for the Encouragement of Arts, Manufactures, and Commerce, vol. xii.

one parallel with it, and another perpendicular to that surface, and the latter only, represented by the line Y, will produce an effect, impelling the kite in the direction O A; and the tension of the string, at the same time, in the direction P T S, will cause the machine to ascend in the diagonal O B of the parallelogram O A B T.* The ascent of the paper-kite not only depends, as may be thus perceived, on the same principles as those which govern the movement of bodies on inclined planes; but it may also be fairly affirmed that the path of the kite in rising is an actual inclined plane, up which it is drawn, by the tension and weight of the string.

140. A well constructed kite may be made to ascend when there is little or no wind stirring; for, by running with it held by the string and inclined obliquely, the air on its inferior surface will be compressed, just as it would be by running with an expanded umbrella held out; and by veering out the string and running at the same time, the kite is drawn up an inclined plane which it forms for itself by the gradual compression of the successive portions of air over which it moves.

The Diving-bell.

141. As air produces peculiar effects when its density is inferior to that of the lower atmosphere, so likewise are certain effects produced by air, the density of which has been augmented by compression or otherwise. Condensed air, if not contaminated with deleterious gases, may be breathed with impunity by animals for a considerable time; though its effects are various on different individuals, and some experience considerable temporary inconvenience from inspiring it. Mr. Bille, of New York, has founded on this property of compressed air an improved method of bottling sparkling liquids, such as ale, cider, and perry. His plan consists in conducting the whole operation of drawing off, bottling, corking, and securing the liquors in question, within an air-tight chamber, into which such a quantity of air may be compressed by a condensing pump or engine, that it may always afford a degree of pressure on the surfaces of the liquors sufficient to prevent the escape of the gas to which they owe their sparkling quality.

142. But the most interesting and important purpose to which the respirability of compressed air has been applied, is that of enabling persons to descend to a certain depth beneath the surface of the sea, by means of the machine called a diving-bell. The

What path does it actually describe in rising?
How may the kite be made to rise in a calm?
How is the ascent in this case produced?
What effect on the respiration of animals is produced by air above the common density?
What application of such air has been made to purposes in the arts?

* Philosophy in Sport made Science in Earnest. New edit. 1833, p 236.

compressibility and impenetrability of atmospheric air may be both at once demonstrated by the simple experiment of holding by the foot an inverted beer-glass, and plunging it perpendicularly in a jar or basin of water, when the portion of air within the beer-glass will be compressed and diminished in bulk, in proportion to the depth to which the glass was pressed beneath the surface of the water: but a limit would occur beyond which manual force would not drive it. If a small bit of lighted wax-taper, attached to a cork, were placed on the water and included under the inverted glass, it would burn in the compressed air longer than in an equal bulk of air at its usual density; but the air would be consumed by the combustion of the taper till it became reduced to about one-third, and the residue would be found unfit for respiration and the support of animal life.

143. A diving-bell is merely a large conical or pyramidal vessel, made of cast iron, or of wood, the latter loaded with weights to make it sink. It is usually furnished with shelves and seats on the sides for the convenience of those who descend in it; and several strong glass lenses are fitted into the upper part for the admission of light. There is likewise a stop-cock, by opening which the air, rendered impure by respiration, may from time to time be discharged and rise in bubbles to the surface of the water; and provision must be made for the regular supply of fresh air, which may be sent down through pipes from one or more large condensing syringes, worked on the deck of a vessel above. The bell must be properly suspended from a crane, or cross-beam, furnished with tackles of pulleys, that it may be lowered, raised, or otherwise moved, according to circumstances.

144. Some have supposed that the ancients were acquainted with the use of the diving-bell, and apparent allusions to it occur in the works of Aristotle. But the earliest direct notice of such a machine is probably to be found in a tract "De Motu Celerrimo," by John Taisnier, who held an office in the household of the emperor Charles V. He states that some experiments were made in the presence of that prince, at Toledo, in 1538, by two Greeks, who descended under water several times in a brazen caldron, without wetting their clothes, or extinguishing lights which they carried in their hands.* Since the middle of the seventeenth century, diving-bells have been often used for the purpose of recovering valuable property which had been shipwrecked.

145. In recent times, the expense attending the construction of a diving-bell, and the difficulty of managing so unwieldy a ma-

How are the compressibility and the impenetrability of air demonstrated?

How is the power of compressed air to support combustion proved?

What is the description of the diving-bell?

How are the operators in a diving-bell supplied with air during their continuance beneath the surface?

What historical account is given of the invention of the diving-bell?

* V. Schotti Technica Curiosa, lib. vi. cap. 9.

chine, have led to the invention of less operose and more convenient methods of making submarine investigations; but there is one instance of the successful employment of diving-bells for the recovery of treasure from the sea, which occurred in 1831, and that attracted attention on account of the skill and enterprise displayed in the conduct of the undertaking. In December, 1830, a British frigate having sailed from Rio Janeiro for England, with 810,000 dollars on board, struck on rocks, and was sunk at Cape Frio. Captain Thomas Dickenson, an officer on that station, obtained permission to attempt the recovery of the treasure; and not being able to procure a diving-bell at Rio, he adapted to the purpose the ship's iron water-tanks, and constructed a huge crane 158 feet in length, and 50 feet above the level of the sea, from which to suspend the bells. Though the bells were repeatedly lost, the undertaking was prosecuted by Captain Dickenson and other officers, till ultimately 750,000 dollars were recovered, besides a quantity of marine stores and other articles.

146. Diving habits, or jackets, adapted for descending under water, have been variously contrived; and among such machines are the Scaphandre, invented by the Abbé de la Chapelle;* and Klingert's machine for walking under water;† but these, though ingenious, are probably inferior to the apparatus recently employed at Portsmouth, England, by Mr. Deane. The essential part of his machinery consists of a capacious metal helmet, covering the head and neck, resting on the shoulders, and attached to the body by straps. In the front are three oval windows of strong plate-glass; from the lower part of the helmet passes a bent tube for the discharge of air which has been breathed; and from the upper part proceeds another tube connected with a flexible pipe, through which fresh air is forced from above. Armed with this head-piece, and a waterproof dress, the adventurer descends from the side of a ship by a ladder to the bottom of the sea, which he can explore at his leisure, and walk to any distance within the length of his air-pipe. To counterbalance the upward pressure of the water at any considerable depth, it is requisite that leaden weights should be attached to the body, in addition to the weight of the helmet, and thick leaden soles for the shoes.‡

147. Some curious inventions, for the purpose of submarine na-

What objection exists to the general use of diving-bells for submarine explorations?

What instance can you cite of the successful employment of these machines for the recovery of lost treasure?

How is Deane's diving apparatus constructed?

What limits the extent to which the diver can extend his examinations when using this apparatus?

How is the body prevented from rising from deep water in the excursions taken with diving dresses?

* V. Sigaud de la Fond Elem. de Phys., vol. ii. p. 249.
† See Tilloch's Philosophical Magazine, vol. iii. p. 172.
‡ Nautical Magazine.

vigation, have been invented in the United States. Robert Fulton, the successful inventor of the steamboat, contrived a machine of this kind, called a Torpedo;* and David Bushnell invented a submarine vessel in which a man might pass a considerable distance under water; and by means of this, and its accompanying magazine of artillery, an attempt was made to blow up a British vessel in the harbour of New York, during the late war with England.† This project appears to have failed merely from the difficulty or rather impossibility of attaching the magazine to the bottom of the ship, which was attempted by means of a sharp iron screw, which passed out from the top of the diving-machine, and communicated with the inside by a water-joint, being provided with a crank at its lower end, by which the engineer was to drive it into the ship's bottom. The machine affording no fixed point to act from, the power applied to the screw could make no impression on the ship; and thus this bold adventure was disconcerted.‡

Describe the method of Bushnell for blowing up an enemy's ships.
Why did this plan prove unsuccessful?

---

* V. Montucla Hist. des Mathemat., t. iii. p. 78.

† For a description of this curious engine, see a paper on "Submarine Navigation," by Charles Griswold, in Silliman's American Journal of Science, vol. ii. p. 94.

‡ For a report on Norcross's diving apparatus, see Journal of the Franklin Institute for January, 1835, vol. xv. p. 25.

The following scientific treatises may be advantageously consulted in reference to the department of Pneumatics:—

Playfair's Outlines of Natural Philosophy, vol. i. pp. 242—262.

Library of Useful Knowledge, treatise on Pneumatics.

Gregory's Mathematics for Practical Men, pp. 346—352.

Ferguson's Lectures on Select Subjects, pp. 195—227.

Cambridge Mechanics, p. 377, where the motion of gases is treated to some extent, and p. 403, theory of the air pump and other machines depending on the atmosphere.

De Luc Recherches sur les Modifications de l'Atmosphere.

Philosophical Transactions, vol. lxvii. pp. 513. 653.

Cavallo's Philosophy, vol. ii.

Playfair on the Causes which affect Barometric Measurements, in the Edinburgh Philosophical Transactions, vol. i. p. 87.

ACOUSTICS.

1. The science which has been designated by the terms Acoustics* and Phonics,† treats of the causes and effects of Sound, and the manner in which it is perceived by the organ of hearing. The idea of sound is excited in the mind when the motions which take place in any of the bodies around us are such as can be communicated to the auditory nerve and thence to the brain. This effect is produced by means of the organization of the ear, the tremulous motions or vibrations of the air being propagated to the tympanum or drum, a thin membrane which closes the aperture of the ear; behind the drum is a cavity in the bone which forms the side of the head, separated by another membrane from an inner cavity, from which branch off variously-formed tubes or canals, which, as well as the inner cavity called the labyrinth, are filled with a limpid fluid; and an expansion to the auditory nerve, or delicate layer of nervous fibres being distributed over the internal surface of the labyrinth and canals, it thus becomes the medium of sensation with regard to sound.

2. There is a passage called the Eustachian tube, which extends from the back part of the mouth to the cavity immediately behind the membranous drum, through which air passes, and therefore the drum vibrates freely when acted on by the sonorous undulations of the external air, which are communicated from the membrane of the drum by a chain of very minute bones and muscles passing from it to the membrane over the entrance to the labyrinth, and corresponding undulations being produced in the contained fluid, impressions are propagated to the nervous lining of the labyrinth, and thence to the brain.

3. Hence it must be apparent, that the sense of hearing, depending as it does on the perfect operation of so complicated an organ as the ear, may be impaired by various causes, or entirely destroyed when the essential parts of the organ are originally wanting, or so greatly injured by disease as to be incapable of performing their functions. Thus some persons are born deaf, the organization of their ears being so defective that they are ut-

What is the object of the science of acoustics?
Under what circumstances is the idea of sound excited in the mind?
How is the effect produced?
What is the tympanum of the ear?
What is the inner cavity of the ear designated?
How is its internal surface lined?
What appears to be the immediate instrument of sensation in regard to sound?
What is the position of the Eustachian tube?
What is the natural consequence, in regard to language, of an original want or an early destruction of the organs of hearing?

---

* From the Greek Ακουω, to hear.
† From Φωνη, a voice, or sound.

terly incapable of perceiving sounds, and therefore can never acquire the faculty of speech by imitating vocal language. Such unfortunate individuals, incapable of obtaining knowledge by the usual channels, may, however, be qualified for high degrees of mental cultivation by the modes of instruction contrived, or rather greatly improved, by L'Epée, Sicard, Braidwood, and others, who have most meritoriously devoted their talents to the instruction of the deaf and dumb.

4. Though the functions of the organ of hearing are clearly ascertained, as to the general principle of action, yet the peculiar purposes of the several parts are by no means equally obvious; nor is it certain that any of them, except the auditory nerve, are absolutely essential to the perception of sound. Some persons naturally have an aperture in the membranous drum of the ear, and in others a similar defect is produced by disease; but in either case, though the faculty of hearing is commonly somewhat impaired, it is not destroyed, not even when, owing to abscess in the ear, the chain of bones* between the membrane of the drum and that covering the entrance to the labyrinth has been disunited. In that case, probably, the vibrations of the air impinging on the inner membrane cause the requisite undulations in the fluid within the labyrinth.

5. There are persons who occasionally amuse themselves and their companions by drawing a quantity of tobacco-smoke into the mouth, and then expelling it through one or both ears; a feat which can be performed only by those who have a natural or artificial perforation of the membranous drum of the ear; and thus they can force the smoke through the Eustachian tube, into the cavity of the drum, and discharge it through the perforation just mentioned.

6. In practising the art of diving, it appears that those engaged in it on first going into deep water become subject to most intense pains in the ears, which continue till they have reached certain depths, when the sensation of something bursting within the ear with a loud report terminates the pain, and they can then descend as low as may be necessary without any further inconvenience. There can be no doubt that all this is occasioned by the vast pressure of the water on the drum of the ear, and its consequent rupture; and probably it would be found on investigation, that pearl-divers, and others accustomed to deep diving, have the auditory faculty more or less impaired.

What effect on the faculty of hearing has a rupture of the tympanum?

What experiment proves the existence of a passage between the mouth and the external ear?

What sensation precedes the relief obtained by divers when they first go into deep water?

---

* This chain consists of three distinct bones, called, from their respective forms, the *hammer*, the *anvil*, and the *stirrup bones*,—*malleus*, *incus*, and *stapes*.

7. Though air is the usual medium of sound, it is not essential to the formation or the propagation of sonorous vibrations. Some substance however, either solid, liquid, or aërial, must form a continuous connexion between the sounding body and the ear; for sound cannot be conveyed through a vacuum. If a small bell be suspended under the receiver of an air-pump, in such a manner that it can be struck with a hammer without admitting air to it, when partial exhaustion has taken place, the sound will be weakened, and after the rarefaction has been carried as far as possible, no sound will be heard on striking the bell. If the experiment be made by inclosing the bell in a small receiver full of air, and placing that under another receiver from which the air can be withdrawn, though the bell when struck must then produce sound as usual, yet it will be quite inaudible, if the outer receiver be well exhausted, and care be taken to prevent the sonorous vibrations from being propagated through any solid part of the apparatus.

8. As sounds become weak when the air surrounding the sonorous body is rarefied, so on the contrary, any sound, as that of a bell, will be perceived to be much louder when the bell is struck in a vessel filled with highly compressed air, than when struck with the same force in a vessel of air of the common density. Hence, too, it happens that when a pistol is fired on the top of a high mountain, where the air is comparatively rare, the report is not so loud as when it is fired at the base.

9. That liquids conduct sound with no less facility than air may be ascertained by ringing a bell under water, when it will be heard as distinctly as when rung above the water. And a person diving under water would plainly hear the sound of a bell struck in the air at a moderate distance. If both the hearer and the sounding body be immersed in the same mass of water, the sound will appear much louder than when passing through an equal extent of air.

10. The propagation of sonorous vibrations through liquids may be rendered visible; for, on rubbing gently with a wet finger the edge of a drinking-glass, half filled with water, sound will be produced, and the surface of the water will be covered with minute undulations. The intensity or loudness of sound in fluids appears

What function does the air perform in regard to the sonorous body and to the ear?

What experiment proves the necessity of a medium for the transmission of sound?

What is the effect of highly condensed air on the loudness of sounds produced within it?

What other evidence is afforded of the effect of pressure on the intensity of sound?

How can we prove that liquids conduct sound?

Does it appear from experiment that liquids are better or worse conductors of sound than air?

How is the propagation of sonorous vibrations in liquids rendered visible?

to be augmented in proportion to the increase of their specific gravity. Thus water, being so much denser a fluid than air, sounds produce a stronger effect in the former medium than in the latter; and therefore it may be regarded as a wise provision of the Author of Nature, that the organs of hearing in fish are much less perfectly developed, and consequently less sensible to the impressions of sound than those of terrestrial animals.

11. Solids, when they possess elasticity, convey sounds to the ear more readily and effectively than gases or liquids. If a person, hard of hearing, places one end of an iron rod between his teeth, while the other end rests on the edge of an open kettle, he will understand what is said by another directing his voice into the kettle, more distinctly than if the voice of the speaker passed through the air, so that he might converse in this manner with any one at a distance at which he would not hear under common circumstances. When a stick is held between the teeth at one extremity, and the other is placed in contact with a table, the scratch of a pin on the table may be heard though both ears be stopped. When sounds are propagated in this manner, the sonorous vibrations must be conveyed through the mouth and along the Eustachian tube to the interior part of the organ of hearing.

12. Among the evidences of the transmission of sound through solid bodies, may be mentioned the common experiment of tying a ribbon or a strip of linen, cotton, or flannel, to the upper part of a large poker, so that it may be supported vertically by holding the two ends of the ribbon; which are to be brought in contact with the ears, and pressed against them, so as to close them, then on swinging the poker so that it may strike as gently as possible against a bar of the fire-grate, or any other metallic substance, a deep sound will be distinctly heard like the tolling of a large bell; and yet if the ribbon be removed from the ears, and the poker suspended by it, and struck in the same manner, the sound will be hardly perceptible. Some experiments will subsequently be noticed, which show that sound not only passes much more readily through elastic solids than through air, but also that it traverses the former with abundantly greater velocity.

13. That peculiar kind of motion in bodies which gives rise to the sensation of sound has been characterized by the term vibration, because a striking analogy may be traced between the tremulous agitation which takes place among the particles of a sounding body, and the oscillations of a pendulum. The nature of sonorous vibrations may be illustrated by attending to the visible

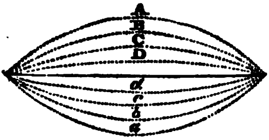
According to what circumstance does their conducting power appear to be augmented?

What conducting power for sound is possessed by elastic solids compared with that of other classes of bodies?

In what manner may a person partially deaf be enabled to carry on a conversation?

What easy experiment illustrates the transmission of sounds by solids?

What name is given to the motion by which sound is produced?



motions which occur on striking or twitching a tightly-extended cord or wire. Suppose such a cord represented by the central line in the marginal figure to be forcibly drawn out to A, and let go, it would immediately recover its original position by virtue of its elasticity, but when it reached the central point it would have acquired so much momentum as would cause it to pass onward to *a*, thence it would vibrate back in the same manner to B, and back again to *b*, the extent of its vibration being gradually diminished by the resistance of the air, so that it would at length return to the state of rest. The string of a violin or a harp drawn aside thus, and suffered to vibrate freely, would propagate its vibrations to the body of either instrument and to the surrounding air, and thus a tone or musical note would be produced and rendered perceptible to the ear.

14. The air usually encompassing sounding bodies on every side conveys the sensation of sound in all directions; therefore the aerial vibrations, or, as they have been termed pulses, must be communicated successively and generally throughout the whole space within the limits of which they are capable of affecting the ear. We may conceive this to happen in consequence of minute expansions and contractions of the particles of air, which, thus pressing on the contiguous particles around them, excite corresponding motions, extending every way from a common centre.

15. These soniferous undulations of the air have been compared to the waves spreading in concentric circles over a smooth pond of water when a stone is thrown into it. And thus as the liquid waves are propagated not only directly forward from the centre, but also if they encounter any obstruction, as from a floating body, they will bend their course round the sides of the obstacle and spread out obliquely beyond it,—so the undulations of air, if interrupted in their progress by a high wall, or any similar impediment, will be continued over its summit, and propagated on the opposite side of it. From this description of the nature of sonorous vibration it will be perceived to consist of the alternate dilation and compression of certain portions of air or other bodies acting mechanically, so as to cause corresponding effects throughout a given space; and the motion thus originated, produces no permanent change of place among the particles of the sonorous mass, but simply an agitation or tremor, so that each particle, like a

What figures are successively assumed by a string or wire thrown into a state of vibration?

What purpose is served by the *body* of a stringed instrument?

How are aërial vibrations or *pulses* communicated?

How may this communication be accounted for without supposing the particles of air to move out of their respective places?

To what have soniferous undulations been compared?

What analogous effects favour the supposition of their similarity?

pendulum that has been made to oscillate, recovers at length its original position. Hence sound is communicated through the atmosphere by the propagation of minute vibrations of its particles from one part of the fluid mass to another without any translation in motion of the fluid itself.

16. "Perhaps we may most distinctly conceive the kind of fact here spoken of, by comparing it to the motion produced by the wind in a field of standing corn: grassy waves travel visibly over the field in the direction in which the wind blows, but this appearance of an object moving is delusive. The only real motion is that of the ears of grain, of which each goes and returns as the stalk stoops and recovers itself. This motion affects successively a line of ears in the direction of the wind, and affects simultaneously all the ears of which the elevation or depression forms one visible wave. The elevations and depressions are propagated in a constant direction, while the parts with which the space is filled only vibrate to and fro. Of exactly such a nature is the propagation of sound through the air. The particles of air go and return through very minute spaces, and this vibratory motion runs through the atmosphere from the sounding body to the ear. Waves, not of elevation and depression, but of condensation and rarefaction, are transmitted; and the sound thus becomes an object of sense to the organ."*

17. That vibration of the particles of bodies which has been indicated as the cause of sound must have a certain degree of velocity in order to produce the required effect. An extended cord may be so slack that when made to vibrate it will yield no sound, its motion being too slow and weak to propagate sonorous undulations through the surrounding air. In order that sound may be procured the tension of the cord must be increased; and it will then be found, that the length remaining unaltered, the number of vibrations in a given time will be augmented in proportion to the additional tension of the cord.

18. It has been ascertained by experiment that a vibrating cord will not produce a sound distinctly appreciable by the most delicate ear, when it makes less than about 32 vibrations in a second.† But the susceptibility of the organs of hearing to grave or acute sounds appears to be different in different individuals. There are some curious observations on this subject in a paper published in

To what natural appearance may we compare the soniferous waves?
Of what real nature are the waves of air?
Will every degree of tension in a cord enable it to produce audible sounds?
What has experiment proved in regard to this matter?
Are all ears equally susceptible to the same classes of sound?

---

* Whewell's Astronomy and General Physics considered with Reference to Natural Theology, b. i. ch. xiv. pp. 117, 118.

† Savart asserts that he has proved by experiment, that a perceptible sound is produced by a cord giving *eight* single vibrations in a second.—Ed.

the Philosophical Transactions, by Dr. Wollaston, "On Sounds Inaudible by certain Ears." The attention of this ingenious philosopher was attracted by the circumstance of finding a person insensible to the sound of a small organ-pipe, which, with respect to acuteness, was far within the limits of his own hearing. He was hence led to try the effect of different modes of weakening the sense of hearing in himself; and he found that by closing the nose and mouth, and expanding the chest, the membrane of the drum of the ear, being subjected to extraordinary tension by external pressure, made the ear insensible to grave tones, without affecting the perception of sharper sounds.

19. This fact affords some evidence in favour of the opinion that the membranous drum of the ear, by means of its apparatus of bones and muscles connecting it with the internal membrane over the labyrinth, is capable of tension and relaxation so as to adapt itself to receive and transmit aërial undulations having different degrees of velocity; and hence it may be concluded that the power of perception of low or high tones depends on the state of the membrane of the drum and parts united to it.

20. The range of human hearing includes more than nine octaves, the whole of which are distinct to most ears, though the vibrations of a note at the higher extreme are six or seven hundred times more frequent than those which constitute the gravest audible sound; and as vibrations incomparably more frequent may exist, we may imagine, that animals like the Grylli (crickets or grasshoppers), whose powers appear to commence nearly where ours terminate, may hear still sharper sounds, which we do not know to exist; and that there may be insects hearing nothing in common with us, but endued with a power of exciting, and a sense that perceives the same vibrations which constitute our ordinary sounds, but so remote that the animal who perceives them may be said to possess another sense, agreeing with our own solely in the medium by which it is excited, and possibly wholly unaffected by those slower vibrations of which we are sensible."*

21. Though sound may be propagated through an infinite mass of air to very considerable distances, yet its intensity or loudness diminishes in proportion as the sonorous vibrations extend from the spot where they are produced. The rate of diminution of in-

What facts did Dr. Wollaston observe on this subject?

In what manner may the sense of hearing for grave tones be voluntarily weakened?

On what is the power of perceiving sounds of different degrees of acuteness probably dependent?

How extensive is the range of human hearing?

What difference in the degree of frequency must exist between the extremes of the audible scale?

What are probably the endowments of insects in regard to sound?

How is the intensity or loudness of sounds affected by the distance from the sonorous body?

---

* Abstracts of Pap. in Philos. Trans., vol. ii. p. 133.

tensity may be inferred from mathematical calculation as well as ascertained by experiment; and the results, which confirm each other, show that other circumstances being alike, the intensity of sound will be the inverse ratio of the square of the distance of the place of observation from the sounding body. The distance to which sound can be transmitted through the atmosphere, depends in some degree on the direction of the wind and local circumstances. Most persons residing within a few miles of a very large bell must have observed that the sound of it will be audible or otherwise, in certain situations, according to the quarter from which the wind blows. Under favourable circumstances sounds may be conveyed to great distances. Instances are recorded of the report of a cannon having been heard thirty leagues from the place where it was fired.*

22. The absolute velocity with which sound is propagated must depend on the nature of the medium by which it is conveyed. Atmospheric air being the general medium of sound, the investigation of its conducting power has at different periods occupied the attention of men of science. Cassini, Picard, and Roemer, members of the French Academy of Sciences, in the latter part of the seventeenth century, made experiments from which they inferred that sound travels 1172 feet in a second of time; Dr. Halley, and Flamstead, the astronomer royal, who pursued the inquiry in England, were led to the conclusion that the common velocity of sound was 1142 feet in a second; and this deduction was confirmed by the varied and extensive researches of Dr. Derham, in consequence of which it has been generally adopted by subsequent writers on this branch of science. This statement, however, is now considered as requiring some correction on account of the influence of temperature; and from a comparison of the experiments of Derham made in the day-time, with some more recent nocturnal observations of French academicians, it appears that the actual velocity of sound, at the zero of temperature of the centigrade thermometer (32 deg. of Fahrenheit) is about 1130 feet in a second; which likewise agrees with other accurate experiments of professor Pictet of Geneva.

23. By adopting either of the numbers last stated sufficiently correct calculations may be made of the distances of objects as inferred from the relative velocities of light and sound; the for-

According to what law does it vary?
On what does the absolute velocity of sound depend?
What is the absolute velocity of sound in air at 32° Fahrenheit?
How is a knowledge of that velocity applicable to the measure of distances?

---

* When the explosion of the volcano of Cotopaxi, in Peru, took place, in January 1803, the noise it occasioned was heard day and night, like continued discharges of artillery, at the port of Guayaquil, 52 leagues distant, by the travellers Humboldt and Bonpland.—Edinburgh Review for Nov. 1814, vol. xxiv. p. 142; from Humboldt's Researches.

mer from its extreme celerity being regarded as appearing instantaneously* on its production, at distances not exceeding a few miles. Thus supposing a flash of lightning to be perceived, and on counting the seconds that elapse before the thunder is heard, we find them to amount to 3½; then if we reckon the velocity of sound at the rate of 1130 feet in a second, it will follow that the thunder-cloud must be distant $1130 \times 3\frac{1}{2} = 3955$ feet. In the same manner may be discovered the distance of a ship at sea, if we see the flash of a gun fired from it, and ascertain the number of seconds that elapse before the report becomes audible. In defect of a stop-watch a rough estimate of time may be made by any person, by counting the pulsations of the artery at his wrist, which in most young people in health will amount to about 70 in a minute.

24. Sounds are propagated with greater or less velocity through gases according to their density; and thus a sharper tone will be produced by a sonorous body in hydrogen gas than in atmospheric air, and a graver tone by the same body in carbonic acid or fixed air. Vapours of water, spirit of wine, or ether, are capable of conveying sounds with degrees of facility proportioned to their respective densities, as appears from experiments made at Arcueil, near Paris, by Biot, Berthollet, and Laplace, the first-mentioned of whom published an account of their investigations in 1807. The vapour of ether conveys sound almost as readily as atmospheric air; for a bell, the sound of which in air could be heard at the distance of 158.5 yards, was heard in the vapour of ether at that of 143.7 yards.†

25. Experiments on the conduction of sound by water were made a few years ago, by Messrs. Colladon and Sturm, in the lake of Geneva. The method of operation was to sink a large bell several feet below the surface of the water, strike it a smart blow with a hammer, the handle of which at the same instant brought a blazing port-fire in contact with half a pound of gunpowder to produce a signal. The sound was heard nine miles by means of a species of ear trumpet, sunk in the water, and having a broad spade-like surface facing the direction in which the sound came. The times were accurately noted, and the distances having been carefully determined by triangulation, the velocity, per second, was found to be 4709 feet.‡

To what expedient may one resort when not furnished with a time-keeper to note the time elapsed between the perception of light and of sound in any given explosion?

How are the different gases related to each other in regard to the transmission of sound?

With what proportionate velocities do the vapours of different liquids conduct sound?

In what manner has the conducting power of water been determined?

---

* See Treatise on *Optics*.

† See Nicholson's Philosoph. Journal, 1812, 8vo. vol. xxx. pp. 169. 173.

‡ See Annales de Chym. et de Phys. vol. xxxvi

26. Examples have been already adduced of the facility with which solid bodies transmit sounds. To these it may be added, that the North American Indians avail themselves of this property of solid matter, applying their ears close to the ground in order to discover the noise made by approaching enemies, when the distance is too great for the sounds to be conveyed through the air. Upon the same principle is founded the utility of the stethoscope,* an instrument invented some years since by Dr. Laennec, a French physician, to ascertain the state of the cavities of the body, especially the chest, as to health or disease. It consists of a wooden cylinder, one end of which being placed in contact with the surface of the body to be examined, and the other resting against the ear of the observer, then by gently striking the body with the knuckles or otherwise, sounds will be perceived indicative of the existence of abscess, schirrus, or any other alteration of structure which may have taken place.

27. Dr. Chladni, a German philosopher, who distinguished himself by his investigations relative to acoustics, estimated the velocity of transmission of sounds by the tone produced by vibration, or in other words, by the musical note emitted by a rod or bar of any substance when struck. By thus comparing the sound of a rod made to vibrate longitudinally with that of a column of air vibrating in a tube of the same length, he found that the velocity of sound in air being represented by 1, the velocity of sound transmitted by tin would be - - - - - - - 7½

By silver	9
By copper	12
By iron	17
By different kinds of wood	from 11 to 17

Iron and glass appear to be among the best conductors of sound, which they transmit at the rate of 17,500 feet, or more than 3 miles in a second.

28. Some very interesting experiments on the capacity of solids to conduct sounds were made by M. Biot, at Paris, in which the research was prosecuted by more direct means than those last stated, and different results were obtained, whence the velocity of the transmission of sound through cast iron appears to be inferior to the preceding estimate. M. Biot took advantage of the circumstance of laying down trains of cast-iron pipes in the French metropolis to form an aqueduct 3120 feet in length. At one ex-

What peculiar use do the American Indians make of the conducting power of solids?

What purpose does it serve in the practice of medicine?

What is the construction and use of the stethoscope?

What is the relation of the metals to each other in regard to the conduction of sound?

What solids appear to be among the best conductors of sound?

In what manner did Biot determine the relative conducting power of iron and of air?

* From the Greek Στῆθος, the breast, or chest, and Σκοπέω, to examine.

tremity of the tubes was fitted a ring of metal of the same diameter as the orifice, in the centre of which were fixed a clock-bell and a hammer which could be made to strike at pleasure, in such a manner that the hammer would fall on the bell and on the ring of metal just mentioned at the same instant: thus the sound of the latter being transmitted through the solid metal or tube itself, and that of the former through the aërial canal or cavity of the tube, the perceptible difference of the time of transmission by the respective mediums might be determined. It was found that by placing the ear against the other extremity of the pipe two sounds were distinctly heard, and the time being very accurately noted, by means of a seconds watch, it appeared from a mean of many experiments that sound is transmitted with 10½ times greater velocity through cast iron than through air, travelling through the former at the rate of 11,865 feet in a second.

29. It is a commonly-received opinion that acute and grave sounds are transmitted in all directions with equal velocity; and an experiment made by M. Biot on the same train of pipes that served for those just recorded tends to confirm it. He caused a man at one extremity of the train to play various airs on the flute, placing himself at the other end to observe the effect. Now a piece of music consisting of a series of notes varying from acute to grave and the contrary, and forming a peculiar melody, adapted to a certain measure, which regulates strictly the intervals of the successive tones, it must follow that if at the distance of 3120 feet any difference had been perceived in the velocity of the different notes, the music would have become confused and imperfect at the distance just stated. This, however, was by no means the case, the melody being as perfect when thus listened to as in the immediate focus of the sounds.

30. There can be no doubt that acute and grave sounds are transmitted through spaces of no very considerable extent without any perceptible difference of velocity; for otherwise there could be no such thing as harmony, or the concord of sounds varying in tone or pitch, except in the immediate vicinity of the source of sound. But that all sounds pass with equal celerity through the same medium to any imaginable distance seems improbable; and more numerous and precise experiments than have hitherto been made would be requisite in order to enable us to decide the point in question.

31. Sounds certainly in some respects interfere with each other. Thus one sonorous body being made to vibrate, all others near it

What was the result of his experiments?

What is the rate of transmission of grave compared with that of acute sounds?

How did Biot conduct his experiments on this subject?

Why are we allowed to suppose an equally rapid transmission for sounds of all degrees of acuteness?

What occurs when of several sonorous bodies near each other, and tuned to accord, one is thrown into a state of vibration?

capable of producing the same tone will vibrate also; and therefore when one body is made to produce a certain note, probably its soniferous vibrations would be checked or interrupted by the emission of a more powerful or discordant sound from another body near it. Hence weak sounds generally are drowned by loud ones; and on the contrary, during the silence of night, many gentle sounds become perceptible which, amidst the din arising from daily labour, business, and pleasure, especially in a crowded city, are completely stifled ere they can reach the ear.

Theory of Musical Sounds.

32. Most persons, in whom the sense of hearing is perfect, possess the faculty of distinguishing certain relations between sounds differing in tone, that is, being more or less grave or acute one than another; and such persons are said to have a *musical ear*, or *an ear for music*,* because pieces of music consist of combinations of such tones or sounds as those just mentioned. The manner in which musical sounds are formed by different instruments, and the peculiar circumstances on which their mutual relations depend, will now be the subject of investigation.

How are weak sounds affected by the occurrence of more powerful ones in their vicinity?

What is meant by "*a musical ear?*"

* There are persons who, though endowed with the sense of hearing in perfection, yet appear to be utterly destitute of an ear for music. They seem to have no perception whatever of the pleasure generally excited by successions of melodious sounds, and therefore (if their own professions are to be believed) they cannot properly distinguish one tone from another, or discriminate between the noise of an itinerant music-grinder and the performance of a musician possessing exquisite skill and taste. It would be unreasonable and unjust to attribute the alleged indifference of such persons to caprice, and to doubt their veracity; for it would be difficult to point out any motive which could induce a person to counterfeit an insensibility to the "concord of sweet sounds." The writer of this note heard a clergyman of his acquaintance, after having witnessed the singing of Catalani, declare that he was utterly unable to ascertain in what respect her performance excelled that of a common ballad-singer, gravely averring that he thought the melody of the one just as agreeable as that of the other. It is deserving of notice that individuals distinguished for poetical talent have been destitute of an ear for music. This was the case with the celebrated poet Pope, one of the most exquisitely skilful masters of the melody of verse that ever existed, who was unable to perceive any difference between the compositions of Handel and the vilest attempts of a wandering fiddler. It appears, likewise, that a highly distinguished poet of the present age, Sir Walter Scott, though not incapable of enjoying music when performed by others, was utterly unable to acquire a practical knowledge of music; and that when young, having been placed under the tuition of an eminent teacher of music at Edinburgh, the attempt to instruct him was relinquished, after a short time, on the ground that he was totally deficient in that indispensable requisite for acquiring the art—a musical ear.—See Annual iography, vol. xvii. p. 179.

33. It has been already stated that the character of a sound as to gravity or acuteness, is determined by the number of vibrations in a given time made by the sounding body, and thence propagated through the air, or some other medium, to the ear. A sonorous body, as for instance, a bell, the dimensions and general form of which remain unaltered, will, when struck, always emit the same sound; for though its sonorous vibrations may be more or less powerful according to the manner in which it is struck, they will always be isochronous, or equal in equal times. Suppose then a series of three bells to differ relatively in size, so that the largest should vibrate when struck 256 times in a second, the next 512 times, and the smallest 1024 times, it would be found that the first bell would yield the sound or tone called middle C of the piano-forte or harpsichord, or that note produced by pressing down the central key of the instrument; the second bell would yield a tone an octave above the former; and the third bell one an octave higher still; for the larger bell would yield the graver sound.

34. The number of vibrations which take place in a sounding body, and the consequent tone which it yields, depend on several circumstances connected with the peculiar form and consistence of the body; and hence the variety of musical instruments, the distinguishing properties of which depend on the diversity of modes in which harmonious sounds can be formed and propagated. The manner in which the tones are emitted by an extended string or wire will afford an example of the modifications of sound produced by alterations of the state and condition of the string as to its dimensions and tension.

35. 1. When two strings of equal diameter are equally stretched, the relative numbers of their vibrations, and of the consequent tones they yield, will be in the inverse ratio of their lengths: thus if two strings A and B have the same size and tension, and if A have double the length of B, the former will vibrate only half as many times in a second as the latter, and will yield a note an octave below the latter.

2. When strings have the same length and tension, the numbers of their vibrations and respective tones will be in the inverse ratio of their diameters.

3. When strings have the same diameter and the same length, the numbers of their vibrations and relative tones will be in the

What remarkable examples may be cited of persons wanting this faculty?

What relation always subsists between the vibrations of a sonorous body of invariable dimensions?

What numbers of vibration must three bells make in order that their tones should be an octave apart, and the lowest one correspond with the middle C of the piano?

On what circumstances does the number of vibrations in a sounding body depend?

What relation subsists between the numbers of vibrations compared with the *lengths* of strings?

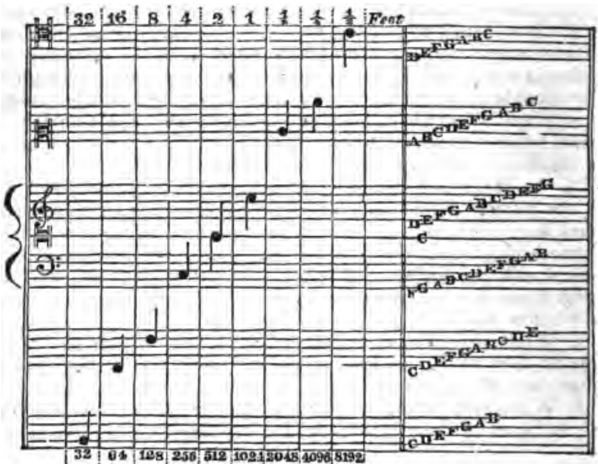
What, compared with their *diameters*?

direct ratio of the square roots of the weights by which they are stretched.

36. It will easily be conceived that a string may be extended so slackly, that when made to vibrate, no audible sound will be produced; and from experimental observations it may be inferred that a string vibrating less than eight * times in a second will not yield a perceptible sound.

37. Columns of air included within tubes, when thrown into the state of sonorous vibration, yield tones bearing certain relations to their lengths; and other circumstances remaining unaltered, a tube of any given length capable of yielding a musical tone, will, when reduced to half that length, yield a tone an octave higher than before. The following scale will show the relative lengths of open tubes requisite to produce a succession of octaves, commencing from the lowest audible sound, and with the numbers of the vibrations taking place during the emission of each sound.

Scale of Octaves corresponding with certain lengths of open Organ-pipes.



Semi-vibrations in one Second.

38. Those who have any acquaintance with musical notation will, on inspection of the preceding table, perceive that the third

What, compared with the stretching weights or *tensions?*

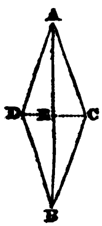
What is the relation, in point of acuteness, between the tones of a pipe of a given length and of one but half that length?

Through how many octaves in music may pipes rise by diminishing their length from 32 feet to 1½ inches?

* As proved by Savart.—Revue Encyclopedique. Juillet, 1831, and Ann. de Chim. vol. xxxvi.—Ed.

and fourth staves marked with the treble and bass clefs, with the single line between them, include three octaves, while the lines above the treble clef and those below the bass clef may all be considered as so may ledger lines. Persons who have no knowledge of music may be informed, that this scale of nine octaves not only includes the utmost range of musical tones ever employed in practice, but also that the notes at either extremity of the scale are rarely introduced, but few instruments being adapted for the production of such tones.

39. The numbers at the bottom of the foregoing scale denote the half vibrations performed respectively in a second by the several columns of air whose lengths are stated above. Sonorous vibrations, like those of a pendulum, extend on either side of the point occupied by the vibrating body when in the state of rest.



Suppose A B, in the marginal figure, to be an extended string or wire; if it be drawn aside to C, and suffered to vibrate, its oscillations will carry it alternately on either side of the central point E; and its passage from C to E may be termed a semi-vibration, but when it has arrived at E, its momentum will cause it to proceed to D, and thus a complete vibration must include a certain space on either side of the central point or line of rest, to which the string will gradually return as its motion progressively declines through the resistance of the air.

40. If we consider the manner in which sound is propagated, it will be manifest that it can only affect our ears by means of semi-vibrations, for the sonorous undulations of air or any other conducting medium consist of contractions and dilations through indefinitely minute spaces; and the impression of any particle of air on the drum of the ear must be made in its semi-vibration towards the ear, while the corresponding semi-vibration will act in the opposite direction.

41. Hence, in estimating the relations between the tones of a sonorous body, as the string of a harp or pianoforte, and the number of its isochronal vibrations, it is usual to reckon the complete vibrations; and therefore the number of effective or perfect vibrations answering to each of the notes in the preceding scale will be just half the number stated at the bottom of the scale; and these numbers will correspond with those of the sonorous vibrations of bells mentioned above.

42. Musical instruments yield not only octaves, but also a

How extensive is the actual range ordinarily employed in musical composition?

What resemblance exists between the oscillations of a pendulum and the vibrations of sonorous bodies?

How is it customary to reckon the number of vibrations of a sonorous body?

What is the difference between one tone and another on a musical instrument, commonly called?

variety of intermediate tones, which have certain relations to each other; and the difference between one tone and another, is termed an interval. When two tones or notes sounded together produce an agreeable effect on the ear, the combination is called a musical concord; and when the effect is disagreeable, it is called a discord. It appears from experiment, that any two notes will form a consonance or concord, more or less perfect in proportion as the relation between the numbers of their vibrations is more or less simple. Thus if one note is the result of a number of vibrations double that of those belonging to another note, the former will be an octave to the latter, and their vibrations will be relatively as 2 to 1.

43. It has been already shown, that any series of vibrations successively duplicates of those preceding them will form so many octaves, all denoted in the gamut or musical alphabet by the same letter. Indeed the agreement between notes produced by a series of vibrations, when those corresponding with the higher or acuter note are exactly double, quadruple, eight times, &c., those corresponding with the lower note, is so perfect, that in musical composition, octaves are considered as having the same effect with notes whose vibrations are equal, and which are therefore said to be in unison.

44. The common musical scale or gamut includes seven intervals, between one octave and that next above or below it, and consequently it consists of eight notes taking in the two octaves. These notes have been distinguished by certain names, each formed of a single syllable; but it is more usual for teachers of music, in this country at least, to designate the notes by the first seven letters of the alphabet, and thus the octaves are always denominated by the same letter as that from which the scale begins.

45. In any series of notes or tones the number of corresponding vibrations will always increase in a certain ratio to the increased acuteness of tone; and on the other hand, if the notes be produced by a string of a given diameter and tension, its length must decrease in proportion to the increase of sonorous vibrations and acuteness of tones. The relations between the numbers of sonorous vibrations and the lengths of strings required for the production of the notes forming a single octave will appear from the following table of the notes of the gamut, or diatonic scale:

What is meant by the terms *concord* and *discord?*

How is the relation of the numbers of vibrations required for two notes, connected with their respective effects on the ear?

What relation has the number of vibrations in a string producing a given tone to that of another sounding an *octave* below?

How are octaves regarded in musical composition?

How many intervals has the common musical scale or gamut?

How are the notes designated?

How will the number of vibrations in any series of notes always be compared to the acuteness of tone?

When a string of given diameter and tension is considered, how will the acuteness of notes vary?

	Names of Notes.	Relative Number of Vibrations.	Relative Lengths of Strings.
C	ut	1	1
D	re	9-8	8-9
E	mi	5-4	4-5
F	fa	4-3	3-4
G	sol	3-2	2-3
A	la	5-3	3-5
B	si	15-8	8-15
C	ut	2	1-2

46. Such is the musical scale that appears to be founded on the relations between sonorous vibrations and the perceptive powers of man; for it has been generally adopted with slight modifications by the inhabitants of all countries with whose music we have any acquaintance. A comparison of this table with the scale of octaves in a preceding page will show how the gamut may be applied to successive octaves, the notes in every octave being divided by similar intervals from each other.

47. The eight or rather seven notes of the gamut (the last being an octave of the first,) are not however separated by equal intervals. On observing the relations between the different numbers of vibrations, we shall find that the relation or interval between C and D is as 8 to 9; that between D and E, as 9 to 10; between E and F, as 15 to 16; between F and G, as 8 to 9; between G and A, as 9 to 10; between A and B, as 8 to 9; and that between B and C, as 15 to 16. Thus it appears that the intervals $\frac{C}{D}$, $\frac{D}{E}$, $\frac{F}{G}$, $\frac{G}{A}$, and $\frac{A}{B}$, are nearly equal; and they are therefore regarded as whole tones; but the intervals $\frac{E}{F}$ and $\frac{B}{C}$ are but little more than half either of the others, and hence they are named semi-tones. In transposing pieces of music from one key to another, attention must be paid to the places of the semi-tones, and hence the principal use of the marks called flats and sharps; the effect of which cannot be understood without some practical acquaintance with music.

48. But though this gamut or musical scale may be considered as the groundwork of all existing music, it must be admitted that it does not appear to have been always known or adopted in its present state, but to have formerly consisted of those notes only which are separated by complete intervals or whole tones; for, in the old Scotch and Irish tunes, the semi-tones are wanting, and hence the peculiar effect of the national music of those nations. And it has been stated that the oldest national airs

What is the relative number of vibrations required to produce G of the diatonic scale, when the C below it is produced by a number taken as unity?

What will be the relative lengths of string in the two cases?

On what is the generally received musical scale apparently founded?

Are all the intervals of the gamut equal?

State the actual intervals between the several letters.

Of what did the gamut formerly consist?

What notes of the scale are wanting in the music of several nations?

of the Orientals, the people of the North of Europe, and even those of the Italians, exhibit the same characteristic omission of the notes F and B, thus increasing the intervals now occupied by the semi-tones in the received scale, so as to make them exceed whole tones.

49. The combination of notes into a successive series, in which one musical tone or sound is heard at a time, constitutes melody or air in music; while the synchronous production of sounds, or the union of two or more successions of musical tones is requisite to form harmony or music in parts. There is thus a radical distinction to be made between melody and harmony, sometimes improperly confounded, the former consisting of music cimple and unaccompanied, and the latter of music in a more complex and artificial form.

50. The construction of harmony or composition of accompaniments for musical airs requires an acquaintance with the concords and discords of the scale of notes; in order that the composer may know how to introduce them in such a manner as to gratify the ear and produce the highest effect. Next to the octave, the most perfect consonance of tones is that produced when the numbers of the vibrations of two notes are in the ratio of 3 to 2, or when the lower note is formed by a string or other sonorous body which makes but 2 vibrations, while the string forming the higher note makes 3 vibrations. Such a concord is called a fifth, as $\frac{G}{C}$ in the preceding table; C, the lower note, being formed by a string which may be 1 foot in length, and G, the fifth note above it, by a similar string only $\frac{2}{3}$ of a foot in length.

51. If the ratio of the vibrations be as 5 to 4, that is, if the lower note makes 4 vibrations in the same time that the higher makes 5, the concord called a third will be produced, as $\frac{C}{E}$. When the ratio of the vibrations is as 5 to 3, the lower note making 3 vibrations while the higher makes 5, the concord called a sixth will be produced, as $\frac{C}{A}$. And if the ratio of the vibrations be as 4 to 3, the lower note making 3 vibrations while the higher makes 4, the interval will be a fourth, as $\frac{C}{F}$, which is sometimes reckoned a concord, as the effect in harmony is not unpleasing. The same observation will apply to the minor third, in which the ratio is that of 5 to 6, as $\frac{E}{G}$; and the minor sixth, in which the ratio is as 5 to 8, as ^{E}, the lower note E making 5 vibrations, while the higher C makes 8.

52. The discords are the second and seventh, the former of

What constitutes melody?

To what art is the knowledge of musical concords and discords requisite?

Which concurrence of notes gives next to the octave the most agreeable impression?

What are the relative numbers of vibrations produced by strings yielding the concord of *fifths?*

How is the *third* produced? *sixth? fourth?*

How are the minor *third* and the minor *sixth* respectively produced?

Which two sets of notes sounding together produce the *discords?*

which produced by two notes sounding together, the interval between which is only a tone or a semi-tone, is particularly disagreeable. The major seventh is the discord produced by notes whose vibrations are in the ratio of 9 to 16, as $\frac{D}{C}$; and the minor seventh is also a discord, arising from notes whose vibrations are in the ratio of 8 to 15, as $\frac{C}{B}$: both these are sometimes introduced.

53. The absolute number of vibrations necessary to constitute any given tone or musical note can hardly be determined with perfect accuracy; for the tone of an instrument which might be presumed to be permanent, as a bell or an organ-pipe, can hardly be supposed to be unaffected by the state of the air; besides which, there may be other circumstances which may cause occasional variation in the number of the sonorous vibrations even of a bell. Nor is it probable that the vibrations of a string or wire, under the same circumstances of length, diameter, and tension, would yield exactly the same number of sonorous vibrations, in different states of the atmosphere, and under different degrees of temperature.

54. Hence considerable difficulties would attend any attempt to ascertain by experiment the relations between sounds or tones, and the vibrations of the sounding bodies. It appears, however, from a paper in the Memoirs of the Royal Academy of Sciences at Berlin, 1823, that some results have been obtained, as the fruit of experimental researches, which agree as nearly as could be expected with theoretical estimates previously made, and which may therefore serve as the basis of future calculations of the numbers of sonorous vibrations corresponding with the different tones and semi-tones of the musical scale.

55. The tone or note whose corresponding vibrations have been made the particular object of investigation is that marked A, occupying the second space from the bottom in the stave distinguished by the treble clef, being the note produced by the third string of the violin, and a sixth above middle C of the pianoforte. The following are the numbers of the vibrations or waves in a second connected with the note in question, as deduced from observations made in different orchestras:

Theatre at Berlin - - -	437.32
Italian Opera at Paris - -	424.17
French Opera - - - -	431.34
Comic Opera - - - -	427.61

56. The difference between these numbers serves to corroborate the remarks already made on the difficulty of deciding by experiment the absolute number of vibrations which may take place

How are the major and the minor *seventh* severally produced?

Is it certain that the same string or other sonorous body always yields under apparently similar circumstances the same number of vibrations?

What musical note has been the object of particular attention in experiments on this subject?

How near an agreement was found in respect to that note in the four orchestras at which it was examined?

when the perception of any given tone or musical sound is produced. Still the results obtained are valuable, as, by comparing them with calculations made on different grounds, measures of the ratios of sonorous vibrations may be deduced which seem deserving of confidence.

57. The number 426⅔ is nearly a mean between those derived from the observations made in the Parisian orchestras; and by adopting it as that of the number of sonorous vibrations corresponding to the note A formed by the third string of the violin when open, the number 256 will be obtained as that representing the vibrations connected with middle C, or the sixth below A. For since the vibrations of A are to those of C as 5 to 3, those of the former being 426⅔ in a second, those of the latter must be 256; because, as 5 : 426⅔ : : 3 : 256. Now this last number being taken to represent the vibrations corresponding to the note C, marked in music by the tenor clef, the octaves in the descending or ascending scale will be denoted by numbers which are so many duplicate multiples of unity.*

58. When an extended string is made to vibrate by striking it or drawing across it a violin-bow, it will yield a tone depending on its dimensions and tension; but besides this, which may be called the fundamental tone, the string will, when the vibration is caused by striking it, emit not only its fundamental or proper note, but also other relative tones, especially the third and the fifth above the proper note. The co-existence of these relative tones with the principal one depends on the excitement of vibrations corresponding with the divisions of the string which would form the principal concords to the fundamental note. When the string is made to vibrate by means of a violin-bow the sound is simple and distinct, arising from the fundamental tone only.

59. If a single string of a harp or pianaforte be struck, other strings of the same instrument tuned in fifths and thirds to the former will be thrown into the state of sonorous vibration, and as the original tone becomes weaker the relative tones or sympathetic concords will be more distinctly perceived. The effect produced on strings by the vibration of other strings near them, tuned so as to form concords, may be visibly demonstrated by placing small bits of paper bent in the form of the letter V inverted thus Λ on one or more strings, so tuned as to yield tones an octave, a fifth,

What open string of the violin corresponds to the note in question?

What number of vibrations may we assume for its rate of vibration per second?

What will be the number for *middle* C of the piano?

How many times can we divide this number and its successive quotients by 2, before we arrive at 8, the lowest number of vibrations which Savart found to produce audible sounds?

Can a string by a single stroke be made to yield more than a single tone?

Illustrate this position.

---

* See Scale of Octaves, of this article, No. 37.

or a third above a particular string; and, on causing the latter to vibrate strongly, the other strings will suffer corresponding vibrations, as will appear from the bits of paper falling off. Hence singular effects are sometimes produced by the sympathetic influence of sonorous vibrations.

60. An account of some remarkable experiments illustrative of the subject under discussion is given by J. B. du Hamel, a French philosopher of the seventeenth century; which are the more deserving of notice, as they are circumstantially recorded. After observing that a glass cup or goblet may be broken by a man's voice, the writer adds, "First of all it is necessary that the tone which the glass is adapted to yield should be ascertained by ringing it, as may be done by giving it a slight fillip with the finger; then, the voice being accommodated to that tone and gradually augmented in loudness and raised to the octave above the original tone, the imperceptible minute particles of the glass shaken by reiterated concussions will be agitated with tremulous undulations, which, increasing by the continued operation of the concussions, will at length attain such force that the glass will fly in pieces. Some caution is necessary in the choice of a glass, which should be quite clean, free from any lines or flaws on the surface, and capable of yielding such a tone when struck, as the voice of the individual making the trial can easily reach."

61. Another experiment exhibited at the same time or place is also thus described: "Two glass goblets are to be procured, into which water is to be poured to the depth of two or three inches, and they must then, by the addition of more water to one or the other as may be requisite, be made to yield the same tone when struck. This having been effected, if a small portion of bent wire be placed across the edge of one glass, then on rubbing the edge of the other lightly with a wet finger, the sonorous vibrations thus excited will be communicated to the glass with the wire on its edge, and while sound is produced the light fragment of the wire will be seen dancing as it were to the music of the glasses."*

62. The sonorous vibrations of plates or disks formed of elastic solids, as glass or metal, may be traced and rendered visible, by methods pointed out by Dr. Chladni, whose researches concerning the doctrine of Acoustics have been referred to elsewhere. He ascertained that sounds might be elicited from plates of glass

On what does the effect probably depend?
What occurs when a single string of an instrument is struck?
How may this be made visible?
What remarkable effects of sympathetic vibration were obtained by Du Hamel?
In what manner does the experiment succeed with the greatest certainty?
In what manner did Chladni operate to produce musical vibrations in elastic plates?

* J. B. du Hamel Operum Philosoph., t. ii. Norimb. 1681. 4to. pp. 411, 565.

ground smooth on the edges, by drawing the bow of a violin over any part of the edge of such a plate; and that when sand had been previously strewed over the surface of the plate, it would become arranged in certain lines according to the manner in which the plate was supported. M. Oersted, who repeated, with various modifications, the experiments of Chladni, ascribes the production of lines in sand, or any other light powder, as the dust of lycopodium, strewed on vibrating plates, to electricity.*

63. Mr. Faraday has recently proposed a different explanation of these phenomena, which attributes them to the formation of currents in the air surrounding the vibrating plate which, proceeding from the more fixed to the agitated parts of the plate, pass upwards and involve in their vortex any light particles of matter which they encounter. He showed that the current of air could be interrupted by walls of card, when the light particles took different directions. He observed that particles of heavy substances, as sand, went to the lines of rest because the current of air was too weak to carry them in its course; but that light bodies, as powder of lycopodium, being easily affected by the air in its motion, passed in a contrary direction.

64. In confirmation of this view of the subject Mr. Faraday stated that when plates are made to vibrate in water instead of air the effect is different, particles of sand being then carried from the quiescent to the agitated parts of the plate, as the lighter particles were in air; and also, that when plates are made to vibrate in a vacuum, even the lightest particles pass to the lines of rest, there being no current of air to sweep them in the opposite direction.†

65. These peculiar figures formed on vibrating plates, though apparently resulting from simple causes, present sometimes singular appearances. The arrangement of the lines of sand, or other substances, depends on the manner in which the vibrating plate is supported, and the point at which the violin-bow is struck against its border; as also on the form of the plate, and other circumstances already noticed. Some idea of the nature of these figures may be derived from the annexed representations; the first figure being produced by holding a square plate of glass with a pair of tongs in the centre, and passing the bow over the middle of the edge at

To what did Oersted attribute the formation of *nodal lines* in Chladni's experiments?

How did Mr. Faraday explain them?

What occurs when plates vibrate in water?

What in the vacuum of an air-pump?

On what does the peculiar arrangement of sand on the vibrating plate appear to depend?

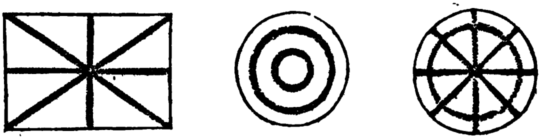
What arrangement of lines will be given by a square plate held by the centre and rubbed with the violin-bow in the middle of one edge?

---

* See Nicholson's Journal of Natural Philosophy. 8vo. vol. x. p. 256.

† Arcana of Science, 1832, p. 77; from Journal, edited at the Royal Institution.

either side; and the other arrangements depend on the shape of the plate and the mode of striking it.



66. It is in consequence of the resonances or sympathetic propagation of sounds, that in a large apartment, tones are sometimes emitted from the walls, floor, ceiling, or furniture; owing to the excitement occasioned by the tone of an instrument or a man's voice acting on some object adapted to yield a tone in concord with the original tone. It may even be observed that one part of a floor or any other surface will be thrown into the state of sonorous vibration by one sound, and another by a different sound; and the tremulous motions thus produced in various objects may be perceived by the sense of touch.

67. The ancient Romans were well acquainted with the doctrine of resonances, and availed themselves of their knowledge in order to facilitate the propagation of sound through their theatres. The method they adopted was to inclose in the walls of those buildings hollow globular vessels, so fixed as to be excited into sonorous vibration by the voices of the actors, and thus add considerably to their effect.

98. Musical instruments, how much soever they may differ one from another as to the mechanical modes by means of which they are made to produce soniferous vibrations, have one common property, namely, that they all yield the same tone relatively to the numbers of their vibrations. Hence the term concert pitch, or the sound of a fundamental note corresponding to a certain number of vibrations performed in a given time by the sonorous parts of several instruments which are to be used in conjunction. Different methods are adopted by musicians for obtaining an invariable tone, from which they may compare and regulate any number of instruments to be used in concert; and the tone of this note being decided, they proceed to adjust the strings of violins, violoncellos, and other such-like instruments, so that they may all correspond with each other, as well as with those instruments which by their construction are fitted to yield permanent tones. This operation is called tuning, or putting instruments in tune.

69. Sometimes the fundamental tone is ascertained by means

What occasions the emission of tones from the walls, floors, and furniture of an apartment?

What advantage was taken of this principle by the ancient Romans?

What common property have all musical instruments?

What is meant by the term concert pitch?

What three methods are employed by musicians to get the invariable tone, or concert pitch?

of a pitch-pipe, which consists of a tube capable of being lengthened or shortened at pleasure by the introduction of a moveable plug; so that by blowing into it at the mouth-piece, either of the notes of the gamut may be produced. Another instrument for obtaining fixed and determined tones is the monochord,* which is merely a string or wire of given length and diameter, the tension of which may be regulated by certain weights hanging from one end, while the body of the string passes over two bridges or other solid supports, and the other end is firmly secured.

70. But the most usual instrument employed by musicians as the index of a fundamental tone is that styled the tuning-fork. It is a steel rod curved nearly into the figure of a sugar-tongs, but having a short handle fixed to the convex side of the curved part, and terminating in a knob: it may be made to yield sonorous vibrations, if it be held by the handle so as to leave the prongs free, and, after striking one of the prongs smartly against the edge of a table or any other solid body, setting the knob against the table. The sound or tone emitted must depend on the dimensions of the rod or its prongs: those that are used for tuning pianofortes or harpsichords yielding the tone called middle C; and other tuning-forks giving the sixth above it, or A, the note which ought to be produced by the third open string of the violin, whence the other strings of that instrument are adjusted.†

71. Instruments of music may be arranged in classes, according to their forms or modes of action. It will be sufficient here to distinguish them into stringed instruments; pulsatory instruments including bells, drums, &c.; those in which sound depends on the vibrations of elastic rods, hemispheres, or plates; and wind instruments. The varieties of the first and the last of these classes are extremely numerous; and many of them were invented at a very early period. It has been questioned which of the two may be justly reckoned the most ancient. A recent ingenious writer seems inclined to decide in favour of stringed instruments. He says, "The lyre or harp is surely as ancient as any instrument on record. The mythologist ascribes the idea of producing sound by the vibration of a string to Apollo; which is said by Censorinus to have suggested itself to him on his hearing the twang of the bow of his sister Diana."‡

72. Among the principal varieties of stringed instruments are the violin, tenor, violoncello, and double bass, in all which the

What is the construction of the monochord?
Into what four classes are musical instruments distinguishable?
Which classes present the greatest variety?
On what circumstance in the action of stringed instruments does the performer chiefly rely for the extension of their range of notes?

* From the Greek Μόνος, one; and Χορδὴ, a chord, or string.

† The tuning-forks of different nations give different tones for the same letter. A London and a Vienna *A* fork have sometimes been found about one-third of a note apart.—Ed.

‡ Philosophy in Sport made Science in Earnest, edit. 1833, p. 300.

relative gravity or acuteness of the tones they emit depends partly on the tension and diameter of the strings, and partly on their lengths, which are regulated by stopping them in certain parts successively by the application of the fingers, principally near the neck of the instrument, while the stopped or open string, as may happen, is made to vibrate by drawing across it a bow armed with horsehair. As more than one string may be put into the state of sonorous vibration at one time, harmony or music in parts, as well as melody, may be elicited from the violin and similar instruments.

73. In the hands of skilful performers the violin exhibits unrivalled powers; as those who have witnessed the magical execution of Paganini, will in general be readily disposed to admit. Those who have never heard him may acquire some faint idea of his extraordinary skill, from the circumstance of his being able to produce abundance of excellent music from his instrument, after having made a monochord of it, by taking away all the strings except one.

74. The guitar somewhat resembles the violin in figure and construction, but it is played on usually by twitching the strings with the fingers, and a variety of notes may be produced by stopping the strings with the left hand, so as to regulate the numbers of their vibrations and consequent tones. The performer generally uses the guitar to furnish an accompaniment to the voice: its power alone being inconsiderable. The harp is likewise played on with the fingers, but its strings are numerous and all open. The pianoforte and the harpsichord have also distinct strings for each tone and semi-tone; and like the harp they are adapted for the performance of music in parts; so that they may serve either for playing symphonies or other pieces of music wholly instrumental, or for accompaniments to the voice.

75. Pulsatory instruments of music display considerable varieties of form, comprising the double drum, the opposite ends of which yield different tones when struck, for the parchment covering one extremity is, by regulating its relative degree of tension, made to yield a sound which is a fifth in tone different from that of the other extremity; kettle-drums consisting of copper hemispheres, the open ends of which are covered with parchment, and two such drums properly tuned being used, they may be introduced instead of a double drum, but will be distinguished by a peculiarity of intonation, though yielding the same notes; the tambourine, a well-known instrument, resembling in principle the preceding; besides some others of a similar nature.

What remarkable fact proves the power of the violin?

In what chief circumstance does the guitar differ from the violin?

For what purpose is it generally employed?

Are the strings of the harp, pianoforte, and harpsichord capable of being varied in tone by alterations of length at the pleasure of the performer?

Enumerate some of the chief pulsatory instruments.

76. Bells, gongs, &c., are open hemispheres, or conical instruments made of some sonorous metals: the latter of which, used in China, are large and very powerful instruments. Among recently-invented musical instruments is one called the Harmonicon, constructed by ranging in one or more lines a number of small oblong disks of glass, each adapted, by its vibrations when struck, to yield one of the notes of the gamut or common musical scale, including two or more octaves according to the size of the instrument: the disks are fixed securely at one end only, so that they vibrate freely on striking them with a hammer much like the hammers of a pianoforte.

77. Glass hemispheres or bell-shaped goblets, fixed in a frame, and tuned to the gamut, by pouring in more or less water, form an agreeable instrument of music, played on by striking the edges with a violin-bow, or by being thrown into the state of sonorous vibration by gently touching them with wet fingers. There are several varieties of these instruments, which, as well as the preceding, have received the names of harmonica,* and harmonic glasses.

78. Wind instruments display no less variety in their construction and mode of action than stringed instruments; and in the opinion of some antiquaries they were invented at a more remote period than the latter. The general principle they involve is that of the production of sounds by the vibrations of columns of air, usually contained in tubes, whose relative lengths and those of the included columns determine the numbers of the synchronous waves or vibrations to which the tones or musical sounds emitted owe their character as to gravity or acuteness.

79. Instruments of this class have been distributed into three kinds: (1.) those in which the contained column of air is made to vibrate by blowing forcibly into one end of an open tube; (2.) those in which the vibration of the air is caused by blowing through a solid mouth-piece, at one end, which merely limits the size and figure of the aperture, and thus adds to the force with which the air is introduced through it; (3.) wind instruments played on with a reed or very elastic mouth-piece, the primary vibrations of which highly augment the sonorous vibrations of the column of air.

80. There is likewise a distinction to be made between tubes open at both ends, without any lateral apertures, and those which have several such apertures, the obvious effect of which must be to lengthen or shorten the tube, or rather the column of air in it,

To what nation is the gong chiefly confined?

How are harmonica constructed?

In what manner may the tones of musical glasses be varied so as to tune an instrument constructed of them?

What circumstance determines the gravity or acuteness of tones given by tubes in wind instruments?

Into how many and what classes are instruments of this nature distinguishable?

on the dimensions of which the sonorous vibrations and concomitant sounds must depend.

81. Among the first mentioned species of wind instruments must be included the trumpet, the bugle-horn, the French-horn, Pan's pipes, and some others, which however they may differ in form, or in the effect of the tones they yield, are all made to sound by blowing through a circular aperture; and from these the German flute is distinguished merely by having the aperture through which air is admitted in the side of the tube, while the end is closed. To the second species of instruments belongs the flagelet, which is played on by means of an ivory mouth-piece, having an aperture of invariable dimensions. The third species of wind instruments comprehends several varieties, some having mouth-pieces possessing a slight degree of flexibility, as the clarionet; others are played on with a reed, forming a highly flexible mouth-piece, as the hautboy and the bassoon. The diversity of sounds produced by different sets of organ-pipes, answering to the respective stops of the instrument, depend on the peculiar forms of the pipes, and especially on the manner in which the air is admitted into them.

82. The Jew's-harp, an instrument too generally known to need description, and commonly despised as utterly insignificant and inharmonious, is however deserving of particular notice, not only as being a wind instrument affording sounds on somewhat different principles from those above described, but likewise because, in the hands of more than one performer, it has been found capable of producing considerable effect, and exciting the admiration of musical amateurs. As the Jew's-harp has no cavity it is almost inaudible when struck, till it is placed between the lips and teeth of the performer, and thus the sonorous vibrations on which its tones depend are formed in the mouth, the tongue or bent wire belonging to the instrument acting the part of a reed.

83. Three tones or notes only can be produced by means of a single harp; the lowest of which may be termed its fundamental note, and the others are its principal concords the third and fifth. From a scale so limited it would be impossible to derive melody, much less harmony; and therefore the instrument was neglected by regular musicians, though commonly used among the peasantry in many parts of Europe, and particularly in the Netherlands and in the Tyrol. Some kind of improvement was effected by the Tyrolese, by uniting two Jew's-harps, or using two at once; and this method was adopted by a Prussian soldier, mentioned in the Memoirs of Madame de Genlis, as having acquired the art of play-

What is the purpose of the *holes* usually seen in instruments of this sort?
Give examples of each of the three classes of wind instruments.
On what do the different tones of organ-stops depend?
What is necessary to the production of sound by the Jew's-harp?
What is its range of scale, and what the notes it can actually yield?
By whom has it been extended and improved?

ing on this instrument with so much skill and taste that he was heard with pleasure and surprise by the king, Frederic the Great, who possessed considerable knowledge of music, and was himself a good performer on the German flute.

84. But to the more recent labours of M. Eulenstein we are indebted for the complete developement of the powers of this little instrument. He devoted ten years to the study of its capabilities, and the means of removing its defects; and having ascertained the compass of tones belonging to it, as stated above, he conceived the idea of extending its power, and supplying the intervals wanting, so as to complete the gamut through several octaves, by joining sixteen Jew's-harps, and then tuning them by fixing more or less sealing-wax at the extremity of the tongue. By means of this construction he effected his object, as by rapidly changing from one harp to another, he could elicit any series of tones, and perform pieces of music, in a manner which delighted and astonished those who heard him.

85. It appears both from theory and experiment, that in the fundamental sound of a tube open at both ends, the portions of the included column of air on the opposite sides of the centre of the tube move in directions contrary to each other. This principle is ingeniously confirmed and illustrated by Mr. Wheatstone, in a paper read before the Royal Institution of London, March 16, 1832; when he exhibited the phenomenon in question, by means of an apparatus consisting of a leaden tube about an inch in diameter and thirteen inches long, bent nearly into a circle, so that its two extremities might be opposite to each other, with a small space between them. Within this space, equidistant from each end of the tube, was held the vibrating part of a square plate of glass thrown into a state of vibration, either by means of a violin-bow, or a hammer, so as to produce its lowest sound, or that denoted by Chladni's first figure. By this arrangement, the plate advancing in its vibration towards one end of the tube, and receding at the same instant from the other, the effects neutralize each other, and no resonance, or augmentation of the original sound takes place. In the middle of the tube was a joint, which allowed either half to move independently round the axis of the tube; and thus the two ends could be brought to the opposite sides of portions of the plate which were vibrating at the same moment on contrary sides of the neutral plane: in this case the impulses were made at the same instant towards each end of the tube, and the augmentation of sound was considerable.* Hence

What remarkable attention has been bestowed on the developement of its powers?

How did Eulenstein tune his instrument?

What appears to be the kind of motion which takes place in the column of air within a tube open at both ends?

Describe Wheatstone's method of exhibiting this principle.

* Report of British Association, p. 556.

it appears that in a tube or pipe, open at both ends, the vibrating column will be double, and therefore only half the length of that in a similar tube closed at one end; so that the latter would yield a tone an octave lower than the former.

86. Mr. Wheatstone investigated the modes of vibration of columns of air in conical tubes, and ascertained that the air in a tube of this form, excited into vibration at its closed end, or at the summit of the cone, yielded the same fundamental sound, and the same series of harmonics as a cylindrical tube open at both ends. Thus he showed that the trumpet, French-horn, and hautboy pipes of the organ, all being conical pipes, produced the same sounds as the cremona pipe, a cylindrical tube, excited in the same manner, and only half their length. He likewise compared the hautboy, a conical tube, with the clarionet, a cylindrical tube of the same length,* and demonstrated that in the former the fundamental sounds were the same, absolutely and relatively, as in the flute, a tube of the same length, open at both ends; and that in the latter the fundamental sounds were relatively as those of a tube of similar length closed at one end.

87. A tube or pipe, the upper aperture or mouth-piece of which is placed close to the lips, as in the case of the trumpet, French-horn, or clarionet, is to be considered as open at the lower end only; and thus its tones are relatively deeper and more powerful than those of the German flute or flagelet, tubes open at both ends; for the aperture through which the flute is blown or made to sound, is not covered by the lips of the performer; and though the mouth-piece of the flagelet is covered in playing on that instrument, it is reduced to the state of a tube open at both ends, in consequence of its having a lateral aperture near the upper extremity.

88. The theory of musical sounds may be elucidated from the consideration of the manner in which tones are produced from the French-horn. As the harmonics or concords of a fundamental note may be obtained by the division of a vibrating string into certain proportions, so the same series of tones may be formed by the spontaneous division and subdivision of the column of air contained in the French-horn. When this instrument is used in concert, it must always be adjusted to a certain length, by increasing or diminishing the number of the cranks, or circular tubes of which it is composed; so that the gravest tone it will yield may correspond with the key-note or fundamental tone of the piece of music

To what result did his investigation lead?

What relation has the tone of a conical to that of a cylindrical tube of the same length?

How is a tube or pipe to be regarded when the mouth-piece fits close to the lips?

How is the French-horn adjusted to a particular concert-pitch?

Which of its notes ought to be adjusted to the key-note?

---

* The bell-shaped part of the clarionet has no effect on its tone.

to be performed. Suppose this tone to be C, if then the horn, properly adjusted, is blown gently, this note will be heard; a stronger blast will double the number of the sonorous vibrations, and produce an octave above the first note; by increasing the force of the blast may be obtained in an ascending series a fifth, then an octave above the second C; then a third, a fifth, and an octave above the third C; then a fourth octave, including nearly all the tones of the common musical scale.

89. Thus in the French-horn, the common bugle-horn, and other instruments formed on the same plan, the different tones are produced by varying the impulse given to the included column of air in blowing them; while in such instruments as the German flute, the same effect is more perfectly obtained by altering the length of the vibrating column, which is done with the requisite ease and rapidity by the apertures alternately opened and closed by means of the fingers or keys.

90. The Æolian harp, in point of construction, is a stringed instrument, but its sonorous vibrations are caused by the impulse of the air; and its tones may be characterized as the music of nature improved by art. It usually consists of an oblong deal box, four or five inches high, and adapted to the aperture formed by nearly closing a sash window, so that the current of air passing through the opening may sweep over wires or harp-strings, extended lengthwise upon the top of the box, in which there must be sound-holes like those of a violin, and the wires are to be supported and stretched by a bridge at either end. Four strings or wires may be tuned so that the third may be an octave above the first, the second a fifth above the first, and the fourth a fifth above the second. But various arrangements may be adopted, in consequence of any of which, alternately increasing or diminishing strains of wild harmony will be elicited from the instrument by the fluctuating impulse of the wind.

91. A colossal imitation of the instrument just described was invented at Milan in 1786, by the Abbate Gattoni. He stretched seven strong iron wires, tuned to the notes of the gamut, from the top of a tower fifty feet high to the house of a Signor Moscati, who was interested in the success of the experiment; and this apparatus, called the Giant's Harp, in blowing weather, yielded lengthened peals of harmonious music, now swelling in loud chorus, and seeming to fill the atmosphere, then dying away on the breeze like the soft tremulous murmurs of a common Æolian harp. In a storm this aërial music was sometimes heard at the distance of several miles.

What will enable the performer to increase the acuteness of the tone to an octave?

In what manner does the mode of varying the acuteness of sound in the common bugle differ from that in the German flute?

What is the common construction and mode of applying the Æolian harp?

What account is given of a remarkable instrument of this construction?

92. The music of nature exhibits boundless variety as to the combinations of tones and the several modes in which they are produced. But besides the warblings of the feathered choir and abundance of other vocal sounds with which we are familiarly acquainted, there are some which are constantly emitted under certain circumstances, yet, though curious and interesting, they seldom attract our notice.

93. Bees, gnats, and many other winged insects in their passage through air excite sonorous vibrations by the viewless flutterings of their wings or other membranous parts of their structure. The intermitting note of the grasshopper is probably the result of a similar mechanism; but some insects of this tribe seem to be furnished with a peculiar organization for the production of their music.

94. Dr. Hildreth states that the American Cicadæ, or locusts, are furnished with bagpipes on which they play a variety of notes. "When any one passes they make a great noise and screaming with their air-bladder or bagpipes. These bags are placed under and rather behind the wings, in the axilla, and something in the manner of using the bagpipes, with the bags under the arms. I could compare them to nothing else; and indeed I suspect the first inventor of the instrument borrowed his ideas from some insect of this kind. They play a variety of notes and sounds, one of which nearly imitates the scream of the tree-toad."

95. Some birds yield musical tones through the percussion of the air by their wings in flight. This circumstance, which perhaps has escaped the attention of naturalists, is particularly observable in the lapwing, or as it is sometimes called from its cry, the pewit. This bird is an inhabitant of the furze-clad downs of Wiltshire; and when it stoops near the ground, in its circling course through the air, as it approaches the observer, a sound may be heard resembling the distant tone of a French-horn, entirely distinct from the dissyllabic scream from which it derives its provincial name; and which is formed like the cries of other animals in the throat or larynx. The peculiar clanging tone first mentioned seemed, as far as could be guessed from repeated observations, to be nearly the same note with the middle C of the harpsichord. It is manifestly caused by the reverberation of the air against the hollow sides of the broad wings of the bird in its rapid wheeling flight; and it is heard only when it happens to come very near the observer.*

How are winged insects generally found to produce sound?
How is the American locust furni hed with musical instruments?
By what means other than the voice are birds sometimes found to give musical tones?

* The common night-hawk affords a familiar illustration of the effect of rapid stooping through the air, producing the "*boo-oo*" often heard on a warm summer evening.—Ed.

The Human Voice.

96. Among the most curious works of nature, must be reckoned the organization on which depend the tones of the human voice. The most ancient physiologists regarded the trachea or windpipe as the immediate organ of sound, comparing it to a flute, and ascribing the voice to the impulse of air against its sides in its passage into the lungs. But Galen controverted this erroneous opinion, by showing that the voice is formed during the expiration of air, or its passage from the lungs, and in its escape from the larynx, at the back of the mouth. Besides the lungs, which propel air in the same manner as it is propelled by a bellows into the pipes of an organ, the parts essential to the production of *vocal sounds* are the trachea or windpipe, the larynx, and its appendages.

97. The windpipe, as the term implies, is merely a cartilaginous canal through which the air issues from the lungs; the larynx is an enlarged continuation of the windpipe, formed, like it, of cartilage or gristle, membrane and muscle; but it is more complicated, terminating above in two lateral membranes, which approach near together, leaving only an oblong narrow opening, called the glottis. The cartilages of the larynx admitting of some degree of motion by means of their attached muscles, the membranes of the glottis, which are connected with them, may be extended or slackened, and thus the vibrations of the air passing through the glottis are regulated, and sounds are modified as to tone. Tendinous cords or ligaments are also extended within the larynx, which are supposed by some physiologists to co-operate with the membranes of the glottis in producing sonorous vibrations.

98. The glottis, or rather the membranes which compose it, thus appears to form the immediate organ of sound; which has been aptly enough compared to the reed of a hautboy, since it is composed of thin vibrating plates, with a narrow variable opening between them. But the surpassing delicacy of the organization in the construction of the glottis abundantly demonstrates the superiority of the works of nature over the most elaborate efforts of art. Dodart, a French physician, who, in the beginning of the last century, investigated the structure of the vocal organs, made a calculation whence he inferred that the intervals of sound capable of being perceived by the ear correspond to contractions of the glottis less than 1-9632 part of its diameter. It is probable, however, that the diversity of tones is caused not merely by alte-

What part of the organs of speech did the ancients regard as the immediate cause of sound?

Who controverted this opinion, and on what ground?

What, besides the windpipe, is essential to the production of vocal utterance?

What is meant by the *larynx?* what, by the *glottis?*

What office does the glottis appear to perform?

rations in the dimensions of the glottis, but is partly dependant on the lengthening or shortening of the entire tube of the trachea, including the larynx, and by corresponding alterations in the form and size of the cavity of the mouth. Yet the power of varying the tones of the voice in singing must depend chiefly on the susceptibility of the membranes of the glottis, the firmness and elasticity of the cartilages of the larynx, and the strength of the muscles by which they are moved, and that of the muscles of the chest concerned in respiration.

99. That the sound of the voice wholly arises from the passage of air from the lungs through the glottis, is proved by the fact that when the windpipe is wounded below the glottis so that the air in expiration passes through the wound, the power of forming sounds is destroyed; while a wound in the throat which leaves the glottis and parts below it uninjured, produces but little effect on the voice; and if a piece be cut out of the windpipe of a man or any animal similarly constituted, the power of uttering sounds of which he is thus deprived will be restored by carefully closing the artificial opening in the windpipe, so that the air no longer escaping by it, may pass through the glottis as usual. Hence those unfortunate persons who cut their own throats so as to wound the windpipe but not the large blood-vessels, immediately breathe through the wound and become silent, but as soon as the wound is dressed and the air no longer passes through it, the power of speaking is restored.

100. The tracheal canal, including the larynx, may even be entirely detached from the animal to which it belongs without losing its property as a vocal instrument. The celebrated naturalist Cuvier, having cut off the head of a screaming bird so as to leave the glottis and parts below it entire, the creature still uttered cries for some time after its decapitation, the organ of voice remaining uninjured. An animal recently dead may be made to utter sounds as when living, as appears from experiments made by M. Ferrein, in 1741, and repeated by M. Biot, a few years since. The latter gentleman employed in his researches the larynx of a pig, with the trachea attached to it, and to the opening of the latter, he fitted the bellows of an organ, and by varying pressure on the larynx with his hand he could increase or diminish the aperture of the glottis while forcing the air through it, so as to imitate exactly the grunting of the pig. The same philosopher subsequently constructed an artificial glottis, the lamina, or membranous plates forming the opening being made

On what operations besides the enlargement and contraction of the glottis is variety of tone supposed to depend?

What direct proof have we that the voice is formed at the glottis?

What experiment did the celebrated naturalist Cuvier institute on this subject?

In what manner did Biot imitate the voice of the living animal?

of gum elastic; and having adapted it to the pipe of a pair of bellows, he was thus enabled to produce vocal sounds.*

101. The aperture of the glottis is naturally more contracted in females and in males before the age of puberty, than in adult males; and therefore, women and children have shriller voices than men, the difference of tone commonly amounting to about an octave. The entire compass of voice in female singers is usually more extensive than in men; for though their scale of musical sounds commences at a relatively high tone, it ascends yet higher in proportion.

102. The human voice may be so modulated as to form a vast variety of musical sounds or tones with rapidity and precision far beyond the effect of any instrument formed by art; for vocal music, on account of its superiority over instrumental music, in point of expression, must always be regarded as the highest excellence of the art. But the vocal organs not only afford tones or sounds distinguished by relative gravity or acuteness, but also modifications of sound, forming the basis of language; and to the possession of the faculty of speech, and the interchange of vocal and audible signs, man is greatly indebted for his superiority over the brute creation.

103. It is during the transmission of the sonorous vibrations through the mouth that the peculiar effect is produced which communicates to the ear the sounds of letters and words, constituting language. The most simple of these articulate sounds are those corresponding with the vowels, the differences between which depend on enlarging or contracting the cavity of the mouth while they are uttered. The consonants, which, it hardly need be observed, cannot be enunciated without the addition of a vowel, require more complicated motions of the parts of the mouth; and hence some of them are called gutturals, as being formed in the back part of the mouth; some dentals, as requiring the application of the tongue to the teeth; and others labials, because they cannot be distinctly pronounced without moving the lips.

104. The success of the researches of men of science concerning the theory of vocal intonation has occasioned different attempts to produce speaking machines, the operation of which should depend wholly on mechanism. In 1779, a prize was offered by the Academy of Sciences at St. Petersburg, for the best dissertation on the theory of vowel sounds, illustrated by actual experiments; and it was awarded to G. R. Kratzenstein, an account of whose

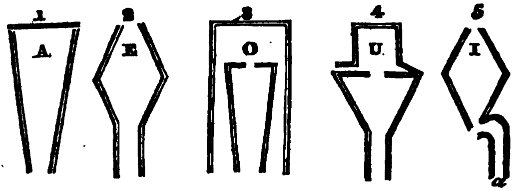
How is the opening of the glottis in females compared with that in males? To what amount do they generally differ?

How is the human voice, in point of variety and rapidity of execution, compared with musical instruments?

On what condition of the vocal organs do the different vowel sounds depend? On what three parts of the mouth are the consonant sounds of language mainly dependent?

* V. Sigaud de la Fond Elem. de Phys., vol. iii. p. 551; Teyssedre Elem. de Phys., p. 214.

researches was published in the Transactions of the Academy. This igenious philosopher showed that the sounds of the four vowels, A, E, O, and U, might be obtained by blowing through a reed into several tubes, the forms of which are represented in the annexed figures 1, 2, 3, and 4; and that the sound of I, as pronounced by the French and other continental nations was produced by blowing at *a*, into the pipe No, 5, without using a reed. Kratzenstein continued his investigations, but probably he did not obtain results of greater importance, as he never published any further account of the progress of his inquiries.



105. M. Kempelen, of Vienna, who distinguished himself by the construction of an automaton chess-player, which has excited much attention, also devoted his ingenuity to the contrivance of a speaking machine. He succeeded so far as to produce an instrument capable of uttering certain words and short phrases in French and Latin. The sounds appear to have been produced by means of a single cavity, the form and dimensions of which might be modified at pleasure. It has been described as consisting of a box, about three feet long, placed on a table and covered with a cloth, under which the operator in exhibiting its powers introduced both his hands, one of which probably was employed in pressing on keys which might communicate with pipes after the manner of those of an organ. This machine was only shown to the private friends of the inventor, and it does not appear that it was ever completed.*

106. A gentleman of Cambridge, England, has more recently prosecuted experiments on the formation of articulate sounds; and having adopted the method of Kempelen, in using a single cavity, he found that by blowing through a reed into a conical cavity the vowel sounds could be produced by altering the dimensions of the aperture for the passage of air from the cavity by means of a sliding board. He also found that when cylindrical tubes, the length of which could be varied by sliding joints, were adapted to the reed, the series of vowels could be produced by gradually lengthening the tube; and when its length was augmented in a

Give some account of Kratzenstein's vocal pipes.
To what extent did Kempelen, the inventor of Maelzel's automaton chess-player, carry the imitation of human speech?
Of what did his speaking machine consist?

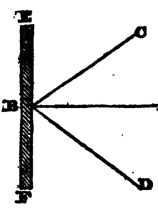
* See Nicholson's British Encyclopædia, art. Androides; Brewster's Edinburgh Encyclopædia, art. Automaton.

certain proportion the same vowels were repeated but in inverted order; and by a further augmentation of the length of the pipe, a second repetition of the vowels took place in direct order.

107. The degree of accuracy with which some birds, and especially parrots imitate the human voice, depends more on their propensity to mimic the sounds they hear than on any peculiar qualifications they possess for giving utterance to articulate tones; and therefore many other animals, beasts as well as birds, might be taught to speak by any one who was disposed to bestow sufficient time and labour on such a task. Pliny the Elder mentions certain nightingales, which spoke Latin and Greek;* but, as the authority of that ancient writer may be considered as somewhat dubious, it will be more to the purpose to observe, that Father Pardies, a learned Jesuit, gravely asserts that dogs had been taught music, and that one of them was so apt a scholar, that he could sing a duet with his master. The celebrated philosopher Leibnitz has given an account of a dog which he saw and heard speak, after it had been under tuition three years. This animal could pronounce thirty words, such as *tea*, *coffee*, *chocolate*; and he merely repeated them after hearing them from his master.†

Reflection of Sound.

108. When sonorous vibrations are propagated through a mass of matter of great extent, and of uniform density and elasticity, as when they are continued uninterruptedly through the open air, the sounds will be heard alike in every direction, and become dissipated or lost in the surrounding space. But if they impinge on some obstacle which interrupts their progress, they will be driven back or reflected; and thus a wall, the face of a rocky cliff, the surface of water, or even a dense body of vapour, may cause the reverberation of sound.



109. The reflection of sound takes place according to the same laws that govern the reflection of perfectly elastic solids. Hence the sonorous vibrations being propagated in right lines, the angle of reflection is always equal to the angle of incidence. Thus suppose a sound to be emitted from A in the annexed figure, and to impinge on a dense plane, E B F at B, it will return in the same line B A, and the reflected sound will be heard at A after the

What was found to be the effect on the vowel sounds of lengthening speaking tubes? On what is the imitative faculty of parrots dependent? What is asserted by Pliny in regard to nightingales? What statements are mentioned of this power in quadrupeds? What is meant by the reflection of sound? According to what laws does it take place?

* Plinii Histor. Natur., lib. x. cap. 42.

† Histoire Critique de l'Ame des Betes. Amsterd. 1749. t. ii. p. 50. De la Connoissance des Betes, p. 129. Histoire de l'Academie des Sciences. An. 1715. p. 3.

original sound, constituting what is termed an echo.* If, however, the sound be emitted from D, so that the line of its direction may form an oblique angle with the plane E F, it will be reflected from B in the line B C, forming a similar oblique angle with the plane E F. The velocity of the reflected sound is precisely the same with that of the direct sound; therefore the sound will be returned from B to C in the same time that it passes from D to B. Hence the sound uttered at D will be heard by a person stationed at C at the end of a period double that which it takes to pass from D to B. So that as sound travels at the rate of 1130 feet in a second, if the distance from D to B should be 282½ feet, the echo will be heard at C in half a second, for in that time the sound would be conveyed $282\frac{1}{2} \times 2 = 565$ feet.

110. It is requisite that the reflecting body should be situated at such a distance from the source of sound that the interval between the perception of the original and the reflected sounds may be sufficient to prevent them from being blended together. When they become thus combined the effect is termed a resonance, and not an echo. The shortest interval sufficient to render sounds distinctly appreciable by the ear is about 1-10 of a second; therefore when sounds follow at shorter intervals they will form a resonance instead of an echo. So that no reflecting surface will produce a distinct echo unless its distance from the spot whence the sound proceeds should be at least 56½ feet, as the sound will in its progress forward and return through double that distance, 113 feet, take up 1-10 of a second. Resonances, or combinations of direct and reflected sounds are heard more or less in all inclosed places of moderate extent; and as they occasion some degree of confusion in the perception of sound, inconvenience arises from this source in rooms appropriated to the purposes of oratory, the voice of a speaker being heard but indistinctly, especially in some situations; but in a concert-room such resonances are rather advantageous, at least they would add to the effect of instrumental music.

111. Some echoes will repeat but one syllable or distinct sound, while others will repeat several in succession. Hence the distinction of monosyllabic and polysyllabic echoes. As it would

Construct and explain the diagram relating to this subject?
What is meant by the angle of incidence of sound?
What by the angle of reflection?
What is the relation of those angles to each other?
What are the comparative velocities of original and of reflected sound?
What name is given to the intermingling of original and reflected sound?
How far must a reflecting surface be placed from the source of sound, in order that an echo should be distinctly heard?
What disadvantage is occasioned by *resonance?*
In what cases may it be found beneficial?
What distinction has been made between echoes?

---

* From the Greek Ἠχώ, a reflected sound.

be impossible to pronounce more than ten syllables in a second intelligibly, it must follow, that if the reflecting body causing an echo should be so near the speaker as to return his voice in 1-10 of a second, the last syllable only of a word uttered would be distinctly re-echoed, for all the preceding would be confounded together. Therefore, if the distance of the reflecting object were but 56½ feet, the sound in going and returning through twice that space would take up but 1-10 of a second, and the echo would consequently be monosyllabic. If the distance of the reflecting object were 113 feet two syllables might be returned; and in general there would be as many syllables repeated as the multiples of 56½ in the number of feet between the source of sound and the reflector.

112. It will be obvious that two persons may be so situated that one may hear the echo of the voice of the other without perceiving the original sound; for the voice impinging obliquely on a reflecting surface may be conveyed uninterruptedly to a person placed in the line of reflection, while some intervening obstacle may prevent the direct passage of the sound. Thus two persons standing one on each side of a mirror might see the reflected figures of each other in the glass, though an opaque body might entirely conceal from either the real figure of the other.

113. Such echoes as have been now described would be produced by a single reflecting body, which would necessarily return or repeat but once each original sound. The most remarkable echoes, however, are those which have been termed polyphonous, because they multiply sounds, or yield several repetitions of a single original sound; the echo arising from successive reflections from a number of different surfaces. Numerous instances of extraordinary echoes are related by travellers and other writers. Dr. Plot, in his History of Oxfordshire, England, gives an account of an echo in the park at Woodstock, that would repeat seventeen syllables in the day-time, and twenty at night: the air being more elastic during the day than in the colder season of the night, the sound would travel faster, and be returned more speedily by the diurnal than by the nocturnal echo. On the north side of the parish church of Shipley, in Sussex, there is an echo which will repeat twenty-one syllables.

114. Among the echoes which repeat the same sound many times one of the most noted is that mentioned by Father Kircher and Gasper Schott in the seventeenth century, and subsequently by Misson and Addison, as existing at the Marquis of Simonetta's villa, near Milan, in Italy. It is produced by two parallel walls constituting the wings of the building, and the echo, which is best heard from a window between them, will repeat a single

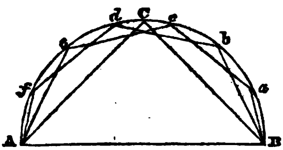
How is the number of syllables echoed necessarily limited?
In what cases may echoes be heard to the exclusion of direct sounds?
What are meant by polyphonous echoes?
From what do they proceed?
What examples of polysyllabic echoes have been recorded?
What cases of polyphonous echoes have been noticed?

word more than forty times, and the report of a pistol nearly sixty times; but not with perfect distinctness except early in the morning or late in the evening, in calm weather. There is an analogous echo at Verdun, produced by two towers distant from each other about 165 feet; and a single word uttered loudly by a person standing between them, will be heard repeated a dozen times.

115. On the Rhine, near Lurley, is a remarkable echo, described by Dr. Granville, caused by the reverberations of sound from the rocky banks of the river, which may be heard to the greatest advantage from a boat in the middle of the stream. This echo repeats musical sounds, gradually fading on the ear till they die away; and it resembles the polyphonous echoes, which are heard on the Lakes of Killarney, in Ireland. A wonderful echo is mentioned by Father Gassendi in his remarks on Diogenes Laertius, since he states that Boissard heard the first verse of the Æneis,

Arma virumque cano Trojæ qui primus ab oris,

repeated eight times at the tomb of Metellus, an ancient monument near Rome. At Genetay, near Rouen, in Normandy, a curious echo is said to exist, the effect of which is such, that a person singing will hear only his own voice, while others at a distance hear the echo and not the original sound; sometimes the reflected sound seems to approach, and at other times to recede, and the sounds are heard in different directions, according to the situation of the hearer.



116. The reflection of sound, instead of producing an echo, may have the effect of concentrating sonorous vibrations so as to render sounds audible with the utmost distinctness at considerable distances from the places where they are emitted. This may happen in consequence of repeated reflections from a curved or polygonal surface, so that the sound being uttered in the focus of one reflecting surface it will be conveyed to the ear placed in the focus of another reflecting surface. Thus a sound too weak to be heard in the direct line A B, in the marginal figure, may be augmented by reflection from B to C, and thence to A, and also by a number of intermediate reflections from *a*, *b*, *c*, *d*, *e*, *f*, and various other points, all tending to A; so that a whisper or the scratch of a pin, which could not be conveyed directly from B to A, would be heard plainly by accumulated reflection from different points in the circular surfaee B C A.

117. The most trifling sound may thus be heard from the oppo-

What singularity exists in the echo of Genetay?
What effect, other than echoes and resonances, may be produced by the reflection of sound?
In what manner may this result be obtained?
Illustrate this by diagram.

site side of the circular gallery at the base of the dome of St. Paul's cathedral, London, hence called the whispering gallery. There is also a whispering gallery in Gloucester cathedral, where a narrow passage seventy-five feet in length extends across the west end of the choir; and the wall forming five sides of an octagon, the voice of a person whispering gently at one end of the gallery is carried by reflection to the ear of a person on the other side of the choir.

118. In a very similar manner sound is concentrated by reflection, from the focus of one reflecting surface to that of another in an elliptical vault. The cupola of the Baptistery of Pisa is thus constructed; so that a person placed in one focus may distinctly hear a whisper uttered in the other focus, though it would be inaudible in the intermediate space. The cathedral of Girgenti, in Sicily, affords an example of a similar construction; in consequence of which the gentlest whisper may be plainly heard from the cornice behind the high altar by a person at the great western door, a distance of two hundred and fifty feet. The ecclesiastics, ignorant of this circumstance, had unluckily placed the confessional in the focus of one of the reflecting surfaces, and persons who happened to have found out the place whither sounds were conveyed, amused themselves for some time by resorting thither to hear secrets intended only for a confessor: at length one of these indiscreet listeners was punished by hearing his own wife confess her frailty; and the affair becoming public, the confessional was removed to a more secure spot.

119. The concentration of sounds sometimes produces very singular effects, of which an instance is thus related by Dr. Arnott: "It happened one day on board a ship sailing along the coast of Brazil, far out of sight of land, that the persons walking on deck, when passing a particular spot, heard very distinctly during an hour or two, the sound of bells, varying as in human rejoicings. All on board came to listen, and were convinced; but the phenomenon was most mysterious. Months afterwards it was ascertained, that at the time of observation the bells of the city of St. Salvador, on the Brazilian coast, had been ringing on the occasion of a festival: and their sound, therefore, favoured by a gentle wind, had travelled over perhaps 100 miles of smooth water, and had been brought to a focus by the concave sail in the particular situation on the deck where it was listened to."*

120. There are some echoes for which it is more difficult to account. Such for example, as that observed by M. Biot in the aqueducts of Paris, where on speaking at the extremity of a tube 951 metres in length, the voice was repeated six times. The in-

In what celebrated structures is the concentration of sound exemplified?
What is related of the cathedral of Girgenti in Sicily?
How have mariners occasionally experienced the effects of concentrated sounds?

* Elements of Physics, vol. i. p. 538.

tervals of these echoes were equal, each being about half a second; the last returning to the ear after three seconds, that is, after the time requisite for the sound to pass through the space of 951 metres. Similar echoes have been noticed in the long galleries of mines. M. Beudant observes that probably, in the experiment of Biot, the tubes were not laid exactly in a straight line, nor throughout of the same diameter; and that in the galleries of mines it may be imagined that the walls or sides were not parallel.*

121. The conveyance of articulate sounds by means of tubes through considerable distances from one part of a building to another is now commonly practised. By this method a message or inquiry can be communicated from a person in his study or office, in the upper part of a high building, to clerks or workmen in the lower part, without loss of time or inconvenience.

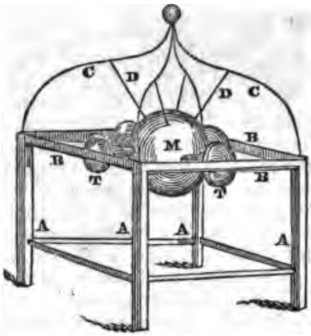
122. The facility with which the voice thus circulates through tubes was probably known to the ancients, and certainly to the cultivators of philosophy in the middle ages. Pope Sylvester II., whose proper name was Gerbert, was almost the only man of science living in the tenth century, and not now forgotten. By his contemporaries he was regarded as a magician, because among the wonderful machines he constructed was a speaking head of brass. Albertus Magnus, and Roger Bacon, in the thirteenth century, incurred similar odium, in consequence of their having formed speaking figures. There can be no doubt that each of these ingenious men adopted the method now described of conveying sound from a distance, so that it might appear to proceed from an inanimate bust.

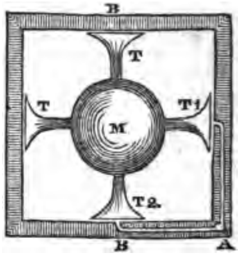
123. By far the cleverest deception of this kind was an exhibition which took place at Paris several years since and afterwards in London, appropriately styled the Invisible Lady, since the apparatus was so contrived that the voice of a female at a distance was heard as if it originated from a hollow globe not more than a foot in diameter, suspended freely from wooden framework, by slender ribbons.

124. A perspective view of the machinery, and a plan of the globe and adjoining parts as constructed by the inventor, M. Charles, are given below. It consisted of a wooden frame, much resembling a tent bedstead, formed by four pillars A, A, A, A, connected by upper cross-rails, B, B, and similar rails below, while it terminated above in four bent wires, C, C, proceeding from the angles of the frame, and meeting in a central point. The hollow copper ball, M, with four trumpets, T, T, issuing from it

How may polyphonous echoes in pipes and mines be explained?
To what useful purpose may the conduction of sound by long tubes be applied?
What instances of ingenious deception have been formed on this mode of transmitting sound?
To what imputation did they subject their authors?
How was M. Charles's invisible lady constructed?

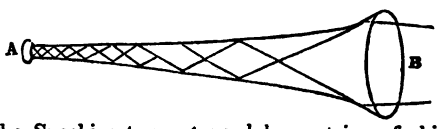
* Beudant Elem. de Phys., pp. 367, 368.





at right angles, hung in the centre of the frame, being connected with the wires alone by four narrow ribbons, D, D. Any question or observation uttered in a low voice close to the open mouth of one of the trumpets elicited a reply which might be heard from all of them, the sound being perfectly distinct, but weak, as if it was emitted by a very diminutive being.

125. The real speaker was a female concealed in an adjoining apartment, and the means by which her voice was made to issue from the globe in the manner stated were at once very simple and ingenious. Two of the trumpet mouths, T^1, T^2, as represented in the plan, were exactly opposite apertures leading to tubes in two of the cross-rails, which meeting at the angle A, opened into another tube descending through the pillar, and which was continued under the floor into an adjoining apartment, where a person sitting might hear what was whispered into either of the trumpets, and return an appropriate answer by the same channel. This machinery differs from the common speaking-tubes, previously noticed, merely in the addition of the hollow ball and trumpets, by means of which the voice is reflected from the cavity of the globe through the trumpets T^1, T^2, into the tube of communication; and thus the effect produced is rendered abundantly mysterious to those unacquainted with the principles of Acoustics.



126. The Speaking-trumpet, used by captains of ships, is an instrument adapted for increasing the intensity or loudness of sounds, by multiplied reflection. It consists of a conical tube, as

In what manner did his machinery differ from ordinary speaking-tubes? Explain the construction of the speaking-trumpet.

represented above, open at both ends, about three feet in length, and formed of copper or tin-plate. On speaking slowly and distinctly with the mouth applied to the opening A, the sound after being reflected from the sides of the tube in the direction of the cross-lines, will escape from the wide extremity B, and be conveyed to a distance proportioned to the length of the tube and the diameter of its bell-shaped aperture. Kircher, in his "Phonurgia Nova," published in 1673, claims the invention of the speaking-trumpet, referring to his "Musurgia," 1650, for an account of the instrument; but his contrivance seems to have been constructed on the principle of the tubes of communication mentioned above, rather than on that of the speaking-trumpet, which was more probably invented by Sir Samuel Morland, who gave a description of it in a work which was printed in London, 1671, under the title of "Tuba Stentorophonica." It is by no means necessary that the speaking-trumpet should be composed of a metallic substance, for the sonorous vibrations will be propagated in the same manner and with equal effect through a similar tube lined with cloth.

127. A Hearing-trumpet is nothing more than a funnel-shaped tube, like a reversed speaking-trumpet; which, when the small end is held to the opening of the ear, conveys to the person using it articulate sounds from without, increased in intensity by repeated reflections from the inside of the tube. M. Lecat invented a double acoustic tube, by which concentrated sounds might be conveyed to both ears at the same time; and which may be used with great advantage by those whose auditory faculty is impaired.

128. The art of ventriloquism appears to depend in some degree on the reflection of sound within the mouth. Professor Dugald Stewart attributed the talent of exciting the perception of articulate sounds, in such a manner as to give them the effect of emission from various distances and directions, wholly to deception and the power of imitation. Those who have witnessed the curious monopolylogues, as he appropriately styles them, of Mr. Mathews, in his theatrical exhibitions, will readily admit that feigned dialogues and other vocal illusions, in which the sounds apparently issue from an object very near the performer, may be solely the effect of exquisite mimicry.

129. The celebrated Peter Pindar, or rather Dr. Walcot, possessed considerable talent as a mimic, and he sometimes amused his friends by the display of his skill. He would quit his apartment on the first floor, as if to speak to a person waiting for him,

By whom is its invention claimed?

Is a metallic substance necessary to produce the effect of this instrument?

What improvement on the hearing-trumpet was invented by Lecat?

In what peculiar art is the reflection of sound applied?

In what manner are we to account for the deception of the ear by mimics who personate several characters at the same time?

What anecdote illustrates this view of the subject?

and shutting the door on those within, he would stand at the stair head, and hold a fancied conversation with his laundress, the bard speaking alternately in his own natural tone of voice, and in the shriller key resembling the voice of a female. He would represent the visiter as demanding payment of her account, and, in spite of the excuses and expostulations of the bard, raising her voice in reply to each apology, and becoming gradually more and more abusive, till at length, when the company, who heard all, might suppose that he had lost all patience at the woman's pertinacity and insolence, the dialogue would be suddenly terminated by a noise which seemed to indicate that he had kicked the laundress down stairs. Such an exhibition, whimsical enough to those not in the secret, would obviously require much less skill and address than the scenes where the performer stands in presence of the audience.

130. The deceptions of the ventriloquist are produced in a different manner, requiring not only the faculty of disguising the voice so as to imitate other sounds, but also the art of determining the apparent source of sound. Among the numberless examples of the feats on record relative to the professors of this art is the following, related as an ear-witness, by Van Dale, the author of a treatise on Oracles. There was, in 1685, in the hospital for the aged at Amsterdam, a woman, seventy-three years old, whose name was Barbara Jacobi, and who was visited by a vast multitude of persons on account of her talents as a ventriloquist. She lay on the side of a small bed, the curtains being undrawn, and turning as if to talk to a man near her whom she called Joachim, she returned answers to her own questions or remarks in a feigned voice. She would accuse her supposed companion of gallantries with other females, make replies for him, sometimes as if he was laughing, sometimes crying, now uttering groans, and then singing songs, and all with such address and effect, that the illusion was complete; and the by-standers occasionally would not be convinced that she had no associate till they had satisfied themselves by searching the bed.*

131. This woman, who was famous for her skill, is also mentioned by Balthasar Bekker, in his curious treatise entitled "The Enchanted World;" and another Dutch writer, John Conrad Amman, in his Dissertation on Speech, states, that he had heard her singular dialogues, and that the feigned voice she uttered seemed to issue from a spot at least two paces from her. The Abbé de la Chapelle, a learned Frenchman, who was a Fellow of the Royal Society of London, wrote a distinct work on ventriloquism,† in

How does ventriloquism differ from mimicry?
What instance of their combination is recorded by Van Dale?
What account of the effect and its cause is given by Amman?

* Antonii Van Dale Polyatri Harlemensis Dissertationes de Origine ac Progressu Idolatriæ et Superstitionum, 4to. p. 652.

† Le Ventriloque ou l'Engastrimythe. Par M. de la Chapelle, Censeur Royal a Paris, &c. Deux parties. A Londres, 1772. 12mo.

which he has collected a great number of notices of persons skilled in this art, and of their singular exploits.

132. One distinguished ventriloquist to whom his work relates, was the Baron von Mengen, a nobleman of Vienna, who in a letter addressed to M. de la Chapelle, states, that he had acquired a facility in speaking as a ventriloquist, by mere practice commenced when a boy, but he professes himself unable to communicate the art to another. Amman in the passage referred to above, expressly asserts that the effect is produced by speaking during the act of inspiration, or drawing air into the lungs, instead of speaking while the air is passing out as usual. The Abbé de la Chapelle attempts to controvert this notion, which, however, seems to be founded on correct observation, as articulate tones can be thus formed differing in intensity from those emitted in the customary mode. Yet some further modification of the speech appears to be requisite to produce all the effects described; and one of the most essential peculiarities will consist in the art of enunciating all, or nearly all, the letters of the alphabet without moving the lips.

133. It is a remarkable circumstance that the art of ventriloquism is practised among the Esquimaux, by individuals who have acquired among their countrymen the reputation of being wizards. The late Captain Lyon, one of the officers who visited the Arctic regions a few years since, had opportunities of witnessing the exhibitions of one of the most skilful of the Esquimaux ventriloquists, and he published an interesting account of the observations he made on those occasions. One of the most important circumstances which he noticed was that the ventriloquist, after having uttered a protracted sound, which lasted while Captain L. had made two inspirations after holding his breath as long as possible, emitted a "powerful yell, without a previous stop or inspiration of air."* Doubtless the previous lengthened sound was produced during inspiration, and therefore the succeeding yell relieved the distended lungs. This observation thus agrees with those which have been made on other ventriloquists. But there seems to be little probability that this subject will be perfectly understood till some skilful ventriloquist may choose to investigate the manner in which the vocal organs are employed in forming such anomalous sounds, and communicate the result of his researches to the public.

Among what barbarous nations has the art of ventriloquism been practised?

In what manner does Captain Lyon account for the prolonged utterance given by the Esquimaux?

---

* Private Journal of Capt. G. F. Lyon. 1824. pp. 358, 361, 366.

Books on the subject of Acoustics.

Playfair's Outlines of Natural Philosophy, vol. i. pp. 281—291.

Robinson's Mechanical Philosophy, 8vo. vol. iv. pp. 376—537.

Library of Useful Knowledge, treatise on Pneumatics, pp. 29—31.

Chladni Traité d'Acoustique, Paris.

Rush's (Dr. James) Philosophy of the Human Voice, Phila. 1827.

Edinburgh Encyclopedia, article *Acoustics.*

Cassini on Sound, Mem. of the French Academy for 1738, p. 128.

Savart Recherches sur les Usages de la Membrane du Tympan. Ann. de Chim. vol. xxvi. p. 5.

Nollet on the Hearing of Fishes, Mem. of the Fr. Acad. 1743.

Euler on the Propagation of Pulses, Berlin Memoirs for 1765. p. 335.

Dulong on the Velocity of Sound in different Gases, Ann. de Chim. vol. xli. p. 113.

Works in the department of acoustics are very numerous; but the number of those which treat the subject with perfect clearness, combined with that exactness which the case seems to require, is perhaps smaller than in most branches which have for an equal length of time been cultivated by the curious and the learned. This arises, in part, from the intrinsic difficulties of the subject; in part, from the fact that many persons, as stated in a preceding page, are insensible to the nicer shades and distinctions of sound, and in no small degree from the discouragements long felt in attempts to make the deductions of theoretical investigation correspond with experimental results. The far-reaching mind of Newton himself, was not able to grasp all the causes which modify the transmission of sound. Indeed the law of La Place, that the theoretical result of Newton must be corrected by multiplying it into the square root of the ratio of the specific heat of air under a constant pressure, to its specific heat under a constant volume, could not possibly have been applied in Newton's time; for the whole doctrine of specific heats was then unknown. Again, the means of exhibiting, in all their variety, the numerous phenomena of vibration, have only for the last few years been supplied by the labours of Chladni, Savart, Biot, Colladon, Faraday and others. The art of composition in music, and skill in its performance, have sometimes been mistaken for the *science* from which they derive their principles. The *art* of rhetoric has in like manner been conceived to constitute the *science* of vocal utterance, until Dr. Rush pushed his analytical researches to the extent of dissecting the very elements of speech, and displaying those operations of the organs which combine to produce or to modify every element.—Ed.

PYRONOMICS.

1. Among those branches of natural philosophy which have attained the rank and importance of distinct sciences, in consequence of the researches of our contemporaries, must be included that, the object of which is, to explore the properties and operations of heat. To designate this department of human knowledge, Leslie has adopted the term Pyronomics, which signifies the laws of heat.* The effects of heat, or rather of relative temperature, have so striking an influence on all bodies around us, and it produces such varied and singular consequences, that whether considered as arising from the modifications of matter with which we are most intimately acquainted, or as depending on the presence of some peculiar subtile agent, it must be desirable that they should be classed and arranged so as to form a systematic series of facts and observations; and to such a system the appellation Pyronomics may be appropriated, as expressive of the objects to which it relates.

2. The cause of heat has formed a subject of controversy among modern philosophers; some of them ascribing the phenomena in which it is concerned to intestine motions of the minute particles of bodies, analagous to those which give rise to sound; while others have endeavoured to prove that heat arises from the presence of a peculiar fluid, or ethereal kind of matter, such as that which has been regarded as the cause of light. If such a fluid exists, it must be destitute of weight, for it has been ascertained from experiment that the addition of heat to any substance produces no alteration whatever in its gravitative force.

3. Dr. George Fordyce instituted researches concerning the effect of temperature on the weight of bodies, whence it was concluded that the abstraction of heat from water occasioned an *increase* of weight. He inclosed 1700 grains of water in a glass globe, and having sealed it hermetically, after ascertaining the weight of the globe and its contents with the utmost accuracy, he immersed it in a freezing mixture, and on weighing it again after the liquid had become entirely congealed, he found it had gained 3-16 of a grain.† Guyton de Morveau, and Chaussier, made corresponding experiments in France, on water and sulphuric acid, from the results of which they drew the same inferences.

To what is the term Pyronomics properly applied?

To what cause have different philosophers attributed the phenomena of heat?

To what result were Fordyce, Morveau, and Chaussier conducted in regard to the effect of temperature on the weight of bodies?

---

* From the Greek Πυρ, fire, and Νομος, a law.

† See Philosophical Transactions vol. lxxv.

4. Other philosophers, however, made comparative trials of the weight of water and sulphuric acid in the liquid state, and when reduced by cooling to the solid form, without being able to detect any difference of weight appreciable by the most delicate balances. The apparent effect of the variation of temperature on the weight of bodies as noticed in the above experiments, may be attributed to the influence of the frozen mass on the density of the surrounding air; therefore, if we admit the observations to be perfectly correct, it may still be contended that they are not conclusive.

5. Count Rumford, having suspended a bottle containing water, and another containing spirits of wine, to the arms of a balance, and adjusted them so as to be exactly in equilibrium, he found that it remained undisturbed when the water was completely frozen, though the heat the water had lost must have been more than sufficient to have made an equal weight of gold red-hot. If, therefore, with Lavoisier and his associates, (the founders of what has been styled the Antiphlogistic System of Chemistry,) we suppose heat to be matter rather than motion, it must be allowed to be an imponderable fluid, and also, as denominated by some philosophers, an incoercible fluid, for though it passes through some bodies with more difficulty than through others, there is no body or or kind of matter which can completely arrest its progress.

6. The terms Caloric* and Matter of Heat have been adopted to designate the hypothetical causes of those phenomena which are referred to the science of Pyronomics; and without admitting the separate existence of such an agent as the caloric of the French chemists, the term may sometimes be advantageously employed to denote the amount of effect produced by relative changes of temperature in the same or in different bodies.

7. Various phrases occur in our own and in other languages expressive of the effects resulting from alterations of temperature, both as regards the impression on our senses, and the changes of form or structure produced in the bodies around us. When we touch a substance more heated than the hand applied to it, the sensation arising from it is styled warmth; and that caused by a substance less heated is named chilliness or cold. But warmth and chilliness, or heat and cold, thus used, are merely relative terms; for a substance which would excite in one person the sensation of heat might at the same time seem cold to another; and if a man, after holding one hand near a fire for a few minutes, and

How has the weight of bodies, as affected by heat, been explained?

In what manner did Rumford seek to determine the question of the ponderability of heat?

What other distinguishing property, besides that of *imponderable*, belongs to the nature of heat?

To what is the term caloric applied?

How may it be shown that hot and cold, warmth and chilliness, are relative terms?

---

* From the Latin *calor*, heat.

laying the other on a cold stone or marble slab, were to dip both in a basin of lukewarm water, the liquid would warm the cold hand and cool the warm one.

8. "There is, perhaps, no subject," says Hutton, "in which the language and ideas of men are more vague, or more distant from true science, than in those of heat and cold. The reason of this will not be difficult to assign. Heat is a term which is applied in different cases; for it is both a principle of action in external things, and a principle of passion in our sensitive mind. But this is only a part of that intricacy with which this apparently simple subject is necessarily involved; for when heat is a principle of action in external things, there are two different effects which occasionally follow this principle as a cause. First, bodies are by heat distended or expanded in their volume: here is one distinct effect. Secondly, without being thus distended by heat, bodies, in receiving that distending cause, are made to lose their hardness, or concretion, and become fluid in their substance: here, then, is an effect distinctly different from the other; and both of these are perfectly different from the feeling of heat and cold which is the immediate information of the sense."*

9. Among the terms indicating various effects or operations of heat, or the appearances which we are accustomed to ascribe to its action on the several substances around us, are some which imply a connexion between heat and light: thus a body like red-hot iron, or burning coals, is said to glow or be glowing; a luminous vapour issuing from a burning body is called flame, and such a body may be said to flame or blaze; when any substance exhibiting these appearances becomes dissipated or dispersed through the air, either wholly or partially, the operation is styled burning or combustion; and when a heated body emits light without combustion, it is said to be incandescent, or in a state of incandesence. The appearance of heat and light in conjunction is often designated fire, a term used by ancient philosophers as characteristic of the matter of heat, and regarded as one of the four elements.

10. The effects of heat on our senses are too variable and fallacious to afford any important assistance in the investigation of its nature and properties; and the principles which form the foundation of the science of Pyronomics must therefore be derived from the consideration of those phenomena which always appear under certain circumstances, so that we can produce them at pleasure

Whence has arisen the vagueness of language employed on this subject?

What two circumstances have particularly contributed to increase the misconception of terms in relation to it?

What is meant by *glowing?* *burning* and *incandescence?*

What character was by the ancient philosophers attributed to fire?

On what must we rely for obtaining the *principles* of pyronomics?

---

* A Dissertation on the Philosophy of Light, Heat, and Fire, by J. Hutton.

by proper arrangements, and estimate with precision the results of combinations by means of which heat is accumulated or dispersed, and its operation on bodies induced, modified, or terminated.

11. The distinguishing properties or effects of heat, or those phenomena which arise from its addition to material bodies, or more simply from the augmentation of their temperature, are of three kinds. 1. Mere dilatation, or increase of volume, which occurs in solids, liquids, or gases, without any change of form. 2. Transformation of a solid to the liquid state, as in dissolving ice or melting lead; and of a liquid to the gaseous state, as in forming steam from water, or vapour from any liquid, by boiling or distillation. 3. Destruction of the texture of bodies by combustion, in consequence of which new combinations of the constituent particles of bodies are formed, the investigation of which falls within the province of the chemist rather than of the natural philosopher.

Sources of Heat.

12. Before proceeding to notice in detail the properties and phenomena of heat, some attention may be advantageously directed to the sources or efficient causes of heat. These are radiation from the sun together with light; certain mechanical operations, as friction, percussion, and compression; and a variety of chemical operations, especially combustion. Heat is also evolved from living animals and vegetables, either by the immediate influence of the vital powers of organized nature, or in consequence of chemical processes, modified by the peculiar properties of organic matter.

13. That the sun is the grand fountain of heat, or the principal cause of elevation of temperature by its action on bodies exposed to its rays, is a fact too obvious to require demonstration. As to the manner in which the effect is produced, different opinions have been entertained. The generally received popular notion concerning the nature and constitution of the sun, as the source of light and heat, is that of an inextinguishable mass of matter in a state of intense conflagration; or, in other words, a globe of perpetual fire, the idea of which has manifestly been derived from comparison of the property of giving heat and light common to the sun, and to flames arising from combustible substances.

14. Sir William Herschel entertained a very different opinion relative to the nature of the solar orb, which from numerous telescopic observations, he was led to imagine to be an opaque

Of how many kinds are the phenomena arising from the augmentation of temperature?
How many and what are the known sources of heat?
Whence has the idea of the *igneous* nature of the sun been derived?
What view did Sir W. Herschel entertain on this subject?

globular mass, encompassed by an atmosphere consisting of transparent elastic fluids, from the decomposition of which heat and light were continually proceeding; and he conceived that the body of the sun, far from being the seat or fountain of perpetual fire, might with probability be regarded as a world furnished and inhabited like the earth to which we are confined. Interesting, however, as such speculations may be, they are not necessarily connected with the subject before us, and must therefore be dismissed with this short notice.

15. In reference to the sun as a principal source of heat, the question will recur, whether heat is a peculiar kind of ethereal matter, which may be emitted from the sun, or rather according to Herschel's hypothesis from the solar atmosphere, and radiating through space together with light, be absorbed by various bodies on the surfaces of the earth and other planets, producing the effects of sensible warmth, expansion of solids and fluids, melting of solids, and boiling or evaporation of liquids, and in some cases, destruction of substance accompanying chemical combinations;—or whether heat and its concomitant phenomena just mentioned may not arise from the propagation of motion through space; the sun or its atmosphere being the grand exciting cause of heat, and producing it in a manner analogous to that in which sound is produced by a bell.

16. According to the former mode of theorizing we must admit the existence of a peculiar penetrating fluid emanating from the region of the sun, and entering with greater or less facility into all terrestrial bodies, on which it produces its characteristic effects: and on the latter supposition, it must be admitted that there exists in the space between the sun and the planets an ethereal medium of inconceivable tenuity, through which vibrations can be propagated with velocity immensely beyond those to which are to be attributed the phenomena of sound.

17. Heat, as depending on the influence of the sun, is unequally distributed over the surface of the earth. Owing to the oblique position of the earth's axis, the solar rays fall more directly on certain parts of its surface at one season of the year than at another; and the inequality of effect arising from this cause, is in some degree compensated by the greater length of time during which the sun shines continuously on those parts of the earth where the direction of the solar rays is least favourable. Thus under the equator the length of the days never exceeds twelve hours, while they increase in extent on proceeding towards the poles, and within the arctic and antarctic circles, the sun shines six months together, and then for six months remains invisible.

What part is acted by the sun on the supposition that heat is material?

What on that of its being the vibration of an ethereal fluid?

In what manner is the heat of the sun distributed over the earth?

How does the obliquity of the sun's annual path to the plane of the equator affect the heat of different parts of the globe?

18. The relative influence of the sun as the cause of heat, at different parts of the earth's surface, attracted the attention of Dr. Halley, who laid the result of his observations before the Royal Society, in a "Discourse concerning the Proportional Heat of the Sun in all Latitudes, with the method of collecting the same." He notices the influence of local circumstances on the temperature of different regions, referring to the effect of the neighbourhood of high mountains, and wide sandy deserts. But his grand object was to ascertain the relation between temperature and latitude, as depending on the direction of the sun's rays, and the respective intervals during which they operate.

19. Since the beginning of the present century, a vast number of facts have been accumulated relative to this interesting subject; and the observations on temperature made in different parts of the world, and especially in high northern latitudes, have enabled men of science to form much more accurate conclusions relative to the temperature of the earth as influenced by its position at different seasons of the year, than those deduced from mere theoretical calculations.

20. From a comparison of the researches of Humboldt in the equatorial regions of the earth, with those of Captains Scoresby and Parry in the colder climates of the north, it has been concluded that there must exist two poles of maximum cold, one in America, and the other in Asia; and that the utmost depression of temperature takes place, not at the north and south poles of the earth, but at those imaginary points. Temperature and climate must chiefly depend on the figure of the great continents of the world; besides which there are a variety of circumstances which must tend to modify the influence of solar heat as connected with the situation of places on the surface of the earth.

21. Mr. Atkinson, in a paper in the "Memoirs of the Astronomical Society of London," (vol. ii.) estimates the mean temperature of the equator at 86°.55; and that of the pole at—10°.53. Mr. Forbes regards the former as decidedly too great, and says "it is probable that the mean temperature of the equator does not exceed 81°.5 or 82°." The mean temperature at the pole can only be inferred from observations at very high latitudes; and hence the following table of mean temperature becomes interesting and important.

	Lat.	Mean Temp.	Observer.
Melville Island	74¾°	— 1½°	Parry.
Port Bowen	73¼	+ 4	The same.

What point did Halley seek to determine in regard to solar heat?

Is the temperature of different parts of the earth's surface dependent solely on latitude?

What important conclusion has been deduced from the researches of travellers in the polar and equatorial regions?

What is Mr. Forbes's estimate of the mean temperature of the equator?

How can we infer that of the pole?

What is the mean temperature of the year at Melville Island?

What is its distance in degrees from the north pole?

	Lat.	Mean Temp.	Observer.
Igloolik	69⅓	+ 7	Parry.
Winter Island	66¼	+ 9½	The same.
Fort Enterprise	64½	+15½	Franklin.

22. "M. Arago had concluded from the results of Scoresby, Parry, and Franklin, that the mean temperature of the pole is 13° Fah. This, however, is upon the idea that the cold is at a maximum at the pole, which is not probable: it cannot, however, be much short of that intense degree."*

23. The relative decrease of heat in ascending above the surface of the earth is a subject highly deserving of investigation. Mr. Forbes says, "The true law of decrease of temperature, such as it would be *if the earth was removed*, must be sought for probably by successive stages of balloon observation, commencing at a considerable height above the surface." The best observations on the relative diminution of heat at increasing heights, are those of Humboldt, derived from experiments made in the equatorial regions of America. The general result of his researches gives 121 toises of ascent for a diminution of 1 deg. of Reaumur's thermometer. Comparative observations at Geneva and on Mount St. Bernard afford a coincident result highly remarkable, the difference of mean temperature of the two stations being 8 deg. 64 min., Reaumur, for 1069 toises, which gives 123½ for 1 deg. Reaumur, or 352 feet for 1 deg. Fahrenheit, and this is probably the most correct mean result which can at present be attained.†

24. An inquiry has been started whether the climate of a particular place, or that of the globe in general, has materially altered during the period of historic record; and some writers have been inclined to decide in the affirmative, alleging the statements of historians that the vine was cultivated extensively for the production of wine in England formerly, though the summers in that country are now too cold to bring the fruit to the requisite degree of maturity. Circumstances of this nature, however, cannot be considered as decisive; and it may be generally concluded that we have no authority for assuming such a change.

25. Yet though the temperature of the earth may be regarded as permanent, so far as it depends on the heat derived from the sun, there seems to be great reason for believing that the whole

What is Arago's conclusion respecting polar mean temperature?
How is the decrease of temperature above the earth's surface to be known?
What appears to be about the mean rate of diminution in temperature, according to increase in height?
From what observations has this result been obtained?
What may we infer respecting the present compared with former states of terrestrial climates?

---

* Report upon the Recent Progress and Present State of Meteorology. By James D. Forbes, F. R. S., in Rep. of the British Association for 1832, p. 216.

† Idem, p. 219.

mass of the terrestrial globe is undergoing a gradual process of cooling, from an originally very intense temperature. Baron Fourier, who has distinguished himself by his investigations relating to this curious topic, has proved that the heat may be very intense at a short distance from the surface, and yet from the extremely bad conducting power of the crust or exterior strata of the earth, that it may exert no sensible influence on the climate: he actually computes it as not amounting to 1-30 of a degree of the centigrade thermometer. Towards the centre of the earth the heat may be of the most extreme intensity, and the phenomena of earthquakes and volcanoes may be imputed to its influence.

26. The process of cooling, which at first must have been comparatively rapid, may be considered as having reached such a rate as to be imperceptible. From experiments made at Paris, in the caves under the Observatory, it is probable that the influence of the solar rays does not extend more than about 100 feet beneath the surface. Therefore the heat there will be nearly invariable; and throughout the superior strata a constant influx and efflux of heat must be going on. As the influence of the sun does not extend beyond a certain depth beneath the surface of the earth, it might be expected that beyond such depth the temperature would continue the same all the year round in every inferior stratum relatively to its position; and that this is the case has been ascertained by M. Cordier, from a collation of numerous facts observed in Cornwall, Saxony, Brittany, Switzerland, America, and other parts of the world. It also appears that in all the inferior strata the temperature increases as we descend, without any exception: a circumstance decisively proving, that there must be a source of heat in the centre of the earth.*

27. Hence it may be concluded, in conformity with the most rational geological speculations, that the planet which we inhabit was at a very remote period in the state of fusion, and like other semi-fluid masses revolving rapidly under the influence of central forces, it has assumed its peculiar form, a flattened spheroid. During how many ages the terrestrial globe continued to emit heat from its surface before compact strata were formed, such as the various modifications of primitive rocks which we behold, and how much longer time elapsed before those rocks became the

On what other cause than solar heat does climate depend?

What conclusions has Fourier derived from his investigations of this subject?

To what cause may earthquakes and volcanoes be imputed?

To what depth beneath the surface of the ground does the influence of solar heat probably extend?

What is constantly taking place at levels above the *invariable stratum?*

How is the temperature of the strata, below the *invariable* one, found to be at different seasons?

What relation has it to the depth of the several lower beds?

What does this prove in regard to the temperature of the central parts of the earth?

* Report of British Association, p. 221.

basis of this world of land and water, numerously peopled with living beings as at present, it would be utterly useless to attempt to conjecture. It is sufficient for us to be able to state, as the result of the most accurate and extensive observations, that the internal heat of the earth no longer affects in a sensible degree the temperature of its surface, or of the strata immediately beneath the surface; and therefore the varieties of climate, and the alternations of heat and cold in the different seasons of the year, as well as the changes attributable to incidental causes, are chiefly owing to the influence of the sun, as the general efficient source of heat.*

28. Among the mechanical means of producing, or rather of exciting heat, friction is perhaps the most usual and effective. In sawing wood, or boring metal, it may be observed that the substances thus exposed to friction soon become sensibly warm. The wheels of carriages sometimes take fire, from friction against the axles when in rapid motion. In some rude countries, as in Patagonia, the inhabitants avail themselves of this mode of procuring fire. They either rub together two pieces of hard dry wood till flame arises, or more artificially insert the blunt-pointed extremity of a rod of hard wood in a small cavity in a thick plank,

What bearing have the observed facts in regard to subterranean heat upon geological theories?

What effect has the internal heat of the earth on the temperature of its surface?

By what mechanical means may heat be excited?

What remarkable facts prove the efficacy of friction in producing heat?

---

* Some very remarkable instances have been recorded of extreme heat, as noticed by several observers. In Winkler's Elements of Natural Philosophy, vol. i. pp. 179—182, are two tables of very high and very low temperatures observed at different times, and in various situations, collected by Professor Heinsius. The highest atmospheric temperature which he records was observed at Senegal, on the coast of Africa, in lat. 16° N. when the heat was 86¼° of Delisle's thermometer, corresponding to 108½° Fahrenheit. This temperature was considerably below that observed at Bagdad, in August, 1819, as stated in the Journal of Science, Literature, and the Arts, edited at the Royal Institution, 1820, vol. ix. p. 423. "On the 26th of August, last year (1819), the thermometer at Bagdad rose in the shade to 120° Fahrenheit, and at midnight was 108°: many persons died, and the priests propagated a report that the day of judgment was at hand." The greatest heat accurately observed in England, of which we have authentic accounts, took place in 1808 and 1825; July 13, 1808, the thermometer, according to the Royal Society's Register, rose to 93°.5; and Mr. H. Cavendish's thermometer at Clapham, to 96°. Dr. Heberden observed the heat in July, 1825, and found that on the 18th of that month the thermometer stood at 96°, and on the following day at 95°.—See Philos. Trans. 1826, part ii. p. 69.

In different parts of the United States the thermometer is frequently known to rise, for a few hours at a time, to 95 or 100 degrees. On the 8th and 9th, 26th and 27th of July, 1834, the thermometer in Philadelphia stood at from 94 to 98 degrees, according to different exposures.—Ed.

and turning it with great velocity between their hands thus obtain sparks and flame.

29. Count Rumford instituted some important experiments on the effect of friction in producing heat.* Having observed that great heat was excited during the operation of boring cannon, he procured an unbored cannon, with the large projecting piece two feet beyond its surface, which is usually cast with the cannon to ensure its solidity; this projecting piece was boared and reduced to the form of a hollow cylinder, attached to the cannon by a small neck; the apparatus being wrapped in flannel to prevent the escape of heat, it was made to revolve on its axes by the power of horses, while a steel borer pressed against the bottom of the cylinder. The temperature of the metal at the commencement of the operation was 60 deg. and the cylinder, having made 960 revolutions in half an hour, it was stopped, and the temperature was found raised to 130 deg. In another experiment a borer was made to revolve in a cylinder of brass, partly bored, thirty-two times in a minute; the cylinder was inclosed in a box containing 18 pounds of water, the temperature of which was at first 60 deg., but rose in an hour to 107, and in two hours and a half the water boiled.

Stockenschneider, an ingenious mechanic of Nieuburg on the Weser, invented a machine, by means of which great heat might be produced, and water boiled by friction.

30. Air does not appear to be necessary to the production of heat by the attrition of solid bodies. Boyle procured sensible heat by making two pieces of brass move rapidly in contact under an exhausted receiver. Pictet, of Geneva, repeated the experiment with success, and found that the introduction of a soft substance between the rubbing surfaces, such as cotton, occasioned an increase of heat. Sir H. Davy insulated an apparatus for exciting heat by friction, by placing it on ice, in the vacuum of an air-pump, under which circumstances heat was produced. He likewise ascertained that two pieces of ice might be melted by rubbing against each other, either in the air of a room below the freezing point, or under an exhausted receiver.

What practice among rude nations is founded on this principle?
In what manner did Rumford investigate the relation of heat to friction?
To what result do his experiments conduct us?
What applications have been made of this principle?
What extraoadinary results were obtained by Davy in his experiments on friction?

---

* The experiments of Rumford seem to prove the incorrectness of that theory which ascribes a material character to caloric; and as he ascertained that the borings taken from his cannon had not undergone any diminution of capacity for heat, it is difficult to ascribe the vast amount of heat developed to any other cause than the vibration of the metal produced by the mechanical operations of rubbing and abrading.—Ed.

† A plan has been started in New England of heating manufactories and other buildings by the friction of metallic wheels, actuated by the same moving power which drives the machinery.—Ed.

31. Compression produces heat either in solids, liquids, or gases. An iron bar may be hammered till it is red hot; and water strongly compressed gives out heat, as appears from the experiments of Dessaignes, as well as from the interesting researches of Mr. Perkins on the compressibility of liquids, which have been noticed elsewhere.* Solids also give out heat when violently extended, as may be ascertained by stretching quickly a piece of Indian rubber, and immediately applying it to the lip, when a sensible degree of warmth will be felt. Mr. Barlow, in his acoount of some experiments on the cohesion of malleable iron, states it as a curious fact, and deserving the attention of philosophers, that frequently at the moment of rupture the bar acquired such a degree of heat in the fractured part as scarcely to suffer a person to hold the bar grasped in his hand, without a slight painful sensation of burning.†

32. But the effect of compression is exhibited in a more striking manner in the production of heat from gaseous fluids, as common air. When air is forcibly compressed by driving down the piston of a syringe, nearly closed at the end, great heat is produced: and syringes have been construced for the express purpose of procuring fire, the heat evolved by the compression of air in this manner being sufficient to kindle dry tinder or touchpaper.

33. The chemical operations in the progress of which heat is produced are numerous, and among the most remarkable causes of the evolution of heat from bodies becoming united, so as to form chemical compounds, are those arising from combustion. All substances are not capable of undergoing combustion, and hence the division of bodies into two classes, namely, combustibles, or inflammable bodies, and incombustibles, or non-inflammable bodies. Among the former are vegetable substances in general, as wood, charcoal, and oils; most animal substances, as hair, wool, horn, and fat; and all metallic bodies.

34. The class of non-combustibles includes stones, glass, and salts. The latter, when exposed to high degrees of heat, under such circumstances that they cannot undergo chemical decomposition, may be made to display the usual appearance of fire, or the combination of light and heat, variously designated by the terms glowing, red heat, or white heat, denoting different degrees of incandescence, and when no alteration has been produced by the high temperature to which they may have been exposed. But combustible bodies are very differently affected by heat. Some

What calorific action attends mechanical compression?

Which class of natural bodies illustrates most strikingly the influence of condensation?

What division of bodies has been formed in reference to the property of undergoing combustion?

What natural substances belong to each of these classes?

Describe the effects of heat on these different classes.

---

* See Treatise on *Hydrostatics*, Nos. 13—15.

† Encyclopæd. Metropol.—Mixed Sciences, p. 70.

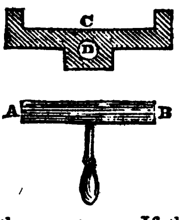
of them at comparatively low temperatures become combined with the oxygen gas contained in the atmosphere around them, and they all undergo similar transformations at certain temperatures, and during such processes heat in the form of fire is frequently exhibited.

35. Among the simple instances of the effect of chemical combination in causing the appearance of heat may be noticed the increase of temperature that takes place when water is mixed with alcohol, and which may be readily perceived on applying the hand to a phial containing the two fluids just after they have been introduced into it. But the mixture of water with sulphuric acid, or, as it is commonly called, oil of vitriol, causes a much greater augmentation of temperature than the preceding; for if an ounce of sulphuric acid be poured into a bottle, containing eight ounces of water, the glass will be so much heated as to render it impossible to hold it; and a more violent heat may be produced by increasing the proportion of the acid.

Characteristic Effects or Properties of Heat.

I. DILITATION OR EXPANSION OF BODIES.

36. The most obvious and direct effect of heat or exaltation of temperature is to add to the bulk of the heated body, or to increase its dimensions, generally in all directions. This takes place in solids, liquids, and gases, without altering their essential properties. The expansive effect of heat on solids, may be exhibited by means of a cylindrical bar of iron, as represented in the marginal figure. When cold, it will be found that the cylinder A B will exactly fit into the space C, in the brass gauge annexed; and it will also pass through the aperture D; but when heated by plunging it for some time into boiling water, it will be so much expanded that it will no longer fit into the space, or enter the aperture. If the bar be cooled, either slowly by exposure to the air, or suddenly by covering it with ice or snow, it will again be contracted, and pass into the cavities as before. The more highly the bar is heated the greater will be the amount of its expansion; and on the contrary, when cooled, its contraction will be in proportion to the reduction of its temperature.



37. The effect of heat in expanding solid bodies, and especially metals, has been advantageously applied to practical purposes.

What examples illustrate the effect of chemical combination on the developement of heat?

What immediate alteration follows the increase of temperature in all forms of matter?

In what manner may it be easily exhibited in the case of solid matter?

What useful applications are made of expansion in the common arts of life?

Thus coopers, in fixing iron hoops on a cask, make them previously very hot, and being adapted in that state to the periphery of the cask, their contraction in cooling binds together the staves of the cask. Wheelwrights also nail on the iron tire or band, while it is nearly red hot, to the wooden wheel of a carriage, and as the metal contracts in cooling, it clasps the parts firmly together.

38. The expansibility and contractibility of iron as an effect of temperature demands the particular attention of architects and engineers, now that metal is so frequently substituted for wood and stone in the construction of roofs of buildings, pillars, arches, and for other purposes. Due allowance should always be made for any alteration of dimensions in metallic beams or supporters, depending on alternations of heat and cold at different seasons of the year, or arising from other causes. In the iron arches of Southwark Bridge, erected by the late Mr. John Rennie, over the Thames, the extreme variations of atmospheric temperature, occasion a difference of height at different times, amounting to about one inch.

39. A curious example of the influence of heat on the dimensions of solids was exhibited some years since at Paris, in the method adopted for restoring to a perpendicular direction the declining walls of a gallery in the Abbey of St. Martin, now the Conservatory of Arts and Trades. The weight of the roof had pressed outwards the side walls of the structure, and excited apprehensions for its safety, when M. Molard contrived to render it secure by the following process: Several holes were made in the walls opposite to each other, through which were introduced iron bars stretching across the gallery, with their extremities extending beyond the walls; and to these projecting parts were screwed strong iron plates, or rather large broad nuts. Each alternate bar was then heated by means of powerful lamps, and their lengths being thus increased, the nuts which had become advanced beyond the walls were screwed up close to it, and the bars suffered to cool. The powerful contraction of the bars drew closer the walls of the building; and the same process being applied to the intermediate bars, and repeated several times, the walls were gradually and steadily restored to the upright position, and the danger apprehended from their declension was averted.

40. Musschenbroek ascertained that heat not only expands metals, but also different kinds of stones, chalk, burnt brick, and glass. Such substances, however, must be perfectly freed from moisture, otherwise increase of temperature will occasion contraction of volume, by dissipating the moisture. Thus wood sometimes acquires an increase of specific gravity by drying. From

To what classes of artisans is this branch of the subject particularly important? Why?

What exemplification of this is seen in bridge building?

Describe the method of Molard to restore walls to their vertical position.

In what case may an apparent contraction follow the application of heat?

some experiments to determine the weight of different kinds of wood at various degrees of dryness, recorded by Mr. Barlow, it appears, that in some cases there is a considerable augmentation of specific gravity. A piece of Riga fir, 11 inches thick, lost $\frac{1}{4}$ of an inch in seasoning, and the weight of a cubic foot was increased from 546 ounces to 562; a piece of American pitch pine, 7$\frac{1}{2}$ inches in thickness lost $\frac{3}{8}$ of an inch, and the increase of weight of a cubic foot was as 518 to 524; a block of Halifax spruce spar, 5$\frac{1}{2}$ inches in diameter, was reduced to 5$\frac{3}{8}$, and the difference of specific gravity was as 541 to 544; and a block of Canada spruce spar, 4$\frac{1}{2}$ inches in diameter, lost $\frac{3}{8}$ of an inch, and the difference of specific gravity, or weight of a cubic foot, was in the ratio of 485 to 512; but in most other cases, the loss of weight was greater in proportion than the diminution of bulk, so that the specific gravity was diminished.*

41. The effect of temperature in the expansion and contraction of glass is an object of common observation, and becomes the cause of frequent accidents. Though the degree of expansion which takes place in glass at any given temperature is proportionally much less considerable than that produced in metals, platina excepted, yet from the irregularity of the effect, glass is easily broken by the sudden application of heat. Glass goblets and tumblers are very liable to fracture, when water heated almost to the boiling point is poured into them; and the danger will increase in proportion to the thickness of the glass; for this substance, admitting heat to pass through it but slowly, the inner surface becomes heated and distended by the hot water before the outer surface, and the irregular expansion causes the vessel to break. In this manner, the glass chimneys now in general use for oil-lamps and gas-burners are often destroyed. M. Cadet de Vaux states that the danger of fracture may be prevented by making a minute notch in the bottom of the tube with a diamond; and in an establishment where six lamps were lighted every day, this precaution being adopted, not a single glass was broken by heat in the course of nine years. A bottle of wine placed near the fire in cold weather, will sometimes fly, as it is termed, especially if a draught of air falls on one side while the other is receiving heat; and the glass cylinder or plate of an electrical machine may be cracked and spoiled by incautiously placing it in a similar situation.

42. On the relative expansibility of different metals by heat depends the operation of compensating pendulums, used for time-keepers and astronomical clocks.†

Is the increase of density a uniform result of the process of drying wood?

State the experiments on this subject.

What peculiar quality in glass renders the effect of expansion in that substance conspicuous?

How does Cadet de Vaux prevent the fracture of lamp glasses by heat?

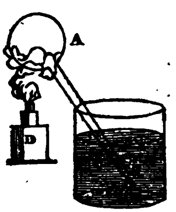
* See Encyclop. Metropol.—Mixed Sciences, vol. i. p. 186.

† See Treatise on *Mechanics*, No. 224.

43. The influence of heat, as a dilating or expanding power, applied to liquids, is greater than in the case of solids. But the degree of action which it exerts is different with respect to different liquids; so that ether is more readily expanded than rectified spirit, the latter is more expansible than water, and water more so than mercury. This might be experimentally demonstrated by filling the bulb of a large thermometer tube with each of these liquids in succession, and then presenting the bulb to a lamp at precisely the same distance, and observing the height to which the liquid would rise in each case in a given time.

44. As different liquids undergo different degrees of expansion at the same temperature, so the expansibility of one liquid will be found to increase or diminish under variations of temperature in a different ratio from those which regulate the expansion of other liquids. This irregular effect of heat is chiefly observable in liquids which boil at a comparatively low temperature, as is the case with water; while mercury, which requires a great degree of heat to make it boil, or become evaporated, undergoes nearly the same amount of expansion by the addition of any given quantity of heat, whether at a low or high temperature; and hence its utility in the construction of instruments for measuring heat.

45. The influence of temperature on the bulk or dimensions of aëriform bodies, whether permanent or non-permanent, is more strikingly exhibited than in the case of the liquids or solids. This may be ascertained by taking a bladder half filled with air, and tying it so that none can escape, when, if it be held near the fire, the included air will expand till the bladder is fully distended; and if while in that state it be plunged into cold water, the air will contract in bulk, and the bladder become flaccid. Such a bladder if very thin, would form an air-balloon, which would ascend, when heated, to the ceiling of a lofty room, and fall down as soon as by the gradual cooling of the air within it the specific gravity of the mass was reduced below that of an equal body of the surrounding air. The expansibility of air by heat may also be demonstrated by means of the apparatus represented below.



46. It consists of a long glass tube A B, with a bulb at one end, and open at the other, which is plunged into the jar of water C; then on heating the bulb by means of the lamp D, the air within the tube will become expanded, and issuing in large bubbles from the aperture B, it will rise rapidly through the water in the jar. On removing the lamp after a considerable portion of the air has been expelled, the water will rise in the tube to supply its place, as the tube

How are liquid and solid bodies comparatively affected by increase of temperature?

What relation have the different liquids to each other in this respect?

cools. The reapplication of the lamp to the bulb at a greater distance than before will again dilate the included air and depress the water in the tube; and the liquid may be made thus to rise and fall alternately by cooling and heating the bulb.

47. It is of importance to observe that airs, gases, and vapours, are all alike affected by given quantities of heat; that is, they not only all expand in the same proportion at certain degrees of temperature, but their rate of expansion under any increase of temperature is likewise uniform. In this respect it will be perceived that gaseous bodies differ from solids and liquids; for while both the latter kinds of matter display the utmost dissimilarity in their relations to heat as an expanding power, the former always undergo expansion in exact proportion to the degree of temperature to which they are exposed.

Instruments for Measuring Heat.

48. The universal influence of heat on the dimensions of material substances affords a convenient method of estimating the relative quantity of heat which will produce any given effect; for since it appears that a certain increase of temperature will always be accompanied by a certain degree of expansion of bulk, it follows, that if we can estimate correctly the degree of expansion in any given case, we may thence infer the amount of temperature. Upon this principle depends the utility of those philosophical instruments called Thermometers* and Pyrometers.†

49. Among the former of these instruments is that which frequently accompanies the barometer, indicating by the expansion of mercury, or some other fluid, the relative temperature of the atmosphere, at different times or places. The mercurial thermometer consists essentially of a glass tube with a bulb at one extremity, and which having been filled with mercury at a certain temperature, introduced through the open end, has been hermetically sealed while full, so that no air can afterwards enter it. As the tube and mercury in it gradually become cooled, the inclosed fluid contracts and consequently sinks, leaving above it a vacant space or

In what degree will the same liquid be found expanded by equal quantities of heat when applied to it at different temperatures?

In what class of liquids is this principle most strikingly verified?

How is the effect of temperature on aëriform bodies exhibited?

How may the ascent of a mass of heated air be visibly illustrated?

Explain the manner in which the expansion of air is proved by heating a glass bulb.

How are the different kinds of air and vapour relatively expanded by heat?

Of what use to science and arts is the principle of expansion?

Of what does the mercurial thermometer consist?

What two points are usually established on the tube before graduating the scale of a thermometer?

---

* From the Greek Θερμος, hot, or Θερμη, heat, and Μετρον, a measure.

† From Πυρ, fire, and Μετρον

vacuum, through which it may again expand on the application of heat. To such a tube it is necessary to add a scale showing at what height the mercury will stand at the temperature of freezing water, and what will be the rate of expansion at any other point, as that of boiling water, together with the amount of expansion at regular intervals between those two points.

50. In what is called the centigrade thermometer, now used in France, the freezing point of water is marked on the scale zero (0°); and the boiling point 100°, the intermediate space being accordingly divided into one hundred equal parts, regularly marked and numbered; and as the scale may be continued to any required extent, above or below zero, any degree of temperature may be thus ascertained, at least between the freezing and the boiling points of mercury; and as this metallic fluid requires a far more intense cold than water does to make it freeze, so it will take a much greater degree of heat to make it boil; and the scale may thus be extended in both directions. Mercury freezes at 40 deg., or 40 centigrade degrees below zero, or the freezing point of water; and it boils or becomes sublimed, *in vacuo*, at +350 deg., that is, it takes a higher temperature by 250 centigrade degrees to make it boil than is required to make water boil.

51. Any fluid might be employed to mark, by its relative expansion and contraction, the temperature to which it might be exposed; and thus sulphuric acid, water, alcohol, oil, and air, have been variously adopted in the construction of thermometers for different purposes. The invention of this useful instrument appears to have occurred in the early part of the seventeenth century; and the mode of measuring heat first employed was by observing the expansion of air confined in a glass tube. It is rather uncertain with whom this idea originated; but among those who have laid claim to it may be mentioned Cornelius Drebbel, of Alkmar, in Holland, and Santo Santorio, professor of medicine at Padua, in Italy; and it is not improbable that this method of discovering the relative effect of high or low temperature may have been independently adopted by both those ingenious men. Drebbel, who passed some part of his life in England, in the reign of Charles I., certainly introduced the knowledge of the thermometer into that country.*

52. The original thermometer was a very imperfect instrument. It consisted of a glass tube with a bulb turned upward, and the lower portion of the stem partly filled with a coloured liquid, and inverted in a globular bottle partially filled with the same liquid; so that the portion of air included in the bulb and upper part of the tube was exposed to atmospheric pressure, and therefore the

How is the freezing point marked on the centigrade thermometer? How the boiling point?

At what temperature on that scale does mercury freeze? and at what point does it boil?

By whom and at what period was the thermometer invented?

What was the construction of the original thermometer?

effect of heat on it could not be accurately appreciated. It was indeed merely adapted to afford a general estimate of the influence of temperature on the bulk of air; much in the same manner as it is exhibited by the apparatus previously described.* This kind of thermometer was improved by the French philosopher Amontons; and Leslie, Wollaston, and others, have adopted several modifications of the air-thermometer, as a delicate instrument for indicating trifling variations of temperature; but the extreme sensibility of air to the impression of heat must ever confine its utility to such purposes as those just mentioned.

53. The greatest defect in the early thermometers arose from the want of a regular scale of temperature, with fixed points to form a medium of comparison between the effects of heat as exhibited under different circumstances, or in its operation on different bodies. Boyle proposed the congealing point of oil of aniseed for this purpose; but Dr. Hooke with greater propriety recommended the freezing point of distilled water; and Sir Isaac Newton, adopting this as the commencement of his scale, or the point zero (0°), he ascertained that 34° would mark the boiling point of water, as indicated by the relative expansion of linseed oil, the fluid which he used to fill his thermometer.†

54. The discovery of two fixed points for the thermometrical scale contributed vastly to the improvement of the instrument; but that of Newton was rendered imperfect by the nature of the inclosed fluid, which did not move freely within the tube, and by the inconvenient length of the degrees of the scale. Hence other men of science employed themselves in contriving by various methods to augment the utility and accuracy of this instrument. Reaumur, in France, invented a thermometer filled with tinged spirit of wine, with a scale divided into 80 degrees between the freezing and the boiling points of water. But as spirit of wine boils at a lower temperature than water, and as it could afford no indication of any degree of heat beyond its own boiling point, on this account, the spirituous fluid was exchanged for mercury; and such a mercurial thermometer, with Reaumur's scale, was in general use in France till the period of the revolution, when it was superseded by the centigrade thermometer, already noticed.

55. The employment of mercury as the most suitable fluid for the thermometer is usually attributed to Fahrenheit, a native of Dantzic, who settled at Amsterdam as a philosophical instrument-maker; and his instruments having the merit of great accuracy

Who are among the improvers of this instrument?
What defect existed in the original thermometers?
What limits the useful application of the air thermometer?
What peculiar disadvantage had the thermometer of Newton?
In what manner did Reaumur divide his scale?
What scale has superseded that of Reaumur in France?

* See above, No. 46.
† See Cotes's Hydrostat. Lect. Appendix, No. II.

and neatness of execution, became much sought after, and his name has been permanently connected with that form of the thermometer, now generally used in England, Holland, and the United States. It appears, however, from the statement of Boerhaave, that the improvement of the thermometer, so far as relates to filling it with mercury, and fixing on the peculiar scale denominated after Fahrenheit, ought rather to be ascribed to Olaus Roemer, a Danish philosopher, to whom we owe the discovery of the velocity of light.* The peculiarity of this scale is, that it does not commence at the freezing point of water, but descends much below it.

56. It is usually stated that Fahrenheit obtained the point, whence he commenced the graduation of his thermometers, by producing artificial cold from the mixture of common salt and snow; but from the authority just cited, it appears that zero of Fahrenheit's, or rather Roemer's scale, was derived from the lowest degree of temperature, or greatest cold which had been observed in Iceland, which was fixed on from an erroneous supposition that this was the extreme of low temperature which was ever likely to become the object of philosophical investigation.

57. Among the numerous modifications of the thermometer proposed by ingenious men, as adapted to the general purpose of indicating variation of temperature, the only one besides the preceding which requires to be here noticed, is that of J. Delisle, member of the Academy of Sciences, at St. Petersburg. It differs principally from other instruments in having a scale, the graduation of which commences at the boiling point of water, and is reckoned downwards: the distance to the freezing point being divided into 150 degrees. Its use is nearly confined to the Russian empire, where it is generally adopted by men of science.

58. As the centigrade thermometer, originally invented by Olaus Celsius, of Upsal, in Sweden, and that of Fahrenheit, are at present commonly used in registering observations on temperature, in France and Great Britain, while those of Reaumur and Delisle have been employed by several eminent philosophers in making and recording their peculiar observations, it becomes requisite that the means should be afforded for ascertaining the relative value of degrees of temperature, according to either of these scales, and of converting any given number of degrees belonging to one scale into degrees belonging to that with which we are most familiar. Fahrenheit's scale, commencing at zero (0°), ascends to 32° the freezing point of water, and thence to 212°, the

In what countries is the scale of Fahrenheit chiefly used?
To whom belongs the application of mercury, and the original use of the scale adopted by Fahrenheit?
How did Roemer actually obtain the zero of his instrument?
Where did Delisle commence the graduation of his thermometer?
Where and by whom was the centigrade thermometer invented?

---

* Boerhavii Elementa Chemiæ, t. i. p. 720.

boiling point; so that there are 180 degrees, in the scale, between these fixed points.

59. The following table exhibits corresponding numbers of the several scales of Fahrenheit, Reaumur, Delisle and Celsius, or that of the centigrade thermometer, from a temperature 12 degrees above the boiling point, Fahrenheit, to 96 degrees below zero.

Fahr.	Reaumur	Delisle	Centigrade	
224	85 3-9	10	106 6-9	
212	80	0	100	Boiling point of water.
192	71 1-9	16 4-6	88 8-9	
160	56 8-9	43 2-6	71 1-9	
128	42 6-9	70	53 3-9	
96	28 4-9	96 4-6	35 5-9	Blood heat.
64	14 2-9	123 2-6	17 7-9	
32	0	150	0	Freezing point of water.
0	14 2-9	176 4-6	17 7-9	
32	28 4-9	203 2-6	35 5-9	
39	31 5-9	209 1-6	39 4-9	Freezing point of mercury.
64	42 6-9	230	53 3-9	
90	54 2-9	251 4-6	67 7-9	Greatest known degree of cold.
96	56 8-9	256 4-6	71 1-9	

60. Hence it will appear, that 1° of *Fahrenheit's* scale is equal to 4-9° of *Reaumur's*, 5-6° of *Delisle's*, and 5-9° of the *centigrade* scale. Therefore in order to convert any number of degrees of *Reaumur* into corresponding degrees of *Fahrenheit*, the given number must be multiplied by 9 and divided by 4, and if it be a number above zero, 32 must be added to the product, and the amount will be the degree required; but if the number be below zero of *Reaumur*, and above zero of *Fahrenheit*, that is any number less than 14 2-9, the product must be subtracted from 32; and if it be a number below 14 2-9, 32 must be subtracted from the product, to obtain the degree required. In the same manner the correspondence between degrees of the *centigrade* scale and that of *Fahrenheit* may be ascertained, only the given number of *centigrade* degrees must be multiplied by 9 and divided by 5. To convert degrees of *Delisle* into degrees of *Fahrenheit*, the given number must be multiplied by 6 and divided by 5, and the product subtracted from 212 will be the number required; but if the number be below zero of *Fahrenheit*, or 176 4-6 *Delisle*, 212 must be subtracted from the product; and if the number required be degrees of *Delisle*

Name the boiling points on the four thermometric scales.

What are the freezing points on them respectively? congealing point of mercury? greatest known degree of cold?

What rules can be given for converting degrees of Reaumur, Celsius, and Delisle respectively into those of Roemer or Fahrenheit?

above zero, 212 must be added to the product to obtain the number required, denoting the corresponding degree of *Fahrenheit*.

61. The mercurial thermometer is the most convenient instrument for measuring any degree of temperature between 644 deg. Fahrenheit, at which the liquid boils, and 39 deg. below zero, at which it freezes. For the mensuration of more intense degrees of cold, a thermometer may be employed filled with alcohol, tinged red by means of alkanet-root; for that fluid, when otherwise perfectly pure, will remain uncongealed at a temperature much lower than that at which mercury freezes.

62. As there is no known liquid that continues unevaporated at a higher temperature than mercury, the relative effect of very high degrees of heat is usually estimated by the alteration of bulk that takes place in solid bodies. Heat generally expands substances of all kinds; but Mr. Wedgwood observed that fine porcelain clay becomes contracted by exposure to great heat; and he found, on investigation, that pieces of pure clay carefully dried, and then exposed to a red heat in a furnace, exhibited a sensible degree of contraction, which remained when they again became cool; and as it further appeared that the contraction proceeded with the augmentation of heat, till vitrification took place in the clay, he conceived the idea of forming a pyrometer, or measurer of heat, consisting of a number of test-pieces of prepared clay, in the shape of small flattened cylinders, and a scale composed of brass rods ¼ inch square, and 2 feet long, fixed to a brass plate, obliquely inclining inwards, so as to be somewhat nearer together at one end than at the other, and marked with a scale of equal parts, commencing at the wider extremity.

63. As the contraction of the clay pieces is permanent, a fresh one must be used for each trial, which is to be made by exposing one or more test-pieces to the heat, the intensity of which is to be ascertained, and when thus heated and again cooled, the contraction that has occurred is to be measured by sliding the piece between the brass rods so far as it will go, and observing the diminution of bulk as indicated by the scale, all the pieces being adapted exactly to fit the widest part of the scale before their exposure to the heat, the estimation of which is the object of experiment. The seemingly anomalous effect of heat on which the property of this instrument depends may be accounted for, as the result of the concentration of the particles of the clay by the more intimate union of the argillaceous and siliceous earths of which it is composed.

64. Each degree of Wedgwood's scale is equivalent to 130 de

Within what limits may the mercurial thermometer be employed?

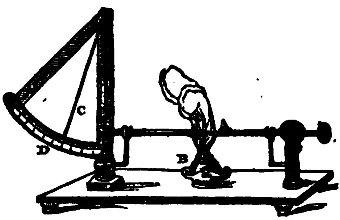
In what manner has it been usual to estimate very high degrees of heat? On what observation did Wedgwood found the construction of his pyrometer? Can Wedgwood's standard pieces be repeatedly used for the same purpose?

In what manner is the contraction of the porcelain pieces to be accounted for?

grees of that of Fahrenheit; and the former commences at 1077°.5 of the latter scale. The mode adopted for instituting a comparison between the two scales was by observing the expansion of a pyrometric piece of silver and of a test-piece of clay, as relatively exhibited at 50 deg. and 212 deg. Fahrenheit, and at higher temperatures as indicated by the brass scale. Having thus obtained a common measure of high temperature, the inventor of the pyrometer proceeded to make various researches concerning the melting points of metals, and other subjects; and it may be stated as the result of his inquiries, that the greatest heat he ever procured was from an air-furnace, amounting to 160 deg. Wedgwood, equal to 21,877 deg. Fahrenheit.

65. Doubts have been started whether the contraction of clay affords a uniform measure of temperature; and the more recent investigations of M. Guyton Morveau, and Mr. Daniell, render it very probable that Wedgwood formed his comparison of the pyrometric and the thermometric scales on an erroneous assumption relative to the melting point of silver. Hence the calculations grounded on experiments made with his pyrometer are not to be absolutely depended on; though the instrument is well adapted to the exigencies of the potter, as affording the means of ascertaining the heat of furnaces with sufficient exactness for many purposes.

66. A great many pyrometers have been invented by various experimentalists, exhibiting different methods for measuring, with more or less accuracy, the relative expansion of bars or wires of iron, or of some other metal.*



Several of these are constructed on the principle of that represented in the margin, in which a bar of metal, A, may be so placed, that when expanded by the heat of a lamp B, one extremity will press against a lever and cause an index, C, to move along the graduated arc D; and by means of such a pyrometer, the effect of heat, applied in the same manner, for a given length of time, to bars of different metals having the same length and diameter, may be ascertained.

67. Mr. Daniell contrived a pyrometer adapted to measure the

How did Wedgwood unite the indications of his scale to those of the common thermometer? What reliance is to be placed upon it as an absolute measure of temperature? To what practical purpose may it be usefully applied? On what principle have pyrometers generally been constructed?

* For descriptions and figures of a number of pyrometers, invented by ingenious British and foreign philosophers, see a Treatise on the Thermometer and Pyrometer, published by the Society for the Promotion of Useful Knowledge.

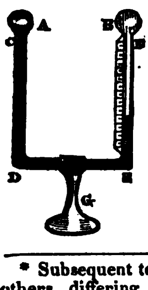
expansion of a rod of plantina, made to move an index over a dial-plate divided into 360 degrees, each equal to 7 degrees of Fahrenheit. He published an account of experiments made by means of his pyrometer, the result of which may be subjoined, as being probably the most exact yet published relative to the effects of high temperatures.*

	Daniell.	Fahrenheit.
Melting point of tin	63°	441°
———— bismuth	66	462
———— lead	87	609
Boiling point of mercury . . .	92	644
Melting point of zinc	94	658
Red heat visible in full daylight .	140	980†
Heat of a common parlour fire . .	163	1141
Melting point of brass	267	1869
———— silver	319	2233
———— copper	364	2548
———— gold	370	2590
———— cast iron	497	3479

68. Pyrometers, or rather metallic thermometers, suited for measuring with great accuracy small variations of temperature, have been constructed by contemporary artists, among whom may be specified Breguet and Frederic Houriet, of Paris, and Holzmann, of Vienna.

In the prosecution of delicate experiments on the influence of temperature, those thermometers may be most advantageously employed in which the effect of heat is exhibited by the expansion of air, included in a small tube with a scale annexed.

69 Among the more recent and useful forms of such instruments, the more important is that called the Differential Thermometer, invented by Leslie, and described in his "Experimental Inquiry into the Nature of Heat."



It consists of two bulbs or glass spherules A and B, connected by the tube C D E F, bent twice at right angles, and supported by a wooden stand G. Within the tube is a small quantity of coloured sulphuric acid; and when a heated substance is brought near to the bulb A, the inclosed liquid recedes, and rises on the opposite side, where its relative height, as indicated by the scale attached to the tube E F, will show the degree of expansion of the air in the tube and bulb A C D. One of the principal advan-

* Subsequent to the publication of this table, Mr. Daniell published others, differing very considerably from these. Besides which, Mr. Prinsep of Benares, in the East Indies, has published the results of some experiments with an air pyrometer, and the editor of this work has made numerous experiments with his steam pyrometer, described in the Amer. Jour. of Science and Arts, vol. xxii. p. 96.—Ed.

† Probably too low.—Ed.

tages attending the use of this instrument is its not being liable to error from changes in the temperature of the atmosphere; for the heat of the surrounding air must act on both bulbs in the same manner, therefore when a heated object is applied to one bulb only, the whole effect produced by it will appear from the different amount of expansion of the enclosed air; or if a cold object be applied the effect will be equally obvious from the different contraction which takes place; and hence the instrument is named a *differential* thermometer.

70. The actual amount of expansion that takes place in different bodies raised to the same temperature is, as already observed, by no means equal. According to recent experiments of Herbert on the expansion of solids by heat, it appears that rods of glass and several metals, of the same length at the freezing point of water, were variously extended at the boiling point. Thus the longitudinal dimensions of each being supposed divisible into 100,000 parts, at 32 deg. Fahrenheit, each substance, at 212 deg. was augmented in the following proportions:

Platina	85 parts.
Glass	86
Gold	94
Iron	107
Copper	156
Brass	172
Silver	189
Tin	212
Lead	262*

71. Liquids also expand unequally at different temperatures, and different liquids are variously affected by the same temperature. The irregular expansion of liquids interferes with the results of experiments made by means of common thermometers; but mercury as exhibiting more uniformity in its rate of expansion

What substance did Daniell adopt for the measure of high temperatures?
What temperature did he assign for that of redness in daylight?
What did he obtain for the melting point of silver?
What for that of cast iron?
What species of experiments may be advantageously prosecuted with the air thermometer?
What liquid is employed in the differential thermometer?
What is one of the chief advantages of this instrument?
Are all bodies equally adapted to the formation of instruments to measure heat by expansion? Why?
By how many millionths of its length, taken at the freezing point, will a bar of platina be found expanded when raised to the boiling point of water? a bar of iron? of silver? of lead?
How are liquids affected by equal augmentations of temperature in different parts of the scale?

* Vieth's Elem. of Nat. Philos. (Germ.), p. 314.

than other fluids, as water or alcohol, is better adapted than they are for thermometrical investigations. Indeed the more readily liquids evaporate under the influence of heat, the greater will be their dilatation, when it takes place without change of form; and therefore ether and alcohol expand more in proportion at relatively high than at low temperatures, and mercury, which requires a great heat to make it boil, increases its rate of expansion more slowly.

72. The following table of the expansions of liquids is derived from the researches of Mr. Dalton, who ascertained that an elevation of temperature from the freezing to the boiling point of water would cause an increase of volume in the ensuing proportions.

Mercury as 1 to	0·0200
Water	0·0466
—— saturated with salt	0·0500
Sulphuric acid	0·0600
Muriatic acid	0·0600
Oil of turpentine	0·0700
Ether	0·0700
Fixed oils	0·0800
Alcohol	0·1100
Nitric acid	0·1100

73. Aëriform fluids, as before stated, all dilate alike, and undergo uniform degrees of expansion at different temperatures. This property of gases and vapours depends on their being destitute of cohesian, so that the influence of heat operates on them simply and independently, its effect not being modified by any opposing power, as in the case of solids and liquids. From the experiments of Gay Lussac in France, and those of Dalton in England, it appears that all elastic fluids, whether airs or vapours, when raised from the temperature of 32 deg. Fahrenheit to 212 deg., become expanded nearly in the ratio of 100 to 137.5; or 100 cubic inches of gas at the freezing point of water, if heated to the boiling point, would be augmented in bulk to 137½ inches. Hence the expansion of volume for each degree of the centigrade thermometer would be 0.375, or reckoning the bulk at zero as 1 (unity), the augmentation for each degree would be 0.00375. Dalton estimates the increase of bulk for every degree at 0.00372, which would be nearly equivalent to 0.00208 for each degree of Fahrenheit's thermometer.

How is the rate of dilatation related to the boiling point of liquids? What examples prove the truth of this principle?

How much is mercury expanded by the addition of 180 degrees Fahrenheit to its temperature at the freezing point?

On what property of gases is their uniform rate of expansion supposed to depend?

How much is the bulk of a gas enlarged by heating it from the freezing to the boiling point?

What will be the rate for one degree?

74. Thus it appears that the density of substances generally bears a certain relation to their temperature, being augmented by cold and diminished by heat, or in other words, contracted by exposure to a low temperature and expanded at a high temperature. So far as we can judge from experiment, the maximum density of solid bodies must be at the lowest temperature which can be produced. And the same may be stated with respect to liquids which are not susceptible of being solidified by cold, or frozen. But this does not always hold good with regard to freezing or congealing liquids; and water is especially remarkable for its property of expanding in the act of congelation, whence, as is generally known, vessels are liable to be burst in winter by the freezing of aqueous liquors contained in them; and loose ice is always seen to float on water, in consequence of its inferior specific gravity.

75. From the researches of Deluc and others, it appears that pure water acquires its maximum density at the temperature of 40 deg. Fahrenheit, whence, if the cold be increased, it expands till it reaches the freezing point 32 deg.; so that ice at 32 deg. has the same specific gravity as water at 48 deg. But for this property of water, large ponds and lakes exposed to intense cold would not merely be frozen over, as is usual in the winter season, but they would become entire masses of solid ice. For ice once formed, if heavier bulk for bulk than the water beneath it, would sink to the bottom of the pond or lake, and remain there to be augmented by fresh descending portions, as long as a frost lasted; but its relative levity causes it to continue on the surface of the liquid which it protects in some degree from the cold atmosphere, and congelation consequently proceeds more slowly.

76. This remarkable property of liquids near the point of congelation is certainly not, as generally stated, peculiar to water, for other aqueous fluids are affected in the same manner; and there is reason to believe that metallic and other substances, which have been melted by exposure to great heat, contract in cooling only to a certain point, and then expand, like water, so that the density of a mass of metal just become solid will be inferior to that of the same metal a few degrees above that at which it takes the solid form.

77. Reaumur states that iron, bismuth, and antimony, are more condensed just before they become solid than afterwards; and he observes that hence figures cast in iron are correctly marked, from the expansion of the metal in cooling, which causes it to press into the most minute indentations of the mould. Sulphur exhibits the same appearances, when used for taking impressions of

What must be the maximum density of solid bodies?

Why are closely corked bottles burst when their liquid contents freeze?

Why does ice not sink to the bottom of cold water?

Is the property of expanding near the freezing point confined to a single liquid?

What causes the accuracy with which iron and other metals fill the moulds, and thus yield "*sharp castings?*"

medals; and it is probable that all bodies capable of fusion by heat, would, under similar circumstances, be found to have less density at the point of solidification than just before the commencement of that process. As to the cause of this phenomenon, the most probable conjecture is that of De Mairan, who, in his Treatise on Ice, ascribes the expansion of freezing water to the new arrangement of its particles consequent to crystallization, so that the minute and still invisible intervals between the molecules of the mass are larger or more numerous in ice than in water 8 deg. above the freezing point. But this interesting topic demands further investigation.

Latent Heat, and its Influence on the Forms of Bodies.

78. No indication is afforded by the thermometer of the absolute quantity of heat which any substance may contain, but merely of the amount of free or sensible heat capable of producing a certain degree of expansion in a column of mercury. If a quantity of ice at 32° Fahrenheit be placed in a jar set in a basin of water considerably heated, the ice will gradually melt, absorbing heat from the water through the sides of the jar; but though it must thus receive successive portions of heat, they would produce no effect on a thermometer within the jar, the mercury in which would remain at the freezing point till all the ice became dissolved. So that any quantity of heat thus absorbed by ice in the act of thawing would become combined with the liquid, constituting what is termed *latent heat*, as not being appreciable by the thermometer.

79. Different bodies require different quantities of heat to raise them to the same thermometrical temperature, or at least they are differently affected by exposure to the same temperature. Thus, if a quart of water and a quart of olive oil be removed, from a room in which the heat of the air is but 40° Fahrenheit, to another room heated to 80°, both liquids would gradually acquire the latter degree of heat, as might be ascertained by placing a thermometer in either liquid. But the oil would be perceived to have become raised to the temperature of 80° much sooner than the water; and hence it has been inferred that a smaller quantity of heat is required to produce an augmentation of 40° of temperature in the former liquid than in the latter. As oil becomes heated more speedily, under the same circumstances, than water, so likewise it cools faster than water; as would appear on reversing the preceding experiment.

To what does De Mairan attribute the diminution of density in bodies at their points of congelation?

To what is the indication of a thermometer limited?

In what change of a solid body is *sensible* converted into *latent* heat?

When equal quantities of different bodies are exposed to a change of temperature, what difference may we expect to find among them while undergoing that change?

Exemplify this in the case of two liquids.

80. When equal quantities of the same body at different temperatures are mixed, the temperature of the mixture will be at the medium between those of the two portions: thus a pint of water 32° added to another pint at 98° would produce a quart of water at 65°; half the difference between the temperature of the hot water and the cold (33°) having been taken from the former and added to the latter. But the result is very different when dissimilar bodies at different temperatures are mingled: for if one pound of water at 156° be mixed with one pound of mercury at 40°, the common temperature will be 152°, instead of 98°, the medium temperature, which would have been that of the mixture if water had been used instead of mercury.

81. From this experiment, it appears that the water gives up 4° of its heat to raise the mercury 112°; whence it has been concluded that water has a greater capacity for heat than the metallic fluid, in the ratio of 112 to 4, or 28 to 1. If the experiment be reversed, by mingling one pound of mercury, at 156° with one pound of water at 40°, the common temperature will be 44°; the mercury having been deprived of 112° of its heat, while the water has acquired but 4°. A pound of gold at the temperature of 150° added to a pound of water at 50° will raise the temperature of the liquid but 5°, while it will lose 95°, the common temperature being 55°. Hence the relative *capacity for heat* of gold and water would be as 5 to 95°; so that the capacity of water for heat must be 19 times greater than that of gold. But the results of different experiments on specific heat, vary considerably from each other. Thus Lavoisier and Laplace make the specific heat of mercury .029, water being 1.000; Petit and Dulong make it .033; Kirwan .033, and Dalton .0357; these differences are, probably, to be attributed to the different methods of conducting the experiments.

82. Several attempts have been made to ascertain with greater precision the quantities of heat given out by different substances under various circumstances. Lavoisier and Laplace constructed for this purpose an instrument called a calorimeter, adapted to measure the quantity of ice melted by different bodies, in the process of cooling from any given temperature to 32° Fahrenheit. Various precautions were employed to prevent the access of external heat, while the cooling process was going on, and for estimating with exactness the quantity of water produced by the fusion of the ice within the body of the instrument.

83. After having determined from experiments with the calorimeter, that the heat absorbed by one pound of ice in melting would

What will be found to take place on mixing equal quantities of the same body at different temperatures?

What two liquids afford a striking illustration of this point?

What term is applied to signify the relative power which different bodies possess of absorbing heat?

What method was adopted by Lavoisier and Laplace to measure the heat given out in cooling?

be sufficient to raise an equal weight of water from 32° to 157°, or 135 degrees,* the French philosophers proceeded to ascertain the relative quantities of heat evolved by different bodies, in cooling, through a certain number of thermometrical degrees, as also in other processes. But the results obtained by means of this instrument are liable to inaccuracy from various causes, which render it difficult, if not impossible, to collect the whole of the water produced from the melting ice; for it has been rendered probable that a part of the water thus formed may sometimes be congealed again in its passage through the lower part of the calorimeter, so that the quantity obtained will afford no certain measure of the effect of the evolution of heat from the body under investigation.

84. Other experimentalists have therefore had recourse to different methods of appreciating the specific heat of various substances. Count Rumford invented a calorimeter, for estimating the quantity of heat given out, in the cooling of heated bodies or other processes, by observing the increase of temperature in a body of water, adapted to receive the heat evolved from the subjects of his experiments. On a similar principle is founded the method of ascertaining the *capacity for heat*, or as it is also termed the *specific heat* of gaseous fluids, employed by MM. Delaroche and Berard.

85. Another mode of conducting researches of this nature, consists in noticing the time required to cool any substance through a certain range of temperature, as indicated by the thermometer, and comparing its rate of cooling with those of other substances. The experiments of Leslie, and those of Dalton, on the specific heat of different bodies were thus conducted; and a similar plan was pursued by MM. Dulong and Petit in their experiments on metals.

86. All these methods of operating are more or less liable to objection; and the results thus obtained can only be regarded as affording some approximate estimates concerning the relative influence of temperature on different bodies. Two other methods of determining specific heat, have recently been put in practice. The first, is that of Weber, who measured the heat given out by stretching a bar of metal, and observing how much the elasticity had been diminished by the loss of heat. The second, is the method of evaporation, employed by the editor of this work, and

What quantity of heat did they find to become latent by the melting of ice?

To what objection is the calorimeter exposed?

How did Rumford attempt to determine specific heats?

To what purpose did Delaroche and Berard apply this method?

What method was employed by Dalton, Leslie, Dulong, and Petit for the determining of specific heats?

What other modes of arriving at the same object have been adopted?

---

* Dr. Black estimated the heat required to melt a given quantity of ice as equal to that which would raise the temperature of the same weight of water from 32 to 162 or 140 degrees.

described in the American Journal of Science,* together with formulæ for calculating the specific heats.

87. As the general effect of heat is to cause an increase in the volume of bodies exposed to its action, producing expansion commonly in all directions, but in different degrees according to the nature of the substance on which it operates, an estimate of the quantity of heat thus operating, or rather of the amount of the effect thus produced, may in this manner be obtained; and the instruments adapted for measuring heat on this principle have been described. But, as already stated, important changes may be caused in bodies by the addition or abstraction of heat without affecting the thermometer in the usual manner; thus solids by exposure to heat may be converted into liquids, and the latter, when heated, boil or become evaporated, or altered from the liquid to the gaseous or aëriform state. It was by observing the dissimilar effect of heat on given portions of ice and water, both at the temperature of 32°, being placed in equally advantageous circumstances for receiving heat, that Dr. Black was led to form his theory of latent heat, as the cause of the liquefaction and vaporization of different bodies.

88. It may be stated as a general principle, deduced from numerous experiments, that when any substance becomes liquefied or melted by heat, a quantity of heat appears to be absorbed by that substance in the process of fusion, which cannot be appreciated by the thermometer; though the depression of temperature in bodies placed in contact with the melting substance is found to be very considerable. Thus water may be frozen by placing a small bottle partly filled with that liquid in a basin containing pounded ice or snow mixed with the salt called muriate of lime; and supposing the temperature of the water to be 52°, or 20° above the freezing point, it will gradually give out heat till congelation takes place, and the quantity of heat which thus escapes from it will be absorbed by the frigorific mixture of snow and salt, which will progressively melt or become liquefied, but will retain the same thermometrical temperature so long as any part of the mass continues undissolved.

89. On this principle depend the artificial modes of reducing liquids to the solid state, by means of freezing mixtures, which usually consist of mineral acids or powdered neutral salts, mixed with snow. Analogous effects will be observed when fusion takes place at a high temperature. Thus spermaceti melts at

What effect, besides expansion, takes place in bodies by additions of heat?

What first led to the formation of Black's theory of latent heat?

What general principle is applicable to the heat of bodies undergoing liquefaction?

Explain this principle in the process of freezing water by frigorific mixtures.

At what point would spermaceti remain stationary when exposed in its solid state to the effect of heat?

* Vol. liii. p. 279.

the heat of 112°, which temperature it will retain as long as any portion remains solid; so that a person might dip a finger into the melting mass while fragments continued undissolved, but when the fusion was completed, any addition would raise the thermometer above the melting point. Tin becomes fused at 442°, and lead at about 602°, and at those temperatures respectively, the metals would remain during the process of fusion; but after it was completed, they might be raised to a red heat. And lead, melted and then made red hot, in a crucible, would immediately be cooled down to its melting point by throwing into it a piece of solid lead.*

90. As absorption of heat or diminution of temperature in surrounding bodies always takes place when a solid substance is melted or changed to the liquid state, so heat is given out when the contrary change occurs of a liquid into the solid state. If a strong solution of Glauber salt (sulphate of soda), made with hot water be poured into a phial, and corked up while warm, provided it be left quite undisturbed, the salt will remain dissolved when below the temperature at which it would otherwise crystallize; then on suddenly opening the bottle a mass of crystals will be immediately formed, and their production will be accompanied with an elevation of temperature easily perceptible by the hand applied to the outside of the bottle. When water is poured on quicklime it loses its liquid form, and, entering into combinations with the calcareous earth, constitutes the pulverulent solid called slaked lime, giving out the same time abundance of heat, a great part of which is carried off by a portion of the water rising in the form of misty vapour.

91. When liquids are exposed to heat they become converted more or less readily into aëriform fluids; thus water is changed into steam, and ether and alcohol into inflammable vapours; and generally all liquids, heated without being decomposed, assume the gaseous form at certain temperatures, and are condensed to the liquid state again by exposure to cold. Different liquids require different degrees of temperature in order to their conversion into the form of vapour. Water boils or becomes evaporated at 212 deg., while alcohol enters into ebullition at 173½ deg., and

How long would it retain this temperature?
What is the melting point of tin? what, that of lead?
What phenomenon presents itself when liquids are converted into solids?
What causes the heat which is observed in the process of slaking lime?
What effect of heat follows the exposure of liquids to its continued influence?
At what temperatures does boiling or *vaporization* take place in water? in alcohol? in ether?

---

* An important investigation of the latent heats of tin and lead, and of various alloys of those and other metals, has been made by M. Rudberg, and will be found in the Annales de Chym. et de Phys., vol. xlviii. p. 353, in which he has shown that alloys have two stationary points, unless mixed in certain proportions, probably those in which they form complete chemical compounds, and leave no excess of either ingredient. —Ed.

ether at 100 deg. But similar changes take place to a certain extent at almost any temperature; for all kinds of aqueous liquids slowly evaporate when exposed in shallow masses at the coldest season of the year; and spirituous or ethereal liquids cannot be preserved long in that state at ordinary temperatures except in closely-stopped vessels.

92. Oily and saccharine liquids do not very readily evaporate in cold weather, but they also become dissipated through the air after longer exposure than those of a more volatile kind. This is a wise provision of nature, for if water obstinately retained its liquid form at all temperatures below 212 deg., the moisture that fell to the earth in the state of rain would never be evaporated during the hottest summers; and abundant inconvenience would arise from the presence of liquids which are now removed more or less speedily at all seasons, through the agitation of the air.

93. Evaporation at low temperatures takes place from the surfaces of solids as well as from those of liquids. Even ice and snow may be observed to diminish in quantity from evaporation during the continuance of a frost. Some interesting experiments on this subject were made in the winter of 1814-15. On the eastern coast of Lake Winnepie, latitude 52 deg. N. November 28, 1814, Mr. Holdsworth hung up a disk of ice, 2 inches thick, weighing 20 lbs.; on the 14th of February it had lost 17 oz., the highest temperature in the interval being 23 deg. Fahrenheit. The experiment was continued till the 31st of March, when the entire loss of weight of the ice by evaporation amounted to 4lbs.; and though the temperature on the 26th and 28th of February had been as high as 36 deg. during more than two hours each day, no dropping took place from the ice, nor was any moisture perceptible on its surface. February 16th 1815, snow was suspended in a crape bag or handkerchief, which, together with the snow, weighed 30 oz. In ten days it had lost 2 oz.; and in nine days more an additional 2 oz.; on the 14th of March, the total loss was 6 oz., or one-fifth of its weight in twenty-six days; the crape continued dry during the whole period.* Hence it appears that a very considerable amount of evaporation takes place from solid ice, when the temperature of the atmosphere is below that of freezing water.

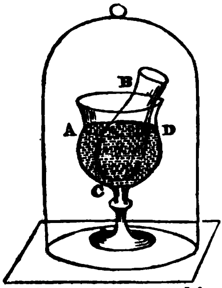
94. Among those circumstances which materially affect the evaporation of liquids, one of the most important is atmospheric

Will *evaporation* always require the same temperature as *vaporization?*
What would be the consequence, were the law of nature different from what it actually is in this particular?
What bodies other than liquids evaporate at low temperatures?
What experiments are related in connexion with this subject?
What interesting general conclusion may be drawn from them?
What circumstance materially affects the rate of evaporation?

---

* Journal of Science, &c., edit. at Royal Institution, vol. ix. pp. 423, 424.

pressure. All liquids readily become evaporated in a highly rarefied medium. Mercury is sublimed with a small degree of heat in the vacuum formed in the upper part of a barometer tube; and water may be made to boil in an exhausted receiver of an air-pump at a temperature much inferior to that at which ebullition takes place under common circumstances. In the same manner the boiling point of water becomes lowered, in proportion to the rarefaction of the air, in ascending high mountains; and in general the boiling points of all liquids will vary in some degree according to the pressure of the atmosphere, as indicated by the barometer.



95. Ether, when placed under an exhausted receiver, rapidly evaporates. It may thus be made to boil while water placed in contact with it freezes. To exhibit this phenomenon, a small flask, B, must be procured, made of thin glass, and nearly fitting into a bell-shaped drinking-glass, C, as represented in the figure. Ether must be poured into the glass, and water into the flask, so that both liquids may stand at the height of the dotted line, A D, and the apparatus thus arranged is to be placed under the receiver of an air-pump, on working which the ether will boil or be converted into vapour; and as it requires heat for this purpose, it will absorb it from the containing vessels and the water which it surrounds, and the latter liquid thus deprived of its heat will be reduced to a temperature below the freezing point and become ice.

96. The diminution of temperature produced by the evaporation of ether is so considerable, that by means of it mercury may be reduced to the form of a solid. This may be effected by inclosing a small quantity of mercury in a flattened spheroid of thin glass, and covering it with thin muslin on which ether is to be dropped as fast as it evaporates, and the heat will thus be so rapidly abstracted from the mercury that it will soon be frozen to a solid mass.

97. Water alone will boil speedily under the exhausted receiver of an air-pump, at the temperature of about 100 degrees of Fahrenheit; but in this case the ebullition soon ceases, in consequence of the pressure of the steam or aqueous vapour, which occupies the space from which the air has been withdrawn.

98. The manner in which a liquid may be made to boil by dimi-

In what manner may water be made to boil below 212°?

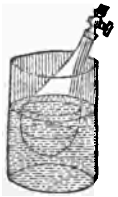
What two contrary effects may be exhibited by withdrawing atmospheric pressure from the surface of two liquids?

Explain the manner in which the experiment is to be conducted.

What effect may be produced by dropping ether on a capsule filled with mercury?

At what temperature will water boil in the exhausted receiver of an air-pump?

nishing the pressure of the atmosphere on its surface may be amusingly exhibited by means of the following experiment:



Let a stop-cock be fitted into the neck of a Florence flask, containing a small quantity of water, and after holding the flask over the flame of a spirit-lamp till the water boils and partly escapes in the form of steam through the stop-cock, let it be suddenly removed from the flame, at the same time shutting the stop-cock; the ebullition will soon cease, and the flask is to be plunged into a jar of cold water, as represented in the margin. The water in the flask will instantly begin to boil again, in consequence of the condensation of the included steam, and the vacuum thus formed in the upper part of the flask. If it be kept long immersed in the jar of water, the ebullition will cease from the gradual cooling of the water within the flask; but if it be taken out of the jar and held near the fire, fresh steam will be formed, and the ebullition may be renewed by plunging the flask afresh into the cold water.

99. The mode of making liquids boil at a comparatively low temperature by the diminution of surface pressure, has been advantageously adopted in some manufacturing processes. Thus it has been applied to practice in the art of refining sugar, the saccharine syrup being concentrated by this means to the point at which it crystallizes or granulates, without any hazard of its burning, or becoming decomposed by excess of heat. In the preparation of vegetable extracts for medical purposes, similar processes have been adopted; and also in making jellies or other kinds of confectionary.

100. Distillation is an operation conducted on similar principles with those just described; but the object is different, for the vapour or steam which, in refining sugar, or making extracts, is dissipated and suffered to escape, as useless, is on the contrary, in distillation carefully preserved, and reduced again to the liquid form by condensation. The method of distilling at a low temperature, by removing the pressure of the atmosphere, has been profitably employed in cases where it was a principal object to obtain products as free as possible from an empyreumatic flavour, or peculiar disagreeable taste. Mr. Henry Tritton has invented an apparatus for distilling spirits, by means of which the vapour is raised in a vessel not exposed as usual to the fire, but surrounded with hot water; and the pipe proceeding from the upper part of it, after

In what other manner may ebullition at low temperature be exhibited?
How may it be repeated when the liquid has become cold?
In what arts has advantage been taken of boiling under diminished pressure?
How does distillation differ from the mere concentration of liquids?
For what purposes is distillation at low temperatures chiefly important?
What is the peculiarity of Tritton's distilling apparatus?

passing in the usual way through a large body of cold water, terminates in a spacious cavity or close vessel, from which the air can be extracted by an air-pump or exhausting syringe. A similar process has been used with advantage in the distillation of vinegar.

101. As liquids boil readily at comparatively low temperatures when the pressure of air or elastic vapour on their surfaces is inconsiderable, so they remain unevaporated at relatively high temperatures, if exposed to extraordinary compression, as when confined in a strong close vessel. Such an engine is that called Papin's Digester, from the name of the inventor. It consists of a metallic vessel of a cylindrical form, with very thick sides, having a cover fitting air-tight, and confined by a cross-bar fastened with screws. When such a vessel, partly filled with water, is exposed to the heat of a fire, a quantity of vapour will be formed within it, which being prevented from escaping will press powerfully on the surface of the liquid, and prevent ebullition, though the heat of the water be raised far above the boiling point, while the quantity and elasticity of the included vapour or steam will also be augmented. The digester ought to be furnished with a safety-valve, which may open when the steam acquires a certain degree of force, below the estimated pressure which the sides of the vessel would be capable of withstanding, and thus the risk of its bursting if over-heated would be obviated. Such machines are employed for extracting the gelatinous matter from bones to make portable soup, and for other purposes.

102. The temperature of steam is always the same with that of the liquid from which it is formed, while it remains in contact with that liquid; and as the elastic force of the vapour is increased in proportion to its degree of heat, the amount of pressure which it exerts will depend on the temperature at which it is formed. Hence the distinction between high and low pressure steam and steam-engines.

103. When steam begins to be produced, as in the process of making water boil, and the heat overcomes the atmospheric pressure on the surface, small bubbles are formed adhering slightly to the sides of the vessel, as may be conveniently observed by using a Florence flask or any other thin glass vessel. These bubbles are formed most rapidly at those points against which the flame is most strongly directed; and if any particular portion of the surface of a common boiler be more intensely heated than the surrounding parts, and the metal become uncovered by the liquid, when the water again comes in contact with it, very elastic steam

Under what circumstances may liquids be made to undergo a high temperature without evaporating?

Describe Papin's digester.

What relation exists between the temperature of vapour and that of the liquid from which it rises?

What distinction arises from the difference of temperatures at which it is produced?

In what manner is the production of steam first manifested?

In what parts of a boiler will its developement be most conspicuous?

will be suddenly formed, which may cause the boiler to burst. Such appears to be the most probable mode of accounting for the numerous accidents resulting from the employment of steam as a moving power.

104. Mr. Perkins has invented an improved steam-boiler, in which a constant circulation of the water is kept up, through a tube or open cylinder in the centre of the boiler, which sweeps off the bubbles from the heated surface of the vessel as fast as they are produced; and thus the formation of steam goes on with uniform regularity. He had observed that two vessels being filled with water, and one placed within the other, when heat is applied so that it can only reach the inner vessel through the liquid contained in the outer one, no steam-bubbles will rise in the former, while they will be rapidly formed in the latter. The fluid in the exterior vessel, consisting of water mixed with air-bubbles, and that in the interior vessel of water only, the contents of the two vessels at the same temperature will differ in specific gravity, those of the outer vessel of course being the lightest. If therefore the bottom of the inner vessel be removed, so that it will constitute an open cylinder with its upper edge a little below the surface of the water in the larger vessel, and supported in that position, as shown in the annexed figure, the unequal density of the fluids in the exterior and interior parts of the boiler, when exposed to the action of fire, will cause the formation of a circulating current.

105. The bubbles contained in the water of the outer vessel, adjoining the fire, will rise continually to the surface; when at a low temperature with a power somewhat exceeding the difference between the specific gravities of air and water, but if the heat be augmented, and the bubbles formed more rapidly, the difference of specific gravity of the respective fluids will be increased, and also the velocity and force of the current. For the fluid in the inner vessel or cylinder, being free from bubbles, will, in consequence of its superior specific gravity, descend and arrange itself beneath the rising columns of the outer vessel, and thus continue the circulation.

106. If the fire be urged so as to produce an extremely intense heat around a boiler of this construction, so rapid and forcible will be the ascending current, that it will draw into its vortex and carry upwards sand, gravel, or stones, or almost any kind of

In what manner has Perkins sought to render the action of the surface of a boiler uniform?

Explain the manner in which the circulation is maintained by the production and escape of vapour?

heavy substance of moderate size which may happen to be in the boiler, sweeping off, in its ascent, all the steam-bubbles which form on the interior surface of the boiler, and keeping it clear from the vapour which might otherwise interrupt the free passage of the heat which it receives into the water; and by the uniform and constant agitation of the whole mass of the liquid, a regular and abundant absorption of heat takes places, and steam is evolved with astonishing rapidity.

107. The steam-engine, a machine of the highest importance, the effective power of which depends on the expansive force of steam or vapour, its general construction and mode of action may here be described. The vapour of water occupies a space about 1700 times larger than the bulk of the water from which it is formed; and hence it may be conceived that in consequence of its expansibility it must strongly resist compression, and that the impetus thus obtained may be variously directed or modified so as to produce motion.

108. At what period steam was first employed as a moving power is uncertain. However the mode of thus applying it, was known as early as the middle of the seventeenth century, since the Marquis of Worcester in his "Century of Inventions," published in the reign of Charles II., describes a machine for producing motion by the force of steam; but though the idea of using steam as a moving power seems to have occurred to several persons about the same period, the invention of the steam-engine properly so called may be fairly ascribed to an ingenious man named Newcomen, who was a locksmith in the West of England; and a patent for such a machine, for raising water from mines, was taken out by Newcomen, in conjunction with Captain Savery, an engineer, who probably contributed to the improvement of the invention.

109. The mode in which steam is made to act is by causing it to raise a solid piston working in a cylinder, like that of a forcing-pump or fire-engine; and the piston-rod rising by the impulse of expanding steam admitted into the cylinder below it, must communicate motion to a beam or lever connected with it. When the piston is thus raised, if the steam be suddenly condensed or withdrawn from under it, a vacuum will be formed, and the pressure of the atmosphere on the piston above will drive it down. It may then be raised afresh by the admission of more steam, to be condensed in its turn, and in this manner the alternate motion may be con-

What striking effects are said to be produced by the currents between the two cylinders of Perkins's boiler?

What is the relation between the bulk of steam and that of the water from which it is produced?

How early was the force of steam, as a mechanical agent, probably applied?

Who invented the steam-engine?

In what manner is the force of steam applied in that machine?

In what way did the atmospheric engine of Newcomen become effective after the piston had been raised by the steam?

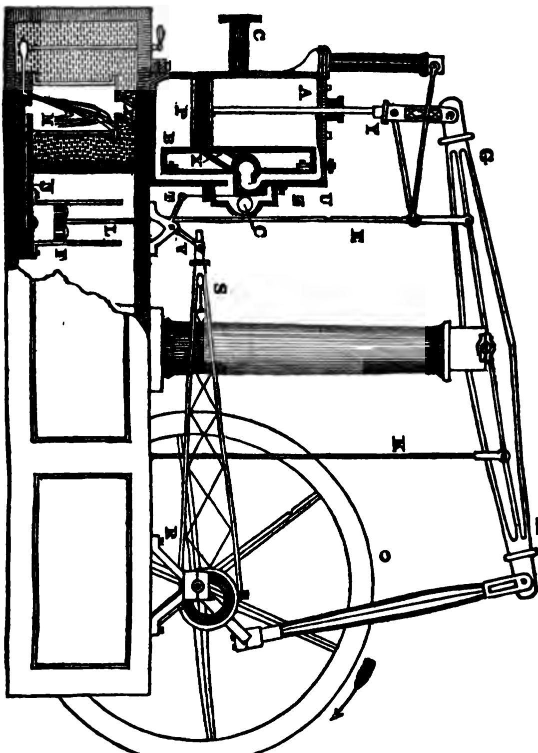
tinued indefinitely. Newcomen's claim to be considered as an inventor depends on his having been apparently the first person who conceived the idea of condensing the steam the moment it had effected its object, by throwing into the cylinder a jet of cold water.

110. Two very important improvements on the original engine were made by the celebrated James Watt. He observed that the cooling of the cylinder by the water admitted into it lessened the expansibility of the steam it received, and that thus much power was dissipated: to prevent which, he contrived a method of withdrawing the steam from the principal cylinder into another, in which the condensation takes place, and from which the water it yields is returned to the boiler to form fresh steam. The other improvement consisted in employing the expansive force of steam to depress the piston as well as to raise it. In the original, or atmospheric engine, the piston, as above stated, was driven down by the mere impulse of atmospheric pressure; but in the improved, or double-action engine, steam is admitted into the cylinder above the raised piston at the same moment that it is removed below it; and thus the expansive force of steam is exerted in the returning as well as the ascending stroke, and a much greater impetus is given to the machinery than by the old method.*

On what does his claim to the invention of the steam-engine rest?
In what did the two principal improvements of Watt consist?
How does his double-acting engine differ from Newcomen's, in regard to the effective mover?

---

* The following notices concerning the invention and improvement of the steam-engine are furnished by Dr. T. Young:—Denis Papin, in 1695, published an account of "a mode of employing the force of steam, by removing the fire continually from one part of the machine to another." Captain Savery exhibited a model of a steam-engine, June 16, 1699, which is described in the Philosophical Transactions. The date of Savery and Newcomen's patent for a steam-engine is in the year 1705; and the latter "introduced the piston." Among the improvers of this valuable machine, Dr. Young mentions the names of De Moura, Smeaton, Beighton, François, who contrived "an engine without a piston, working the cocks by a tumbler;" Droz, Cartwright, Hornblower, Woolf, and Edelcrantz, besides WATT.—*Lectures on Natural Philosophy*, 1807, vol. ii. pp. 257, 258.



111. The preceding figure will enable the reader to form a correct idea of the principal parts of a steam-engine, and of its mode of action. A B denotes the principal cylinder; P its piston, acting by its rod Y on the extremity of the beam G H, the other extremity of which is connected with the fly-wheel; C, a tube or passage by which steam formed in the boiler is conveyed to the conducting pipes T U, to be admitted on either side of the piston P alternately; O, the fly-wheel, which by the rods R S, moving eccentrically, acts upon the rectangular lever V, which by means of the valve Z regulates the admission of steam by the conduct-

Delineate separately the several parts of Watts's double-acting low pressure engine, and explain their uses.
Make a drawing of the whole engine, and show the connexion of these parts.

ing pipes; M, the condenser; X, a tube by which the steam passes from the cylinder into the condenser; N, a tube to convey the water after condensation to the pump L; F, the piston of the pump L, worked by its rod E attached to the beam G H; K the piston-rod of a pump to inject water into the condenser.

112. From this description, the mode of action of the engine may be readily understood. Suppose the piston P to be at the top of the cylinder A B, the lower part being filled with steam, then by means of the lever V, the steam-valve Z will be drawn down so as to admit steam by the upper branch of the conducting pipe U, into the cylinder above the piston: and at the same time a passage will be opened to let the steam below escape into the condenser. Thus the piston will be driven to the bottom of the cylinder, when the steam-valve again opens to admit steam by the lower branch of the conducting pipe T, into the cylinder below the piston, while the other passage also opens to permit the steam above the piston to escape through the tube X into the condenser. Thus the manner in which the piston alternately rises and falls is shown, and by the connexion of its rod with the lever G H, it works the pumps, and turns the fly-wheel, whence the moving power may be propagated through trains of machinery for any purpose required. The fly-wheel may be moved in the manner represented in the figure, by a crank connected with a rod descending from the arm H of the great lever; or the toothed wheels called the sun and planet wheel may be applied, in the mode that has been explained elsewhere.*

113. Various other arrangements are adopted for modifying or regulating the motions of different parts of the machine. Thus the piston rising vertically is connected by a system of jointed rods with the extremity of the arm G of the great lever; and as that lever turns on a pivot, the end of the arm must form an arc of a circle, but by means of the rods the motion is so modified that the piston is allowed to rise in a curve of double curvature of so large radii at the point described, as not to differ sensibly from a right line.† Another contrivance, regulating the velocity of a steam-engine, is that called the governor, previously described, which by the rising of the revolving balls closes, and by their descent *opens* the passage from the boiler to the cylinder;‡ and there are various others adapted to particular purposes.

114. It has been mentioned that the degree of the elastic force of steam depends on the amount of pressure sustained by the sides of the vessel in which it is formed. In the common low-pressure

By what two methods has the alternating motion of the piston rod been converted into continued rotary motion?

For what purpose is the system of jointed rods invented by Watt applied to the steam-engine?

What is the elasticity of steam used in engines acting on the principle of Watt?

---

* See Treatise on *Mechanics*, No. 219 † Ibid. No. 220.
‡ Ibid. No. 228.

engine the steam used is generally formed under a pressure not exceeding twenty pounds on a square inch, and therefore when the expansive force of the steam exceeds it, the valve opens, and the force of the steam is consequently reduced. This pressure is only five pounds more than that of the atmosphere, and the boiler is furnished with a safety-valve, loaded with that weight to each square inch of its surface; but in the double-action engine, the pressure of the atmosphere being excluded, the whole pressure of twenty pounds is by the aid of the condenser made available; and thus such an engine, if its piston be of equal size, will have the same power as a high-pressure engine working with steam of the force of thirty-five pounds on the square inch, because fifteen pounds are here employed in overcoming the resistance of the atmosphere, into which the steam is finally thrown.

115. The high-pressure engine, being simpler in construction, as well as smaller, than the double-action low-pressure engine, is more advantageously used than the latter, where it is requisite to employ considerable power within a confined space; and therefore it has been adopted in steam carriages. In these engines, the steam is not condensed, but is suffered to escape, after it has acted on the piston; and as it is formed under extraordinary pressure, varying from fifty or sixty to two hundred and sixty pounds on the square inch,* its expansive force is relatively very great. The attention of those who have been engaged in the construction and improvement of steam-carriages has therefore been chiefly directed to the contrivance of boilers in which high-pressure steam may be formed with the least possible risk of explosion; and Mr. Goldsworthy Gurney and others appear to have so far succeeded as to have produced carriages worked by steam in which persons may travel at least as safely as in coaches drawn by horses, and with a degree of velocity incomparably greater.

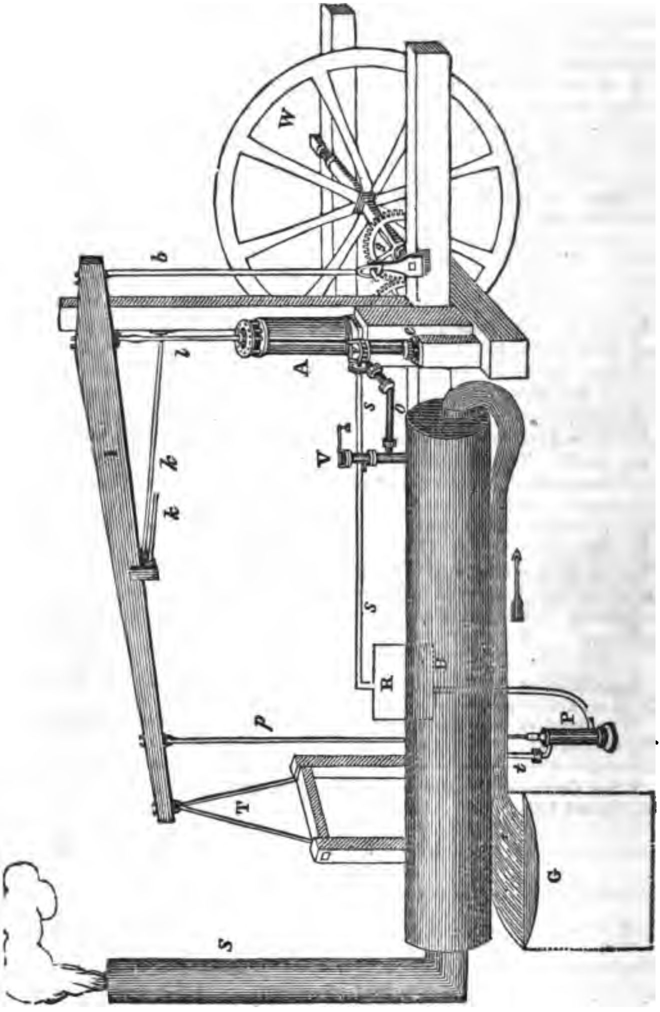
How much of the force of *high steam* is lost by the resistance of the air to its final expulsion from the cylinder?

What renders the high-pressure engine peculiarly adapted to locomotive carriages?

---

* See Gordon's Treatise upon Elemental Locomotion, 1832, pp. 62, 80, 96, and 100.

Oliver Evans's Steam Engine.



116. The high-pressure steam engine invented by Oliver Evans of Philadelphia, in 1784,* and for which he obtained a patent from the state of Maryland in 1787, (the *confederated* states not having adopted a general system of patents,) is the original of all those powerful machines which for the last few years have astonished the world with their wonderful performances.

117. The accompanying figure is a pretty accurate representation of a model of Evans's engine, now in the collection of the Franklin Institute. By a comparison with the machine of Watt, it will be seen how greatly the genius of its inventor had simplified the structure which has called forth such lofty encomiums from some of Watt's biographers. It must be remembered that the inventor was not insensible to the peculiar adaptation of his machine to the purposes of locomotion on land, but that this was one of the express objects of his patent. The parts of the high-pressure engine will be understood by a reference to the figure.

118. A is the working cylinder, to which the steam, equal to several atmospheres in pressure, is admitted by the pipe *o* and the rotary valve *v*.

B is the boiler of a cylindrical form, with a return flue placed below the centre of the outer shell, so as to be constantly covered with water when it stands about at the level of the line B.

S is the smoke pipe springing from the interior flue, after the latter leaves the head of the boiler.

119. G is the fire grate or furnace, from which the flame passes in the direction indicated by the arrow.

P is the force pump, which draws water from a reservoir of hot water, R, placed above its own level. This water is kept hot by the steam which escapes from the cylinder A after it has performed its office there.

p is the pump rod connected with the moving beam above.

V is the safety valve connected with the boiler and furnished with a graduated lever and weight to regulate the pressure.

120. I is the working beam connected to an upright support by the two rods *k k*, to the *oscillating triangle* T, the *pump rod p*, the *piston rod l*, and the *shackle-bar b*, which last gives motion to the fly-wheel W.

g is a toothed wheel, geared to another of the same diameter, which being connected with the two equal bevel wheels at *e*, communicate motion to the rotary valve *v*.

s is the escape pipe, by which the steam is conducted to the tank or reservoir R.

By what means is the flow of steam into the cylinder in Evans's engine allowed to take place?

How is the interior flue arranged in reference to the water line?

How is the hot water force pump arranged with relation to the reservoir from which it is supplied?

What is the purpose of the two small bevel wheels seen in the figure?

---

* Evans began to *build* steam-engines on his plan in 1801, but in 1794 he had sent drawings and specifications to England, where they remained on the death of Mr. Sampson, by whom they were carried out.—Ed.

Propagation of Heat.

121. When any considerable mass of matter, whether consisting of a single substance, as a body of water or atmospheric air, or of several substances mingled together, exhibits a uniformity of temperature, if another substance, either more or less heated than the general mass be added to it, the equilibrium of temperature will be partially disturbed, for a time, and then restored; the whole mass taking heat from the substance added to it, if the latter be comparatively hotter than the mass, and giving out heat to it, if it be relatively cooler. Heat is thus propagated, or communicated from one body to others, having a tendency to become generally diffused among bodies, and cause them all to exhibit the same degree of thermometrical temperature. There are two modes in which the propagation of heat may take place; namely, by conduction, and by radiation.

122. Propagation of heat, by conduction, always takes place when any substance is brought into contact with another which is relatively colder. Hence it is that the temperature of the air in deep cellars and caves seems to be higher in winter than in summer. The degree of heat in such places is at both seasons nearly the same; but the surface of the body in winter being colder than the air of a subterraneous cave, will attract the heat from it, and in the summer, on the contrary, the air will rob the body of its superior heat. It appears, from the experiments of MM. Bertholet, Pictet, and Biot, that heat is communicated more readily by a stroke or blow from a heated body than by simple contact.*

123. The laws of the propagation of heat through bodies by conduction, may be dedueed from the following experiment: suppose a bar of metal, two or three yards in length, to be placed in communication with a constant source of heat, and let ten holes be bored in it at equal distances from each other, from one end to the other, and filled with mercury, thermometers being plunged into the fluid metal in all the holes; then deducting the difference of the temperature of the air from that of the several thermometers, we obtain the temperature of the bar at so many relative distances from the source of heat. These distances must necessarily constitute an arithmetical progression of numbers, and it will be

What effects result when a mass of matter at one temperature is mixed with another mass at a different degree of heat?

In how many modes does the propagation of heat take place?

What is meant by the term conduction?

What effect has percussion produced by a hot body different from that of simple contact?

In what manner may the laws of the propagation of heat through bodies be estimated?

What progression will the diminutions of temperature follow when the points of the solid under examination are at distances from the source of heat forming an arithmetical series?

---

* Memoires d'Arcueil, t. ii. p. 447.

found that the decrease of temperature will take place in a geometrical progression, forming a rapidly diminishing scale of numbers. The rate of diminution of heat is indeed so rapid, that it would be impossible to raise the temperature of one end of a bar of iron two yards and a half in length, a single degree, by any heat applied to the other extremity; for the heat requisite for that purpose would be greater than what was sufficient to melt the iron, as might be shown by calculation.

124. Though heat has a tendency to spread by conduction through all bodies, yet some receive and give it out with much greater facility than others. Among solid substances the power of conducting heat varies very considerably. Metals in general conduct it more readily than wood, and the power of conduction is different in different metals. Hence the handle of a metal teapot or coffee-pot is commonly made of wood; since if it was of metal, it would become too hot to be grasped with the hand, soon after the vessel was filled with boiling water.

125. Dr. Ingenhousz ascertained the difference of conducting power among several metals, by dipping into melted bees-wax cylindrical rods of various metals of the same dimensions, and when the equal coating of wax on all the rods was become solid by cooling, he plunged them to the same depth into heated oil, and from the difference of time required to melt the wax, in each case, he inferred the conducting power of the respective metals. It thus appeared that silver was the best conductor of heat, then gold, tin, copper, platina, steel, iron, and lead. So that the power of conduction in metals seems to be independent of their density, tenacity, or fusibility; for the specific gravity of silver is inferior to that of gold or platina, yet its conducting power is greater; while it has less tenacity than either of those metals; and it is not so readily fusible as tin or lead.

126. Next to metals, precious stones, as the diamond, the topaz, and other dense earthy compounds, appear to be the readiest conductors of heat: then stony bodies, porcelain, and glass, and porous earthy compounds, such as brick and pottery. Wood conducts heat very imperfectly, whether in its usual state or in that of charcoal; either of which may be held by the fingers very near the part which is burning and red hot.

127. Animal and vegetable substances of a loose texture, as fur, wool, and cotton, are extremely indifferent conductors of heat. Hence their utility, either as natural or artificial clothing, in preserving the warmth of the body, in consequence of the obstruction they present to the passage of heat through them. It is pro-

How far might a bar of iron be heated by exposing one end only to the most intense heat?

Which class of solids comprises the best conductors of heat?

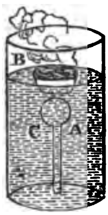
To what practical purpose is the low conducting power of wood applicable?

What order did Ingenhousz find among the metals in regard to conducting power?

What class of bodies hold the second place in conduction?

bable, however, that in such cases the effect partly depends on the quantities of air contained in the interstices of such loose substances; since air is one of the very worst conductors of heat.

128. Liquids conduct heat very slowly and imperfectly. If mercury be poured into a jar, and boiling water poured over it, the metallic fluid will receive heat but slowly from the water above it. A thermometer let down a few feet below the surface of a pond or of the sea, would, on being drawn up, indicate a lower temperature than that of the surface water; for the latter, heated by the rays of the sun, would communicate by conduction little or no heat to the water below. Indeed it has been questioned whether water has the power of conveying heat at all by conduction.



129. In the marginal figure, let A represent a cylindrical jar of water, with an air thermometer, C, immersed in it, and having its bulb very near the surface; B is a small copper basin floating on the water just above the bulb, and separated from it only by a thin stratum of the aqueous fluid; yet, when burning charcoal is placed in the basin, though the surface of the water beneath it may be heated to the boiling point, the temperature just below will scarcely be sufficient to produce any effect on the thermometer: so that it may be concluded that water does not transmit heat downwards by conduction.

130. It may be reasonably inquired how it happens that water is readily made to boil by the application of heat. A little consideration will show that the effect in a great measure depends on the manner in which the liquid is heated, by placing it above the source of heat. Thus, the lower stratum of the liquid, being expanded by the heat communicated to it through the bottom of the containing vessel, rises to the top in consequence of its inferiority of specific gravity, and the water above sinks down to supply its place and be heated in the same manner, till the whole mass acquires the same temperature. The mode in which ebullition is facilitated by the formation of air-bubbles, and the ensuing circulation of the fluid in ascending and descending currents, has been already described.

131. Air, like water, appears to have no observable effect on the propagation of heat by conduction; and it may be concluded that gaseous fluids conduct heat, if at all, with degrees of difficulty increasing in proportion to their rarefaction. It is owing to the extreme rarefaction of the atmosphere at great distances from the common level of the earth's surface, as upon high mountains, and

On what circumstance do porous, animal and vegetable substances probably depend for their low conducting power?

What facts and experiments show the low conducting power of liquids?

Explain the apparatus by which this principle is illustrated.

How does it appear that the rapid communication of heat to water is consistent with its low conducting power?

In what manner do gaseous bodies communicate heat?

its increased capacity for heat, that the excessive cold observable in such situations is to be attributed. Yet though the atmosphere is so bad a conductor of heat, substances may be warmed or cooled by the relative temperature of the air; for the expansion of air by heat, and necessary production of aërial currents, causes a rapid transmission of heat through the air, and thus the temperature of any body in contact with it may be raised or lowered according to circumstances. Air also readily conveys heat by radiation, as will be subsequently explained.

The Caloric Engine.

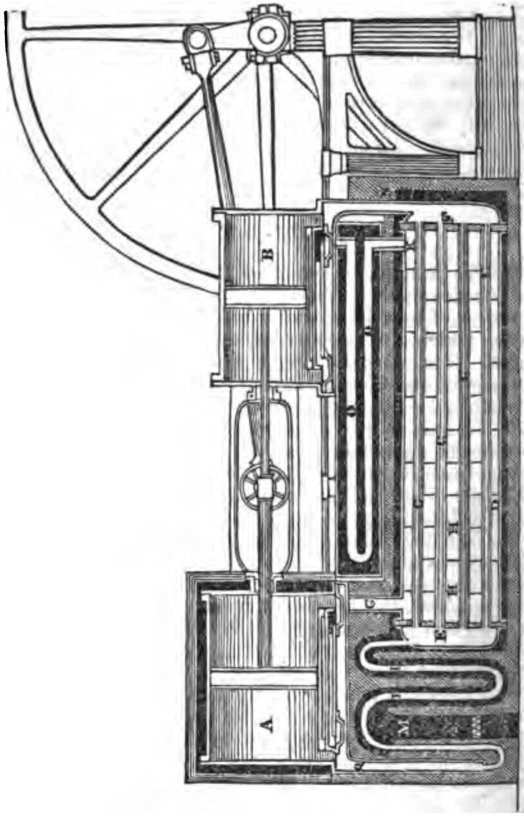
132. The principle of communicating heat by *circulation*, is applied in connexion with the rapid absorption and subsequent communication of heat by metallic bodies, in the construction of a machine which has recently been invented by Mr. Ericson, of London. It is called the Caloric Engine, and is actuated by the successive dilatation and contraction of a quantity of compressed and partially heated atmospheric air, or other permanent gas.

133. This air or gas being made to circulate in opposite currents through a series of small metallic tubes, causes a constant transfer of heat from one part of the machine to another, whereby an alternate dilatation and contraction of the impelling medium is effected and kept up.

134. Thus the Caloric Engine possesses a novel and important feature when compared with the steam-engine, viz., that of being actuated over and over again by the same heat, or nearly so; and it may be added, that it presents to natural philosophy an illustration of the fact that heat does not lose its energy in producing mechanical force, but remains in undiminished quantity after having caused the dilatation which produces that force. At the same time this new invention presents to mechanical science a wide field for improvement, since (unlike the steam-engine) its principle is such that the quantity of force it produces has no other relation or proportion to the fuel it requires than that established by a more or less perfect machine and transferring apparatus.

135. The action of the Caloric Engine and the transfer of the heat will be ready understood by referring to the annexed diagram.

On what principle is Ericson's caloric engine constructed?
What essential feature does it possess different from that of the steam-engine?



136. The engine consists of two cylinders, A and B, of *unequal* diameters, the large one being always kept at a high temperature, and the small one always cool. These cylinders are provided with pistons and valves, similar to those of a high-pressure steam-engine, and their piston-rods are connected so that the one piston cannot move without the other. The two cylinders communicate with each other by means of a number of small tubes, C, passing through a vessel, D, called the regenerator, and all terminating in chambers or caps, E and F, attached to the ends of the regenerator, and so arranged that the hot air, after having performed its duty in

In what state is the larger cylinder of Ericson kept?
Explain the several parts of this machine, and state their several uses.

the large or working cylinder A, passes through the pipe G, into the *body* of the regenerator D, for the purpose of giving out its heat to the small tubes C, in its passage towards the small cylinder B, and thereby becomes cooled and reduced in volume.

137. In order to effect this more completely, a number of partitions, H, having segments cut out alternately from their tops and bottoms, are introduced into the body of the regenerator, giving a very circuitous motion to the hot air in its passage from the pipe G to the pipe K.

The cold air, forced, by the action of the piston of the small cylinder in a contrary direction, through the small tubes C (these being also provided with small partitions for changing or intermixing the particles of air), will, during its passage from the cap F to the cap E, on its way to the hot cylinder, take up the heat imparted to those tubes by the contrary hot current which passes through the body of the regenerator, and thereby become heated and enlarged in volume.

138. It will be evident that if compressed air be admitted into both cylinders on one side only of their pistons, the greater surface of the one will be acted upon with greater force than the less surface of the other; hence motion must ensue: and by reversing the position or the "slide valves" at the termination of each stroke, it will be continued. It need hardly be stated that the difference of the *volumes* of air contained in the two cylinders will cause neither deficiency nor accumulation during the action; because in the large cylinder the air is in a heated state, and in the small one cold.

139. Some loss of heat will of course be unavoidable in the transferring process, and this is compensated by passing the air, previous to its entering the hot cylinder, through a series of small tubes, L, communicating with the cap E, and induction-pipe Q, and exposed to fire, contained in a stove, M, the combustion being supported by ordinary draught, and the waste heat made to pass round the regenerator, and carried off at N into a common chimney. At the same time the air which has passed through the body of the regenerator still retains a small quantity of heat when entering the pipe K; it is therefore passed through tubes O, immersed in cold water, or exposed to some other cooling medium, previous to entering the small cylinder.

140. The marked difference, then, between the caloric engine and the steam-engine consists in this: that the heat, which is required to give motion to the caloric engine at the commencement, is returned by the transferring process, and thereby made to work the engine over and over again, requiring but a small addition of heat to compensate for losses caused by radiation, &c.; while on

What is the purpose of the small perforated partitions in the regenerator, and in its included tubes?

To what cause of loss is the air in this engine exposed?

How is that loss supplied?

How is the quantity of disposable force in this engine proportioned to the size of the two cylinders respectively?

the other hand, in the steam-engine the heat is constantly lost by being thrown either into a cold condenser, or into the atmosphere, like so much waste fuel.

141. From what has been stated it must be inferred that those bodies which absorb heat most freely also part with it most rapidly; that is, they are sooner heated and more speedily become cooled than other bodies. Metals, which are generally the best conductors, and therefore communicate heat soonest, cannot be handled when raised to a temperature of more than 120 deg.; water becomes scalding hot at 150 deg.; but air applied to the skin occasions no very painful sensation when its heat is far beyond that of boiling water.

142. Some curious experiments on the power of the human body to withstand the influence of heated air were made by Sir Joseph Banks, Sir Charles Blagden, Dr. Solander, and Dr. George Fordyce; and an account of them was published in the Philosophical Transactions for 1775. These gentlemen found that they could remain for some time without inconvenience in a room where the heat was 52 deg. above the boiling point. But though they could thus bear the contact of the heated air, they could not bear to touch any metallic substance, as their watch-chains or money. Eggs placed on a tin frame in the heated room were roasted hard in twenty minutes; and a beef-steak was overdone in thirty-three minutes. Similar experiments have been often repeated, especially by persons who have made public exhibitions of their power of sustaining heat, in which, however, there is nothing extraordinary, or which may not be explained as the result of habitual practice.

143. Mr. Chantrey, the celebrated sculptor, made some observations analogous to those just noticed, by means of a stove or oven which he uses for drying plaster casts and moulds. A thermometer suspended in this heated cell, usually stands at 300 deg. yet the workmen enter and remain in it occasionally some minutes, without difficulty. Persons unused to such a temperature found that they could easily support the heat for a short time; but one gentleman inadvertently entering the oven with a pair of silver mounted spectacles on, had his face burnt where the metal came in contact with the skin; thus experimentally ascertaining the different effect of air and silver at the same temperature.

144. On the strong attraction of metals for heat, and the consequent facility with which they abstract it from other bodies, depends, in a great measure, the effect of Sir Humphry Davy's safety-lamp, to be used in mines, or other places infested with that kind of inflammable gas called fire-damp. Flame is gas, or air

What relation exists between the power of bodies to absorb and to communicate heat?

How is the difference of various substances in this particular strikingly exhibited?

Describe the experiments of Banks, Blagden, and others.

What curious observations were made by Chantrey?

On what principle is the usefulness of Davy's safety-lamp dependent?

in the state of combustion, and all gases require a very high temperature to make them burn; so that the flame of gas becomes extinguished by lowering its temperature. This may be experimentally demonstrated by approaching to a weak flame a large mass of iron, as by gradually lowering a thick iron ring over the flame of a small cotton thread dipped in oil; which, being deprived of its heat by the metal, would go out.

145. In a similar manner, the temperature of any inflammable vapour may be reduced below what may be termed the burning point, by passing through fine wire-gauze. Thus, if a small portion of camphor be placed in the centre of a piece of wire-gauze about a foot square, and a lighted candle applied to the under surface, the vapour of the camphor will be kindled and burn below the gauze, without passing through to inflame the camphor upon it. Hence may readily be understood the effect of the safety-lamp, which is a kind of lantern of fine wire-gauze, within which a candle or wick, fed with oil, will burn in security amidst an atmosphere of fire-damp; for though the vapour may enter and become inflamed within the lantern, the flame cannot pass through the close tissue of the wire-gauze to occasion an external explosion.

146. Heat is not only communicated from one body to another by conduction, or by means of circulating currents, but it is also conveyed to considerable distances, through any elastic fluid, as air, by radiation. This mode of the transmission of heat resembles that in which light is propagated; and, as light and heat are frequently transmitted together by radiation, the effects of radiant heat were generally attributed to the light by which it is observed to be accompanied. The ancient Greeks and Romans were acquainted with some of the extraordinary effects of radiant heat produced by burning-glasses; and thus Archimedes is said to have consumed the ships of the Romans by such instruments, during the siege of Syracuse; and several centuries later the philosopher Proclus in the same manner destroyed the fleet of Vitalianus, before Constantinople.

147. Many experiments have been made in modern times on the effect of the transmission of radiant heat through convex lenses, and of its reflection from concave mirrors, which show that by these means its power may be vastly augmented, and which tend, upon the whole, to corroborate the statements of ancient writers relative to the action of burning-glasses.

148. The following results are said to have been obtained from the exposure of different substances to the rays of the sun, col-

What is the true nature of flame?

How can we *prove* that flame is prevented from traversing wire-gauze by the cooling of the burning gas?

What other substances besides permanent inflammable gases, may be kept below the burning point, by wire-gauze.

Explain the difference between radiation and conduction.

What evidence have we that the ancients knew the effect of radiation?

What results have been obtained by modern experiments on burning lenses?

lected by means of a lens two feet in diameter, with a focal distance of three ells, in experiments made at Leipsic in 1691.

149. Pieces of lead and tin were instantly melted; a plate of iron was soon rendered red hot, and afterwards fused; a burnt brick was converted into yellow glass; and amianthus, one of the most refractory bodies, was in a short time reduced to the state of black glass.* Analogous experiments were subsequently performed in France, with a more powerful lens, constructed by order of M. Trudaine de Montigny; and in England, with Parker's burning lens, which was presented to the Emperor of China, when Lord Macartney was sent on an embassy to the court of Pekin. This last instrument was a double convex lens, three feet in diameter, three inches thick in the centre, and weighing 212 pounds. Its aperture, when set, was 32½ inches; its focal distance 6 feet 8 inches: but the focal length was generally shortened by a smaller lens. The most refractory substance fused was a cornelian, which required 75 seconds for its fusion; a chrystal pebble was fused in 6 seconds; and a piece of white agate in 30 seconds.†

150. Important experiments have likewise been made with concave mirrors and with combinations of plane mirrors, which, though relatively less powerful than lenses, may more conveniently be rendered efficient at greater distances. M. Dufay used both parabolical and spherical mirrors made of plaster of Paris, gilt and burnished; and with one of the latter, 20 inches in diameter, he set fire to tinder at the distance of 50 feet. The Abbé Nollet made corresponding experiments with concave mirrors constructed of pasteboard, covered with silver or gold leaf and burnished.‡ But the most remarkable experiments of this nature were those of Buffon, who had a machine composed of one hundred and sixty-eight small plane mirrors, so arranged that they all reflected radiant heat to the same focus. By means of this combination of reflecting surfaces he was able to set wood on fire at the distance of 209 feet, to melt lead at 100 feet, and silver at 50 feet.§

151. The heat of the sun may be concentrated by means of a concave mirror, or by being transmitted through a convex lens; but the heat of burning bodies in general, though readily reflected by a concave mirror of metal, produces little or no effect by means

What remarkable effects were obtained by the Leipsic experimenters?
What refractory materials were fused by Parker's lens?
What kind of reflectors were used by Dufay for burning mirrors?
What apparatus was employed by Nollet and Buffon for the same purpose?
How may the heat of the sun be concentrated?
How is common *culinary* heat affected by transparent solid lenses?

---

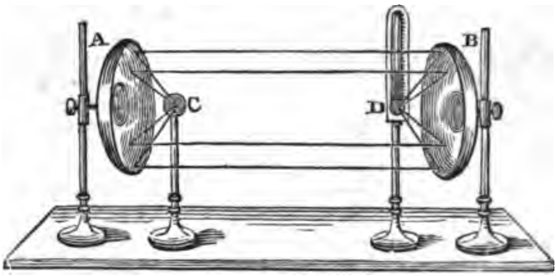
* Sigaud de la Fond Elem. de Physique, vol. iv. pp. 172, 173.

† Dr. Young, in Lect. on Nat. Philos., vol. ii. p. 407, from Cavallo.

‡ V. Histoire de l'Academie Roy. des Sciences, An. 1726, p. 165. Nollet Leçons de Physique, t. v. p. 218.

§ V. Hist. de l'Academie Roy. des Scien., An. 1747, p. 82; and 1748, p. 305.

of a lens. In a paper published in the Memoirs of the Academy of Sciences of Paris, in 1682, by M. Mariotte, he stated that radiant heat from a common fire, concentrated by a concave mirror, has its effect destroyed by the interposition of a plate of glass; and the Swedish philosopher, Scheele, from numerous experiments, inferred that glass intercepts entirely the radiant heat of a fire; and that a glass mirror reflects the light, but prevents the passage of the heat, while a metallic mirror reflects both heat and light. It has however been since discovered, that though the heat of burning bodies commonly exhibits different effects, in passing through glass, from those which are perceived in the passage of solar heat, they may probably depend on the far inferior intensity of the heat arising from combustion compared with that of the sun. For when a very intense artificial heat with light is produced, as that of charcoal ignited by a voltaic battery, if a small lens be placed before the brilliant star of fire thus obtained, and its focus be cast on the ball of a delicate air thermometer, some elevation of temperature may be perceived.



152. That heat radiates from bodies in right lines, and that it may be reflected to a focal point by a mirror, like light, may be demonstrated by the apparatus represented above. It consists of two concave mirrors, A and B, of planished tin or plated copper, about one foot in diameter, and placed exactly opposite each other, at the distance of about ten feet. In the focus of one mirror, at C, must be placed a heated body, as a ball of iron; and in the focus of the other mirror, at D, a differential thermometer. The rays of heat, then, impinging on the mirror A, are reflected through the air to the mirror B, whence they converge to its focus at D, and produce an effect on the thermometer proportioned to the degree of heat of the iron ball or other heated body.

What result was alleged to have been obtained in regard to this subject by M. Mariotte and by Scheele?

What is now found to be the fact in regard to the passage of the heat, produced by combustion, through glass?

What explanation is to be given of the difference between that and solar heat? Describe the apparatus called *Pictet's conjunctive mirrors*.

How does it appear that the effect on the thermometer is not the consequence of *direct radiation*?

153. That this effect is not produced by the mere dispersion of the heat through the air may be evinced by holding a pasteboard screen between the mirror B and the thermometer, when the latter, though as near the source of heat as before, would be hardly, or not at all, affected by it. And if the ball be moved out of the focus of the mirror A, towards the thermometer, though thus brought nearer to it, the effect will be greatly diminished.

154. The flame of a candle, or a flask of boiling water, being substituted for the heated ball, the same effect will be produced. If a body yielding a stronger heat, as burning charcoal, or a red hot ball of iron, be placed in the focus of one mirror, and a piece of phosphorus in that of the other, the phosphorus will be instantly inflamed; and in the same manner may be effected the detonation of fulminating silver, or the deflagration of gunpowder. For the exhibition of the latter experiments may be adopted by Sir H. Davy's arrangement of the mirrors, vertically opposite to each other.

155. An extraordinary and somewhat problematical phenomenon which may be exhibited by such mirrors, is the apparent radiation of cold. For if a ball of ice or snow be substituted for the heated iron in the focus of the mirror A, the thermometer will show a reduction of temperature. It has been hence inferred by some, that cold is a peculiar kind of subtile fluid, capable of being propagated by radiation; but the effect has been more generally attributed to the abstraction of heat from the thermometer by the frozen mass opposite to it.

156. Those bodies which reflect heat most powerfully, like the polished mirrors above described, do not acquire heat from the rays impinging on their surfaces; so that such a mirror might be held a long time opposite to a fire without becoming perceptibly warmer. But if the surface of the metal be made rough by scratching it with sand-paper, or covered with paste mixed with chalk or lamp-black, it will rapidly absorb the rays of heat, instead of reflecting them. Hence it appears that the effect of radiant heat greatly depends on the state of the surfaces of bodies.

157. "Leslie discovered, by experiments made in 1802, that the heat emitted by radiation was affected by the nature of the surface exposed. The action of a blackened surface of tin being 100, that of a steel plate was 15, of clean tin 12, of tin scraped bright 16, when scraped with the edge of a fine file in one direction 26, when scraped again across about 13, a surface of clean lead 19, covered with a gray crust 45, a thin coat of isinglass 80, resin 96, writing-paper 98, ice 85. Heat as well as light is so projected from a surface, as to be equally dense in all directions, conse-

What cases of incipient combustion may be produced by reflected heat?
How is the apparent radiation of cold exhibited? and how explained?
What relation appears to subsist between the *reflecting* and the absorbing power of bodies?
What is the effect of roughening or colouring the surface of a reflector?
What discovery did Leslie make in regard to the radiating power of different surfaces?

quently from each point, in a quantity which is as the sine of the angle of inclination. The radiation is not affected by the quality of the gas in contact with the surface, but it is not transmitted by water."*

158. As polished metals absorb heat very slowly, so heat is but slowly emitted from the surfaces of such metals; and thus boiling water would continue at a high temperature much longer in a silver tea-pot than in one of black earthenware; so that vessels of polished metal are best adapted for preparing tea or other vegetable infusions.

159. Substances of a light and very brilliant colour reflect heat readily, but do not absorb it; while black or very dark coloured bodies absorb the heat that falls on them, reflecting little or none of it. If pieces of white cloth and other pieces of black cloth be laid, in similar circumstances, on the surface of snow, it would soon become melted beneath the black cloth, but remain perfectly solid under the white. In some of the mountainous parts of Europe, the farmers are accustomed to spread black earth or soot over the snow, in the spring, to hasten its dissolution, and enable them to anticipate the period of tillage.

160. It may be generally assumed that all bodies of unequal temperature tend to become of equal temperature; if in contact, by conduction; if at sensible distances, by radiation of the excess of heat; and in the latter case whether the radiation reach the cooler body directly, or by an intervening reflection.†

What class of surfaces emit or *radiate* heat most readily?

What influence has *colour* on the absorbing and reflecting powers of bodies respectively?

What advantage is taken in Europe of Franklin's discovery respecting the melting of snow beneath black surfaces?

In what two modes do all bodies of unequal temperatures tend to an equality in this respect?

---

* Dr. Young's Lectures on Natural Philosophy, vol. ii. p. 407.

† See Report on the present State of our Knowledge of the Science of Radiant Heat, presented to the British Association, by Professor Powell, in 1832.

Works of reference on the subject of Pyronomics.

The following, among other works on the science of heat, may be consulted in further prosecuting the study of this department.

Thompson's Treatise on Heat and Electricity.
Library of Useful Knowledge, treatise on Heat.
" " " " on the Construction of Thermometers and Pyrometers. Two numbers.
Webster's edition of Brande's Manual. Boston.
Turner's Chemistry, by Dr. Bache. Phila. edition.
Ure's Dictionary of Chemistry. Article *Caloric*.
Leslie on Heat and Moisture.
Crawford on Animal Heat.
Dalton's New System of Chemical Philosophy.
Leslie's Experimental Inquiry into the Nature of Heat.
Walker on Cold.
Many articles in Silliman's Journal, the Journal of the Franklin Institute, Annales de Chimie, and other contemporary periodicals.

OPTICS.

1. Among the grand sources of our knowledge of the works of nature is the faculty or sense of sight or vision, to which we owe the perception of light and colours, and the means of judging concerning the forms and appearances of the numerous bodies around us. The highly curious, interesting, and important phenomena with which we thus become acquainted constitute the subjects of the science of Optics,* or the theory of light and vision.

2. This department of natural philosophy may be considered as furnishing topics for investigation under different points of view: 1. As relating to the general properties of light, and its effect on the organ of vision; 2. With reference to the reflection of light from the surfaces of bodies; 3. With reference to the refraction of light, or the alteration it undergoes in passing through transparent bodies; 4. As regards the phenomena of colours; 5. As respects certain modifications of reflected and refracted light, which have been characterized as resulting from the polarization of light.

3. Among the multitudes of bodies which we can perceive, some are visible by their own light, and these are styled luminous bodies; while others have no such illuminating property, and can be seen only by means of the light afforded by the former. Luminous bodies consist of those which are original and permanent sources of light, as the sun, fixed stars, and probably comets; and those which exhibit light only under certain circumstances, especially while undergoing combustion, as in the case of minute fragments of steel struck off by the collision of flint with steel, or in the common process of burning a candle, oil in a lamp, or coal-gas.

4. Any bodies which do not interrupt the passage of light, or which admit of other bodies being seen through them, are called transparent bodies;† those which prevent entirely the passage of light are termed opaque bodies; and those which allow other bodies to be seen through them obscurely and imperfectly are named semi-transparent substances. Transparency and opacity, however, depend much on the relative thickness or thinness of substances; for even air, which affords less interruption to the passage of light

What classes of phenomena are embraced in the science of optics?
Under how many and what different views may this science be regarded?
On what is the distinction of *luminous* and *non-luminous* bodies founded?
How are the terms *transparent*, *semi-transparent*, and *opaque* respectively applied?
Are transparency and opacity to be regarded as absolute or relative properties of matter?

---

* From the Greek Οπτομαι, to see.

† The words *transparent* and *diaphanous* are synonymous; the former being derived from the Latin, *trans*, through or beyond, and *parens*, apparent; and the latter from the Greek, Διαφανης, shining through, or translucent.

than any other kind of matter, is not perfectly diaphanous; nor will the densest metal completely prevent the influence of light.

5. It has been calculated that the atmosphere, when the rays of the sun pass perpendicularly through it, interrupts from one 1-5 to ¼ of their light; but when the sun is near the horizon, and the mass of air through which the solar rays pass is consequently vastly increased in thickness, only 1-212 part of their light can reach the surface of the earth. "By a peculiar application of my photometer," says Sir John Leslie, "I have found that half of the incident light, which might pass through a field of air of the ordinary density, and 15½ miles extent, would penetrate only to the depth of 15 feet in the clearest sea-water, which is therefore about 5400 times less diaphanous than the ordinary atmospheric medium. But water of shallow lakes, although not apparently turbid, betrays a greater opacity, insomuch that the perpendicular light is reduced one-half in descending only through the space of six, or even two feet.

6. The same measure of absorption would take place in the passage of light through the thickness of two or three inches of the finest glass, which is consequently 500,000 times more opaque than an equal bulk of air, or three hundred times more opaque than an equal *weight* or *mass* of this fluid. But even gold is diaphanous. If a leaf of that metal, either pure or with only 1-80 part of alloy, and therefore of a fine yellow lustre, but scarcely exceeding 1-300,000 of an inch in thickness, and inclosed between two thin plates of mica, be held immediately before the eye, and opposite to a window, it will transmit a soft green light, like the colour of the water of the sea, or of a clear lake of moderate depth. This glaucous tint is easily distinguished from the mere white light which passes through any visible holes or torn parts of the leaf. It is indeed the very colour which gold itself assumes, when poured liquid from the melting-pot.

7. A leaf of pale gold, or gold alloyed with about 1-80 part of silver, transmits an azure colour; from which we may, with great probability infer, that if silver could be reduced to a sufficient degree of thinness, it would discharge a purple light. These noble metals, therefore, act upon white light exactly like air or water, absorbing the red and orange rays which enter into its composition, but suffering the conjoined green and blue rays to effect their pas-

What portion of the sun's light, when vertical, is supposed to reach the earth?

How great a portion is *interrupted* when the sun is near the horizon?

What calculation has Leslie instituted between the transparency of air and that of water?

What is found to be the degree of opacity in shallow lakes compared with sea-water?

How much does the opacity of the best glass, weight for weight, exceed that of common air? What examples of transparency are found in bodies commonly reckoned opaque?

How is the colour of light found to vary when transmitted through bodies which are imperfectly transparent?

sage. If the yellow leaf were to transmit only 1-10 part of the whole incident light, we should only conclude, that pure gold is 250,000 times less diaphanous than pellucid glass.

8. The inferior ductility of the other metals will not allow that extreme lamination, which would be requisite, in ordinary cases, to show the transmission of light. But their diaphanous quality may be inferred, from the peculiar tints with which they affect the transmitted rays when they form the alloy of gold. Other substances which are commonly reckoned opaque, yet permit in various proportions the passage of light. The window of a small apartment being closed by a deal board, if a person within shut his eyes for a few minutes, to render them more sensible, he will, on opening them again, easily discern a faint glimmer through the window. If this board be planed thinner, more light will successively penetrate, till the furniture of the room becomes visible, and perhaps a large print may be distinctly read.

9. Writing-paper transmits about the third part of the whole incident light, and when oiled it often supplies the place of glass in the common work-shops. The addition of oil does not, however, materially augment the diaphanous quality of the paper, but renders its internal structure more regular, and more assimilated to that of a liquid. The rays of light travel without much obstruction across several folds of paper, and even escape copiously through paste-board."*

10. The chief sources of light, as already observed, are permanently luminous bodies, or celestial fire, especially the sun; and terrestrial fire, or that given out during combustion, or incandescence. There are, however, some cases in which light is exhibited under circumstances apparently unconnected with the influence of the solar rays, or of terrestrial fire. The exhibition of light accompanies many electrical phenomena; as lightning, the luminous traits produced by brushing with the hand a cat's back in the dark, and many others which will be more particularly noticed in the subsequent part of this volume.

11. Phosphorescence is another kind of luminous exhibition, where light is emitted without sensible heat, and the effect seems to be but remotely, if at all, dependent on either of the grand sources of luminosity which have been pointed out. Common

What relation may be computed to subsist between the transparency of gold and that of glass?

What would be the comparative transparency of gold and common air?

How may the partial transparency of wood be demonstrated?

What is the effect of oiling paper on its power of transmitting light?

What are the chief sources of light?

From what sources, independent of these, are the phenomena of light occasionally produced?

What is the distinction between phosphorescence and the luminousness of burning bodies?

---

* Leslie's Elements of Natural Philosophy, vol. i. pp. 20—22.

phosphorus* is a highly combustible body, burning fiercely at a certain temperature, with intense light and heat: it also gives out light at a very low temperature, without apparent heat, but this is the effect of slow combustion: it was, however, ascertained by Dr. Van Marum, a Dutch philosopher, that phosphorus covered with dry loose cotton, or sprinkled with resin, would shine under the exhausted receiver of an air-pump,† a situation in which it seems impossible that any combustion can take place, on account of the deficiency of atmospheric air. But there are phosphorescent bodies which yield light under circumstances which have no connexion whatever with the process of combustion.

12. Decayed wood, and sometimes peat or turf, have been observed to shine in the dark; and some kinds of fish, as soles, whiting, tench, and carp become luminous when tainted, but before they grow putrid; lobsters and crabs often display phosphorescence in similar circumstances; and also butchers' meat, occasionally.

13. There are many animals of the lower orders that emit light in greater or less abundance while living. Among insects, the glow-worm (*Lampyrus Splendidula*) is the most generally noted for its illuminating powers, in European countries, and the common firefly of the United States; there are, however, other insects in some degree possessing similar properties, as the common centipede, found under tiles or flowerpots in gardens, which when irritated gives out bright flashes of light. But the most remarkable shining insects are natives of the West Indies and South America; and of these the *Elater Noctilucus*, a coleopterous‡ insect, affords a splendid specimen. "It is an inch long, and about one-third of an inch broad, gives out its principal light from two eye-like tubercles placed upon the thorax; and the light emitted from them is so considerable that the smallest print may be read by moving one of these insects along the lines."§

14. The surface of the sea is observed by the mariners to be occasionally illuminated; and the light generally, if not always, is produced by certain marine phosphorescent animals. There are some peculiarities in these luminous appearances, which have been described as exhibiting five varieties; "the first shows itself in

How did Van Marum exhibit the phenomena of phosphorescence?

What examples of a purely phosphorescent appearance can be mentioned?

How does it appear that neither combustion nor putrescence is necessary to the production of phosphorescence in animal substances?

Among what tribes of animals are the phosphorescent classes chiefly found?

---

* From φως, light, and φερειν, to bear.

† See Arcana of Science, for 1832, p. 130; and Brewster's Edinburgh Journal of Science, N. S.

‡ So called from the character of the wings.

§ Introduction to Entomology. By Rev. W. Kirby and W. Spence. 8vo. vol. ii. p. 413.

scattered sparkles in the spray of the sea, and in the foam created by the way of the ship, when the water is slightly agitated by the winds or currents; the second is a flash of pale light, of momentary duration, but often intense enough to illuminate the water to an extent of several feet; the third, of rare occurrence, and peculiar to gulfs, bays, and shallows, in warm climates, is a diffused pale phosphorescence, resembling sometimes a sea of milk, or of some metal in a state of igneous liquefaction; the fourth presents itself to the astonished voyager under the appearance of thick bars of metal of about half a foot in length, ignited to whiteness, scattered over the surface of the ocean, some rising up and continuing luminous as long as they remain in view, while others decline and disappear; and the fifth variety is in distinct spots on the surface, of great beauty and brilliancy. The light of the first variety is more brilliant and condensed than that of any of the others, and very much resembles every way the red gold and silver rain of the pyrotechnist. This together with the third kind are produced by myriads of various minute crustaceous animals, the smaller *Medusæ* and *Mollusca*, and perhaps some *Annelides*; the second appears to proceed from the gelatinous *Medusæ*, of a larger size; the pyrosomæ are the cause of the fourth kind, which may be often witnessed by vessels bound to India, or the eastward of the Cape of Good Hope, occurring in the calm latitudes near the line.

15. "The *Sapphirina Indicator*, an insect somewhat resembling in appearance the woodlouse (*Oniscus*), and about one-third of an inch in length, emits the last variety enumerated, which appears to be limited to the seas situated to the north and west of a line drawn from the Cape of Good Hope to the southern extremity of the Island of Ceylon."*

16. Some flowers have been remarked to emit flashes of light while growing on the plants to which they belong. These miniature lightnings sometimes are perceived of a summer evening, in warm close weather, issuing from the petals of the African and the common marygold, the nasturtium, and the tuberose.

17. Many mineral bodies give out light under particular circumstances. This is the case with some diamonds, and varieties of rock crystal, which become luminous on being removed into a dark room after exposure to the rays of the sun. What is called the Bolognian phosphorus, is artificially prepared by mixing into a paste, with gum tragacanth, powdered sulphate of barytes, or

How many and what varieties of luminousness are exhibited at sea?
What causes the first variety?
How is the fourth kind to be explained?
In what part of the ocean is the pyrosoma found?
Where the sapphirina indicator?
What plants are known to emit luminous flashes?
Under what circumstances may certain minerals appear to emit light?
What artificial imitations of these substances have been prepared?

* Thompson's Zoological Researches and Illustrations. 1832. 8vo.

ponderous spar, and dividing the mass into thin cakes, which are to be carefully calcined in an open fire and suffered to cool slowly: they then shine in the dark after being exposed to the sun.

18. Canton's phosphorus, which consists of sulphuret of lime; and Baldwin's phosphorus, which is nitrate of lime, have analogous properties; and oyster-shells, calcined by putting them into a coal or charcoal fire, for about an hour, and when cold taking off a thin scale from the inside, will be found to be become phosphorescent. There are minerals which are rendered luminous in the dark by exposure to a temperature of red heat, as phosphate of lime, from Estramadure, and some kinds of flour or Derbyshire spar, fetid carbonate of lime or swinestone, quartz, and ponderous spar.

19. Light may be elicited from violent friction or collision of incombustible bodies, just as fire is from flint and steel. Thus bright sparks may be produced by striking one piece of common flint or rock crystal against another; rubbing together two pieces of bonnet-cane will cause the emission of light, in consequence of the *epidermis* or scaly coating of the cane being composed of siliceous earth; and loaf sugar yields a pale light, from the collision of two lumps in the dark, the effect being merely the exhibition of phosphorescence, for though sugar is an inflammable substance, the luminous appearance is unaccompanied by combustion.

20. Light, considered as the cause of vision, or the medium by which objects become perceptible to sight, exhibiting a variety of tints to the eye, has generally, since the publication of Sir Isaac Newton's theory of light and colours, been ascribed to the emission of a peculiar ethereal fluid from the sun and all other luminous bodies. This subtile fluid or ether was supposed to be perpetually streaming in all directions from the sun and fixed stars, travelling with a velocity 900,000 times that of sound through the air, and yet consisting of particles so extremely minute as to pass through the densest substances without at all altering their structure, or interfering during their progress in the slightest degree with each other. Descartes, who died in 1650, had advanced a different hypothesis to account for the action of light, founded on the admission of the existence of an ethereal fluid, not subject to a motion of translation, or passage from one part of space to another, but capable of being thrown into the state of undulation by the impulse of luminous bodies, and the undulating motion being indefinitely extended, would obviously propagate the influence of light through any given space.

21. The theory of undulation, as it is termed, was adopted and improved by Huygens, the contemporary of Newton, whose sys-

By what mechanical means may combustible bodies be made to emi light?

Is any real combustion produced in these cases?

What theories did Newton advance to account for the phenomena of light and vision?

At what rate did he find it necessary to suppose light to travel?

tem of emanation or emission of light, proposed by the latter, principally through the authority of his great name, prevailed almost universally till about the middle of the last century, when it was attacked by Leonard Euler, who, in his "Letters on different subjects of Natural Philosophy, addressed to a German Princess," has pointed out the difficulties which occur in attempting to explain the phenomena of light according to Newton's doctrine or theory of emanation, and has advanced many striking arguments in favour of the theory of undulation, showing the analogies between the modes of propagation of light and sound, and demonstrating the general agreement of the hypothesis with those facts which constitute the basis of optical science. Euler, however, gained but few converts among his scientific contemporaries, and the opposite theory was generally admitted as correct till about the beginning of the present century, when Dr. Thomas Young, in the Bakerian Lecture, read before the Royal Society, in 1801, entered into an elaborate disquisition concerning the theory of light and colours; and deduced from the principles laid down by Newton himself, the three following hypotheses:

22. 1. That a luminiferous ether, rare and elastic in a high degree, pervades the whole universe. 2. That undulations are excited in this ether whenever a body becomes luminous. 3. That the sensation of different colours depends on the frequency of vibrations excited by light in the retina. To these he added a fourth hypothesis, assuming that all material bodies have an attraction for the ethereal medium, by means of which it is accumulated within their substance, and for a small distance around them, in a state of greater density but not of greater elasticity.*

23. Subsequent discoveries have tended to confirm the theory of undulation, which affords a more unobjectionable mode of explaining the phenomena of polarized light, and other appearances, than is furnished by the theory of emanation; and the former has been embraced by the most distinguished philosophers now living or recently deceased; as Fresnel, Arago, Sir John Herschel, Sir D. Brewster, and others, who by their own discoveries have contributed to extend the boundaries of science.

24. The propagation of light always takes place in right lines, projecting on every side from luminous bodies. Such radiating lines or rays, diverge from each other in their passage, forming what is called a pencil of light, as exhibited in the marginal figure.

What substitute for the theory of emission was adopted by Descartes, Huygens, and Euler?

What three positions were established by Dr. Young on this subject?

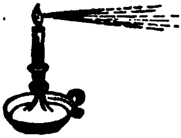
What relation did he assume to subsist between the luminiferous ether and common matter?

Which of the two theories appears at present to possess the greater number of advocates among the cultivators of this science?

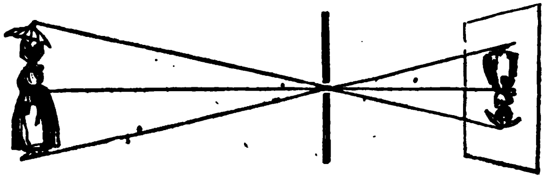
In what lines does the propagation of light take place?

* See Philos. Transact. for 1802; and Abstract of Papers in the Phil. Trans., vol. i. pp. 64, 65.

A similar effect may be produced by admitting into a darkened room, through a minute aperture in a window-shutter, the light of the sun which would be perceived proceeding in a diverging bundle or pencil of rays; and on presenting to it a flat board, a luminous image would be formed, increasing in diameter with the increase of distance from the aperture at which the plane was held, and which, by variously inclining the plane, might be made to assume elliptical or other curved figures.



25. Images of variously-shaped bodies seen by light thus admitted through a small opening are always in a reversed position, in consequence of the obliquity or divergence of the rays of light.



That this effect must take place will be readily perceived from the preceding figure, which shows that the rays in passing through the opening must cross each other, and thus rays coming from the superior parts of objects, impinge on the relatively inferior portion of the plane, and those from the higher parts strike on that portion of the plane below the other rays: the spectra or images produced must consequently be inverted.

26. It is stated above that the dimensions of the images thus formed decrease in proportion to the distance from the opening at which they are situated. Thus if the plane on which the image of an object is received, be placed at exactly the same distance before the aperture, as the object stands behind it, the size of the image will coincide with that of the object, for the pencils of rays on either side would be alike. If, however, the plane be removed nearer the aperture than before by one-half, the image will be but one-fourth of the size of the former; at one-third the distance, its size would be one-ninth; at one-fourth the distance, one-sixteenth; the diminution taking place in the ratio of the squares of the distances of the plane from the aperture. The intensity of light diminishes in the same proportion: thus suppose a candle to be

By what experiments can this be proved?

How is the rectilinear course of rays proved by the images formed in a dark room by light admitted through a simple aperture?

What ratio will the size of such an image have to the distance of the screen from the aperture?

How does the intensity of light vary with the distance of the *radiant* or source of light?

placed at the distance of one yard from the face of a dial or time-piece, the light thrown on it may be represented by the number 1; if then it be removed back to two yards, the light will be but ¼ as much as before; at 3 yards 1-9, at 4 yards 1-16, at 5 yards 1-25, at 25 yards 1-625.

27. This reduction of light, in proportion to the distance of the luminous body, is the necessary effect of the divergence and consequent dispersion of the radiant pencil; and hence it may readily be conceived, that an inconsiderable light can only be visible at a comparatively trifling distance, and that its influence in rendering non-luminous objects visible, must be limited to a much shorter distance than the extreme point at which its light will be perceptible.

28. The apparent size of all visible objects is to be explained on the same principles with those that govern the formation of images by light transmitted through an aperture, as just described. When we take a view of an illuminated body, its image becomes traced in shadow, exhibiting, however, its proper colours on the retina, a nervous membrane that lines the interior surface of the eye. A more particular description of the structure and apparent uses of the different parts of the organ of vision will be introduced after the nature and causes of the refraction of light have been explained; but the relation between visible images of objects and the angular distances of the objects themselves may here be concisely pointed out.

29. From what has been previously stated concerning the diminution of the light of a pencil of rays in proportion to the distances of the point whence they diverge, it must be evident that the nearer to the eye any object may be placed, so much more numerous will be the rays of light passing from it which can act upon the eye so as to form the image on the retina. The number of the rays indeed will increase or decrease as the squares of the distances of objects, after the manner already described. This, however, is to be understood as the law that regulates the propagation of light simply and independently of the medium it traverses; for air, the most transparent of bodies, interrupts in some degree the passage of light through it, as elsewhere observed; and therefore the apparent dimensions of objects must be considerably influenced by the nature of the medium through which they are beheld.*

30. The angle formed by the crossing of the rays of light passing from the opposite extremities of a visible object is called the

What causes this variation?
How is the apparent size of objects dependent on their distance?
How must the apparent brightness of an object be affected by its nearness to the eye?
What is meant by the *angle of vision?*

* See the subsequent part of this treatise, relating to the Refraction of Light.

angle of vision. Now that angle will be relatively very contracted when the radiating lines are emitted from an object extremely minute, or from one placed at a great distance. Thus there are insects too small to be visible to the naked eye even when brought as near to it as possible; and some objects of immense size, as the fixed stars, each of which probably is many thousand times larger than the earth, appear as mere points from the remote situations they occupy; while there are doubtless multitudes of other stars yet more remote, and therefore quite invisible, even when the heavens are surveyed through the best telescopes. Unless the angle of vision be more than one second of a degree, the object whence the rays proceed will not be visible, without it be very strongly illuminated.

31. The velocity of light is so great that it was long supposed to pass instantaneously through any given space; and though it has been ascertained that it occupies a certain time in its passage proportioned to the distances traversed, yet so rapid is its apparent motion, that in observing the effect of light at places a few miles distant from each other the time need not be taken into the account. The rate at which light is propagated was discovered by Olaus Roemer, in making observations on the eclipses of the satellites of Jupiter.

32. If the transmission of light were instantaneous, it must be obvious that the reflected light of the sun would take up no more time in passing from any one of the planetary bodies to the earth, when they are farthest from us, than it does when they are nearest; and as the situation of the earth with respect to the other planets is different in different parts of her orbit, the satellites of Jupiter, on emerging from the shadow of that planet, would be seen as quickly when the earth was in one part of her orbit as in another. But this is by no means the case; and the effect of the transmission of light is such, that when the earth is between Jupiter and the sun, the satellites, after being eclipsed, are perceived rather more than eight minutes sooner than they ought to appear according to the time as calculated by the most accurate tables; and when the earth is in the opposite part of her orbit, so that the sun is between this planet and Jupiter, the satellites emerge about eight minutes later than the calculated or mean time.

By what two circumstances may that angle be diminished till the object becomes imperceptible?

Give some illustrations of both cases.

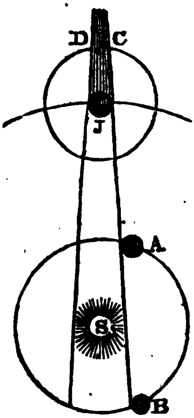
What is generally the least angle under which an object can be seen?

What was formerly thought of the motion of light?

Why do we make no account of the time occupied by light in traversing distances on the earth's surface?

How would the instantaneous transmission of light through space enable us to see the heavenly bodies in different parts of the earth's orbit?

What is found to be the fact in regard to Jupiter's satellites?



33. In the annexed diagram, let S represent the sun, A and B the earth in different parts of her orbit, J, Jupiter, D, his nearest satellite entering the shadow of that planet, and C, the same satellite, emerging from the shadow. Now the time of the commencement or termination of an eclipse of the satellite, as stated from calculation in tables, is the instant at which the satellite would appear to enter or emerge from the shadow, if it could be seen by an observer from the sun: and it is found from repeated observation, that the eclipse takes place about 8 minutes earlier than the calculated period, when the earth is in the nearest part of her orbit, as at A, and 8 minutes later when she is in the opposite part of her orbit, as at B. Hence it will be apparent that light takes up 8 minutes in passing through a space equal to half the diameter of the earth's orbit, or the distance between the earth and the sun, which is ninety-five millions of miles; so that it moves at the rate of $95{,}000{,}000 \div 8 \times 60 = 197{,}916$, nearly 200,000 miles in one second.

34. The aberration of the fixed stars also shows with what speed light is propagated; Dr. Bradley having ascertained that this phenomenon depends on the motion of the earth in her orbit, in connexion with the velocity of light. The effect thus produced on the apparent places of the fixed stars at different times, termed aberration, is familiarly explained by Professor Robison. He observes, that if hailstones were falling perpendicularly, they would pass freely through a tube held steadily in a vertical position; but if the tube were moved round in a circle while the hailstones were falling they would impinge against its side, unless the tube were inclined forward, at an angle of 45 deg., supposing the velocity with which the tube was moved was equal to that of the falling hail. "In the very same manner, if the earth be at rest, and we would view a star near the pole of the ecliptic, the telescope must be pointed directly at the star. But if the earth be in motion round the sun, the telescope must be pointed a little forward, that the light may come along the axis of the tube.

What is the *true time* of commencement or termination of the eclipse of one of those satellites?

Construct and explain the diagram, showing the velocity of light.

How long does it require to traverse a semi-diameter of the earth's orbit? How far will it travel in a second?

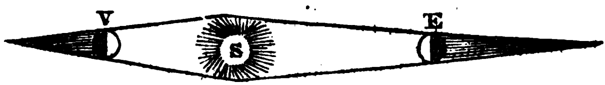
On what does the aberration of the fixed stars depend?

By what supposed arrangement of apparatus may the aberration of light be illustrated?

What must the absolute direction of a telescope be in regard to the position of the body viewed?

35. "The proportion of the velocity of light to the supposed velocity of the earth in her orbit is nearly that of 10,000 to 1: therefore the telescope must lean about 20 sec. forward. Half a year after this, let the same star be viewed again. The telescope must again be pointed 20 sec. ahead of the true position of the star: but this is in the opposite direction to the former deviation of the telescope; because the earth, being now in the opposite part of her orbit, is moving the other way. Therefore the position of the star must appear to have changed 40 sec. in the six months. It is easy to show that the consequence of this is, that every star must appear to have 40 sec. more longitude when it is on our meridian at midnight than when it is on the meridian at mid-day. The effect of this composition of motions, which is most susceptible of accurate examination, is the following. Let the declination of some star near the pole of the ecliptic be observed at the time of the equinoxes. It will be found to have 40 sec. more declination in the autumnal than in the vernal equinox, if the observer be in the latitude of 66 deg. 30 min.; and not much less if he be in the latitude of London. Also every star in the heavens should appear to describe a little ellipse, whose longer axis is 40 sec."*

36. As the total absence or privation of light produces darkness, so the partial defect of light occasions shade; and when any opaque body interrupts the passage of the rays of light, the figure of that body or its outline surrounding a dark area will be formed on any plane surface beyond the opaque body, constituting its shadow. The depth or darkness of the shadow is always in direct proportion to the intensity of the light; and if an opaque body be illuminated by several lights at once, differently situated, as many shadows will be formed as there are lights present; as may be observed with respect to any object in a room where two or more candles are burning. If the luminous body be larger than the opaque body that intercepts its rays, the shadow will be in the figure of a pyramid the base of which will be equal to the surface of the opaque body, and its extent will depend on the distance at which the luminous body is situated from that which intercepts its light.



What is the proportion between the velocity of light and that of the earth's progressive motion?

How much must a telescope be inclined forward of its real object in order to see a remote luminary?

Why will it appear to be again in advance of its true position at the end of half a year?

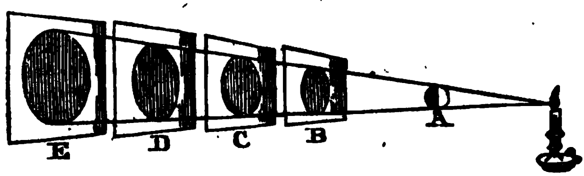
On what is the intensity of shadows dependent?

What will be the form of shadows when the *radiant* is larger than the intercepting surface?

* Elements of Mechanical Philosophy, 1804, vol. i. pp. 264, 265.

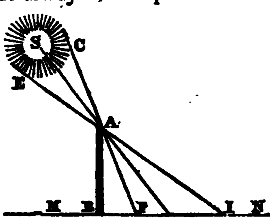
37. Thus, in the preceding diagram, suppose S to represent the sun, V the planet Venus, and E the earth; then if the two planets were of equal size, Venus being nearer than the earth to the sun would cast a shorter conical shadow than our planet.

38. If a shadow be formed by an opaque body of exactly the same dimensions with the luminous body whose rays it interrupts, the shadow will be a cylinder of an area equal to that of the two bodies, and extending infinitely in length. But if the luminous body be smaller than the opaque body the shadow will be a truncated pyramid, the larger base of which must be at an infinite distance. In the former case the rays of light will proceed in parallel lines till they are intercepted, and the consequent shadow will preserve the same dimensions throughout its indefinite extent; and in the latter case the rays will be divergent, and the shadow formed will increase in dimensions in proportion to the distance between the two bodies.



39. This will further appear from considering the relative dimensions of the same figure when the shadow is thrown on a plane surface at different distances from the source of light. Thus let A be an object illuminated by the light of a candle, and B, C, D, E, be a succession of screens, B being the nearest, and E the most distant; the former, therefor, will have the smallest shadow, and the latter the largest.

40. The proper shadow or dark outline of an opaque body, formed when it intercepts the rays of light from a luminous body, is always encompassed or bordered by a kind of demi-shadow, or as it is termed, penumbra.* Thus, in the annexed diagram, let S represent the sun, or any other source of light, and A B any opaque body, the true or proper shadow of which, on the plane M N, will be terminated by the tangential line C A F, and the space B A F will be entirely shaded; but the penumbra will extend from F to I, including the space

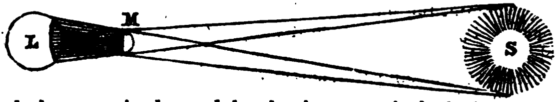


How is this illustrated in the solar system?
Exhibit and explain the diagram on this subject.
What form will the darkened space possess when the opaque body and the *radiant* are of the same size?

* From the Latin *pene*, almost, and *umbra*, a shadow

F A I, which will be partially enlightened, the shade gradually diminishing as it recedes from F towards I, where it will be terminated by the second tangent E A I.

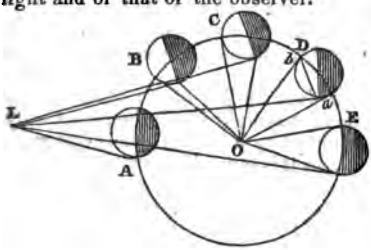
41. An eclipse of the sun being occasioned by the interposition of the opaque body of the moon between the earth and the sun, the proper shadow will be a frustum of a cone converging from the moon towards the earth, and there will be a fainter shadow or penumbra surrounding the former. This is shown in the annexed figure, where S represents the sun, M, the moon, and L, the earth;



the dark space is denoted by the inner conical shadow, beyond which, on either side, extends the penumbra.

42. Shadows are in general regarded as being perfectly black, as they certainly must be where the light of a luminous body is completely excluded by an opaque body placed before it. But shadows, as they commonly appear, are found to vary in colour as well as intensity, according to circumstances. Thus, the shadows produced by the sun at different hours of the day, and those caused by different sorts of lights, if attentively examined, will be perceived to consist of green, blue, violet, or red tints more or less sullied by black.

43. The figure of the enlightened part of an opaque body, seen by means of a fixed light, depends on the relative position of the light and of that of the observer.



Let L, in the marginal figure, be the place of the luminous point, O the situation of the observer: then, an opaque sphere placed at A would not appear at all enlightened; at B, the enlightened portion of the sphere would assume the form of a crescent; at C it would be a semi-circle; at D it would approach to a circle; and at E the circle would be complete. The phenomena would be repeated, but in

What will be its form, if the opaque body be larger than the luminous one?

What is meant by a penumbra?

Explain it by diagram.

What is the form of the *umbra*, or proper shadow in eclipses of the moon?

What is that of the penumbra?

What variety appears in the colours of shadows?

How are the successive appearances of the moon to be explained?

Draw and describe the diagram for its *phases*.

inverse order, in proceeding through the opposite positions, from E to A. The extent of the enlightened part visible from the point O, is determined by the tangents drawn from the small sphere to the points L and O: thus *a b* marks the enlightened part which is visible of the sphere D.

44. This diagram and description will serve to explain the phases of the moon, or her various appearances, as enlightened by the sun, and viewed from the earth in different parts of her orbit. That satellite being invisible at the change, or new moon, as at A, and afterwards exhibiting more and more of her surface till it becomes a complete circular disk, or full moon, as at E; after which the waning moon travels on to A, whence a fresh succession of changes takes place.

CATOPTRICS.

45. Besides the general effect of light in rendering visible all objects within the influence of the rays extending from luminous bodies to those around them, there are peculiar phenomena which take place when the rays are thrown on substances presenting very bright or smoothly polished surfaces. For in such cases, if the surfaces are very highly polished, they are no longer visible when thus illuminated, but exhibit perfect pictures of any objects placed in front of them, that is between the light and the polished surface. The effect just described is one with which all adult persons in civilized countries are so familiarly acquainted, in consequence of the general use of mirrors or looking-glasses, that they cease to excite wonder or observation; but brute animals, ignorant savages, and doubtless very young children, when they behold for the first time an image in a mirror, must suppose it to be a real object.

46. The effect of such an exhibition on a game-cock has been often noticed, and that brutes and children may be thus deceived may easily be admitted; but it might be apprehended that a savage could hardly be ignorant of the effect of light on the smooth surface of clear water, and that he would therefore view without surprise his own image in a looking-glass. This, however, is not always the case; and a modern traveller relates an amusing story of a savage, who, on being shown his face in a pocket glass, became excessively alarmed, and could by no means be induced to

At what point does the moon become invisible from immersion in the sun's rays?

How may an opaque surface be rendered invisible?

What familiar illustration of the case is afforded by the use of mirrors?

What evidence have we that only the image formed by the mirror is really visible?

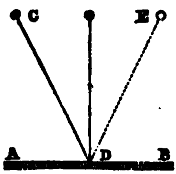
What confirmation do travellers afford of the correctness of this supposition in regard to mirrors?

approach again either the glass or its owner, conceiving that the individual who could *take his likeness*, by means of his mysterious machine, might perhaps appropriate his proper person, and keep him and sell him for a slave.

47. The common term reflection has been adopted to denote the direct effect of light in producing images of bodies in their proper places, and also the indirect effect of light in forming, by means of polished surfaces, images of bodies in some place or places different from that where they appear by direct light. The latter kind of reflection alone, or that caused by variously-formed mirrors, or more or less perfectly polished surfaces, constitutes the subject of that branch of science called Catoptrics.* Reflecting surfaces may form images, the apparent situation of which will be more distant from the observer than the surface or mirror itself, as happens in the case of common looking-glasses, or convex mirrors; or the images may be formed between the eye of the observer and the reflecting surface, and may therefore appear in the air, as will be perceived in some cases where concave mirrors are used. Other singular effects may be exhibited by means of cylindrical or conical mirrors, or by various arrangements of mirrors, and by combinations of them with other optical glasses.

Reflection from Plane Surfaces.

48. Rays of light are reflected according to the same laws that regulate the motions of perfectly elastic solids; for a ray impinging on a reflecting surface will be returned or reflected in such a manner that the angle of incidence shall be exactly equal to the angle of reflection.† Hence if a ray of light falls horizontally on a plane mirror held vertically, it will be reflected in the same right line; but if it falls obliquely, it will be reflected with the same degree of obliquity; that is, the returning line and the line of incidence will form similar angles with a perpendicular drawn between them.

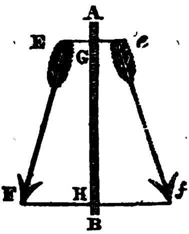


49. This may be shown by admitting through a small aperture, into a dark chamber, a ray of light, and receiving it on a metallic mirror A B; if it fall obliquely in the direction C D, it will be reflected in the line D E, and will form a lucid spot at E on a plane properly placed to meet it. Since all rays falling on a reflecting surface relatively preserve, after reflection, directions corre-

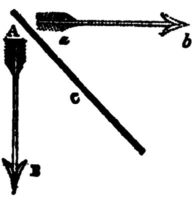
To what two sets of phenomena is the term reflection applied?
What is meant by catoptrics?
In how many positions, with reference to their distance from the eye, may images be formed by reflecting surfaces?
According to what laws are rays of light reflected?
How may this be experimentally demonstrated?

* From the Greek κατοπτρον, a mirror.
† See Treatise on *Mechanics*, No. 31.

sponding with those they had previously, therefore a ray falling on a mirror perpendicularly would be reflected on itself, and consequently could produce no lucid image.



50. The relative position of the image of an object as seen in a reflecting plane will be such that every part of the image will appear as far behind the plane as the object itself is before it. Let A B represent a plane mirror, and E F any object, as an arrow; then draw, from the points E and F, the perpendiculars E G and F H to the surface of the mirror, and produce those lines to *e* and *f*, so that E G shall be equal to *e* G, and F H to *f* H, and *e f* will be the position of the image which will be exactly equal to the object, as the quadrilateral figure G *e f* H will be equal to the quadrangle G E F H. From inspection of this figure it will be perceived, that the rays of light proceeding from that part of the object nearest to the surface of the mirror will be reflected so as to form the part of the image nearest to the plane of the mirror in the opposite direction. Hence when trees or buildings, or any other objects, are reflected from an horizontal plane, as the surface of a pond or a smooth stream of water, they will appear inverted; for their lower parts being nearest to the reflecting surface are seen immediately within it, while their tops seem to hang downwards, or to extend deeper beyond the surface.



51. When a mirror, C, in the annexed figure, is inclined forward at an angle of 45 deg. an object A B, if placed in a vertical position, will form an horizontal image *a b*; and if the position of the object be horizontal, that of the image will be vertical.

52. A person standing before a plane mirror placed vertically opposite to him, will not perceive the image of his whole person, if the length of the mirror be less than half his height. But if the upper part of the mirror be inclined forward, more of the image will become visible, in proportion to the dimensions of the mirror, than when it is placed vertically; and hence a person may view himself from head to foot in a looking-glass

Explain the diagram relating to the incident and reflected rays.

Into what line will a ray falling perpendicular to a reflecting surface be reflected?

Explain the relative position of parts of an image formed by a reflecting plane.

Why do trees, buildings, or other objects seen by reflection from a surface of water, appear inverted?

How may a vertical object be made to produce a horizontal image?

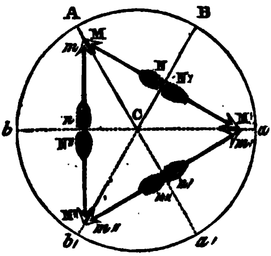
How long must a vertical plane mirror be, in order that the whole person may be seen by an eye immediately in front of it?

What expedient enables us to see the whole person in a small mirror?

of a moderate size, by giving it a due degree of inclination, but then the image as well as the mirror will appear in an oblique position.

53. Any one looking into a fixed mirror, and at the same time stepping backwards or advancing forwards, would perceive his image also to recede or approach, but with double the velocity of the actual motion. This will be understood by recurring to what has been stated relative to the angle under which the image is perceived.

54. A number of images may be formed and peculiar effects produced by means of two mirrors, either inclined or parallel, and opposite to each other, for the image of an object which is delineated behind one mirror may thus serve as an object to be reflected from the surface of another mirror.



55. If any object, as M, N, be placed between two plane mirrors inclined towards each other at an angle A C B, several images will be perceived, all situated in the circumference of a circle. This may be demonstrated by drawing the image in its place behind each mirror, and considering each image as forming an object in its turn, the image of which is also to be drawn. Thus it will be perceived that the image of M N in the mirror A C is *m n*, while its image in B C is M′ N′; and in the same manner the image formed by the reflection of the first image *m n* in *b* C will be M″ N″, while the image of M′ N′ in *a* C will be *m′ n′*. It will further appear that *m″ n″* is the image of both M″ N″ in the mirror *b′* C, and of *m′ n′* in the mirror *a′* C, one of the images covering the other, if the angle A C B be 60 degrees, or the sixth part of a circle, as in the diagram; but, if the angle be any greater or less, the image *m″ n″* will be two-fold; that is, the two images will not exactly coincide. On this principle is formed the Kaleidoscope,* invented by Sir D. Brewster, and by means of which the reflected images, viewed from a particular point, exhibit symmetrical figures under an infinite variety of arrangements of beautiful forms and colours.

56. If the two mirrors are placed opposite and parallel to each other, an indefinite multitude of images will be perceived, becoming more and more indistinct by repeated reflection, till at last they

How may the image be made to advance or retire?
How may the image of one reflection be made the object of another?
Explain this by the diagram.
What optical toy is constructed on the principle of multiplied reflection?
What appearance results from reflections between parallel mirrors?

* From the Greek καλος, beautiful, ειδος, a form, and σκοπεω, to view.

vanish in obscurity. This effect may be advantageously observed in an apartment where two mirrors are fixed on opposite sides of it, with a lustre, or some such object between them. One of the rooms at Fonthill Abbey, built by the eccentric Alderman Beckford, was wainscoted, as it were, with mirrors of plate-glass; and thus it presented to the spectator an interminable vista on every side, filled with a seemingly infinite multiplicity of objects.

57. Common mirrors are formed of glass, to the back of which is attached an amalgam or mixture of tin and quicksilver, which adhering to the surface of the glass forms a smooth polished plane, capable of reflecting the rays of light which impinge on it more abundantly than almost any other kind of mirror. The principal reflecting surface in this case is that where the metallic covering joins the back part of the glass; and the image there formed under ordinary circumstances is so bright and distinct as to prevent any other from being perceived. If however, a lighted candle be held before a glass mirror, so that its rays may fall on the glass obliquely, several images may be perceived; as a faint one at the outer surface, another much more intense just behind the former, and several others gradually receding, and becoming fainter and fainter, till they vanish in the distance. The first faint image is formed by reflection from the outer surface of the glass, the second, or principal image, at the surface of the amalgam, and the others by reflection within the glass. These interfering secondary images, though of no importance in a common mirror, would produce confusion in more delicate optical instruments, such as the reflecting telescope, the mirrors of which therefore are constructed entirely of polished metal, which, presenting only one reflecting surface, affords a single image.

58. Among the natural phenomena produced by the reflection of light, by far the most important is that of atmospheric reflection, for without it few objects would be visible excepting those on which the rays of the sun might fall in a direct line between that luminary and the eye. But the rays of light falling on the particles which compose the atmosphere are thence reflected in every direction, and thus daylight is produced even when the whole visible hemisphere is covered with clouds, and the face of the sun is hidden from our view. But for reflection, all opaque bodies would cast perfectly dark shadows; and on turning our backs to the sun the objects before us would be involved in the deepest obscurity.

59. Some of the less usual phenomena depending on atmospheric reflection are extremely curious, as that called the Mirage,

Where has this experiment been exhibited on a grand scale?

How are common mirrors constructed?

What part does the glass act in the formation of images?

How are the numerous images, visible in an oblique direction to the surface of the mirror, produced?

Why are not glass mirrors employed for reflecting telescopes?

What would be the effect of opaque bodies, if the atmosphere were destitute of reflecting power?

and a variety of aërial spectra of an analogous kind. The mirage is generally perceived on sandy plains in hot climates, as in Egypt and in South America; and it has been often described by travellers.

60. In the middle of the day, when the sun shines on the level surface of the sand, the appearance of a sheet of water is observed at the seeming distance of about a quarter of a mile; the deception being so complete, that any person unacquainted with its cause would inevitably suppose he was approaching a lake or river. Like real water, the spectral lake reflects objects around, so that houses, trees, and animals, are perceived with the utmost distinctness in this singular mirror. As the observer advances, the visionary stream recedes, still keeping at the same apparent distance, but with changes of scene, by the disappearance of images first beheld, and the formation of new ones from other objects, as they successively become liable to reflection.

61. The French philosopher Monge, who witnessed this phenomenon in Egypt, published a satisfactory explanation of it in the first volume of the *Decade Egyptienne;* and about the same time a similar exposition of the cause of it was given by Dr. Wollaston, in the London Philosophical Transactions. The latter also produced an artificial mirage in the heated air over a mass of red-hot iron; and he observed the same appearance in bodies seen across the surfaces of two differently refracting fluids placed one above the other in a transparent vessel.

62. He thus accounts for the phenomenon: in the middle of the day, the sandy soil becoming very hot, the stratum of the air in contact with it acquires a very elevated temperature, and hence, being dilated, its density is found inferior to that of the strata immediately above it, and the luminous rays which fall on this dilated stratum, at an angle comprised within a certain limit of 90 degrees, are reflected at its surface as from a mirror; and they convey to the eye of the observer the reversed image of the lower parts of the sky, which are then seen on the prolongation of the rays received, and consequently appear below the real horizon. In this case, if nothing corrects the error, the limits of the horizon will appear lower and nearer than they really are.

63. If any objects, as villages, trees, or the like, render it evident to the observer that the limits of the horizon are more remote, and that the sky is not so low as it seems, the reflected image of the sky will appear to form a reflecting plane of water. The villages and the trees will emit rays which will be reflected just as rays

How is the *mirage* formed?
Give some account of that appearance.
How may the effect be imitated?
What explanation did Wollaston give of that phenomenon?
How is the imagination led to the supposition that the reversed image of the lower part of the sky is nearer and lower than the true visible horizon?
How does it appear that trees, buildings, &c., ought to appear reversed in the inverted image of the sky?

would have been if coming from the part of the sky intercepted by them. And these rays will produce a reversed image below the objects seen by direct rays. The limit at which the luminous rays begin to be reflected being constant, and the rays that form the largest angle with the horizon appearing to come from the point nearest to the spot where the phenomenon commences, this point must be at a constant distance from the observer: hence if he advances, the border of the lake will seem to recede, as actually happens.

64. MM. Jurine and Soret, in September, 1818, observed, on the lake of Geneva, a phenomenon analogous to the mirage, but which, instead of being caused by horizontal reflection, was produced laterally by the heating of vertical strata of air on the sides of mountains, which border on the lake where the phenomenon occurred.

65. Those meteorological phenomena, called paraseline* and parhelion,† appear to be produced by reflection. When the moon rises after mid-day, and consequently at a time favourable to the appearance of the mirage, if the light of the sun and the clearness of the atmosphere allow the moon to be seen just as she gets above the horizon, two images of that satellite may be perceived. The parhelion is sometimes observed at sea, but it is a much more rare phenomenon than the preceding, depending, however, on a similar cause. Among the instances recorded of the appearance of these mock suns may be mentioned the occurrence of four solar images observed at Rome in March, 1629, one being much tinted with the colours of the rainbow, and the others faintly coloured. Parhelia were seen by Cassini, in 1689; and they have also been noticed in England, Scotland, and America.‡

66. On similar principles to those which serve to explain the mirage depend those appearances called looming, or the elevation of objects seen in the distant horizon above their usual level; such as the Fata Morgana, observed in the Straits of Messina; and the singular apparitions of ships and other objects in the air, sometimes in a direct position, but more frequently inverted.

67. The following figures are given from drawings of aërial spectra, observed at Dover, England, in May, 1833. When the real ship is visible, a double image may be formed, consisting of an inverted figure immediately over the ship itself, and another

How is the constant retreat of the imaginary lake or river to be explained.

May any other than horizontal strata of heated air produce the effect of mirage?

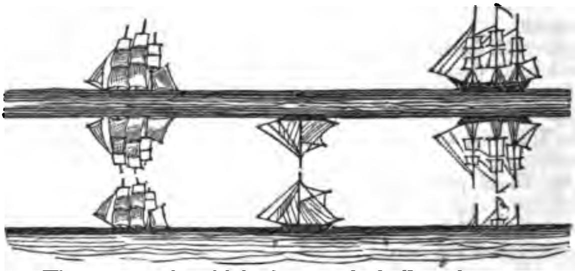
What other phenomenon witnessed at sea is to be explained on the principles of atmospheric reflection?

* From the Greek preposition Παρα, with, and Σεληνη, the moon.

† From Παρα, with, and Ηλιος, the sun: i. e., appearing together with, or accompanying the sun.

‡ For an account of the frequent appearance of parhelia, see *Parry's* account of his stay at Melville Island.—Ed.

figure in an erect position, above the preceding. If there is a single figure only, it will usually be inverted with respect to the real ship below it. Sometimes a double image, or an erect figure with one below it inverted, will appear when the vessel thus reflected is wholly invisible, or perhaps its topmasts be seen, while the remaining parts are hidden by the convexity of the earth's surface.



68. The manner in which these and similar phenomena may be caused by reflection may be comprehended by reference to the analogous effect of spherical mirrors, subsequently noticed. But it is probable that, where double images of objects appear, the effect depends chiefly on the refraction of light, owing to the varying density of the atmosphere; and the circumstances under which such a state of the air may be produced have been pointed out and illustrated by Dr. Wollaston.* The refraction being greatest where the change of density is the most rapid, and less on each side of this point, the whole effect must be similar to that of a convex lens.

69. In reference to the Fata Morgana, Dr. T. Young says, "It may frequently happen in a medium gradually varying, that a number of different rays of light may be inflected into angles equal to the angles of incidence, and in this respect the effect resembles reflection rather more than refraction."†

Reflection from Convex Surfaces.

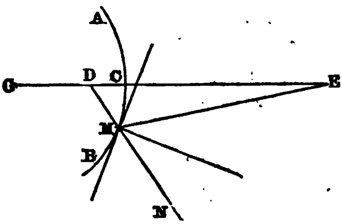
70. The effect of light reflected from a convex mirror is to produce a miniature picture of any objects placed opposite to it; the images thus formed appearing, to the eye of the observer in front,

How will the appearance of spectre ships be affected by the nearness or remoteness of the real ships which cause the spectra?
How is refraction affected by change of density in the air?
What circumstance of the air may cause varying rays of incident light to be reflected to a focus?
What appearance is explained on this supposition?
What is the effect of reflection from a convex mirror?

* See a paper "On Double Images caused by Atmospheric Refraction," in Philosophical Transactions for 1800.
† Lectures on Natural Philosophy, vol. ii. 302.

to be situated within or behind the mirror. Thus the globular bottles filled with coloured liquids in a chemist's shop-window present in pleasing variety the moving scenery of the street without; the upper hemisphere of each bottle exhibiting all the images inverted, while the lower displays a duplicate of them in an erect position. Hollow spheres of glass, covered on their interior superfices with an amalgam similar to that used for silvering looking-glasses, are sometimes suspended in apartments, where they present panoramic pictures of surrounding objects; and convex mirrors are common articles of ornamental furniture exhibiting analogous phenomena.

71. The images formed by reflection from a convex mirror must always be smaller than the objects by which they are produced, because the rays which form them become convergent in their passage to the eye of the observer. In the annexed figure let A B represent a convex mirror, the segment of a sphere, whose radius is the line G C; and therefore the point G will be the centre of the sphere, and the focus of the mirror.



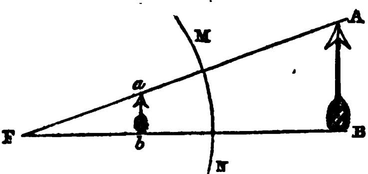
72. If an object be placed at E, at a great distance before the mirror, its image will appear behind the mirror at a point near D, which will become the virtual focus, and will be situated at half the length of the radius of the sphere, or at the middle point between the imaginary focus and the surface of the mirror; and the magnitude of the image will be to that of the object in the ratio of the line C D to C E; that is, it will be as much smaller than the object as the line C D is shorter than the line C E.

73. If, therefore, the object be brought nearer to the surface of the mirror, the image also will approach to meet it, and become proportionally enlarged; so that if a part of any object be brought into contact with the convex surface of the mirror, the image of that part will appear of precisely the same size as in the object itself: but unless the object be extremely small, or the mirror be a segment of a very large sphere, it must be obvious that only a small portion of an object can be made to touch the mirror, and hence the entire image must ever be to some extent inferior in size to the object by which it is produced. Not only will the rays

How may bottles of liquid and polished spheres produce double images?
What relation has the size of objects to that of their images in convex mirrors? Explain the diagram.
How far from the *centre of curvature* will an image formed by parallel rays of light falling on a spherical convex mirror appear to be situated?
What will be the effect of bringing the object nearer, so that rays may fall *divergent*?

falling directly on the mirror, as E C, be reflected so as to form an image at D, but so likewise will any incident ray whatever, as E M, which will be reflected in the direction M N, so that the angle B M N will be equal to the angle C M E;* and when the eye is at N, receiving the reflected ray M N, it will see the object E, according to that direction, and the image will appear in the mirror at D.

74. A convex mirror by reflection converts parallel rays into divergent rays, those that fall on it in diverging lines are rendered still more divergent when reflected, and convergent rays are reflected either parallel or less convergent. Suppose then an object of some assignable magnitude A B, as represented in the margin, to be placed before a convex mirror M N, the rays of light proceeding from each part of it will be reflected as if from a single point, and an image will be formed as before, in the line drawn from each extremity of the object to the imaginary focus of the mirror F; and in the same manner from other points, so as to form a complete image of the object. And this image must necessarily appear less than the object itself; for the rays which proceed from the extremity A will be reflected to the eye as if they proceeded from the point *a*, and those reflected from B as if from the point *b*, while the rays from the parts between A and B will be reflected from intermediate points; and therefore the image must appear smaller than the object, by which it is produced.



75. An object reflected from a convex mirror will not only form an image diminished in proportion but also defective in the outline; for the virtual focus of reflection will vary for different parts of the same figure; therefore unless the object be relatively very small, or the curvature of the mirror very considerable, the central portion alone of the object will yield a correct image. Such at least will be the effect unless the curvature of the mirror be accurately formed, and expressly adapted to the purpose. The human eyeball constitutes an admirable convex mirror, reflecting minia-

How may we conceive the incident rays on a convex mirror to be affected by an imaginary tangent plane at the point of incidence?

How will the rays reflected by a convex mirror be found in the three cases where they are respectively *parallel*, *divergent* and *convergent* before incidence?

Explain this by a diagram.

---

* Every ray falling obliquely on the surface of a convex mirror may be regarded as impinging on a point which forms part of a plane tangential to the curved surface of the mirror; and a line drawn perpendicular to such tangential plane will bisect the angle formed by the incident and the reflected ray, as is shown by the dotted lines in the preceding diagram.

ture images, the delicacy and beauty of which have repeatedly furnished topics of poetical allusion and metaphor. Here we perceive a striking instance of the vast superiority of the works of nature over those of art.

76. A convex reflecting surface of variable curvature may afford many ludicrous caricatures of the human figure, or of that of any other animal, especially if the object be brought very near the mirror. That part of the surface which is most protuberant will exhibit a comparatively diminished image, and the effect will be heightened by alternately advancing and withdrawing different parts of the person, and thus the disproportion between the head and the body or lower limbs may be rendered more remarkable. For if the head and trunk be thrown backward, while standing near the mirror, the image will display a diminutive head and body supported by preposterously swelled and gouty legs; and on the contrary, if standing more backward, the body be bent with the head stretched out towards the mirror, it will present a monstrous bloated figure with a dropsical head and body perched on spindle shanks.

77. Sir David Brewster has published, in the Philosophical Magazine, an account of a curious convex metallic mirror, recently brought from China to Calcutta, the general appearance and effect of which is thus described: "This mirror has a circular form, and is about 5 inches in diameter. It has a knob in the centre of the back, by which it can be held, and on the rest of the back are stamped, in relief, certain circles with a kind of Grecian border. Its polished face has that degree of convexity which gives an image of the face half its natural size; and its remarkable property is, that *when you reflect the rays of the sun from the polished surface, the image of the ornamental border and circles, stamped upon the back, is seen distinctly reflected upon the wall.*" Mr. Swinton, the gentleman who transmitted from the East Indies the preceding statement of this apparent reflection of figures through an opaque substance, proposed a conjectural explanation of the strange phenomenon, as depending on the difference of density in different parts of the metal, occasioned by the stamping of the figures on the back, the light being reflected more or less strongly from parts that have been more or less compressed.

78. But Sir D. Brewster, judging from the description, which alone had been transmitted to him, infers that "the spectrum in the luminous area is not an image of the figures on the back; but that the figures are a copy of the picture which the artist has drawn on the surface of the mirror, and so concealed by polishing, that it is invisible in ordinary lights, and can be brought out only in the sun's rays." He had observed radiated lines and concen-

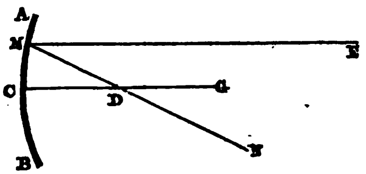
What defect has an image reflected by a convex mirror?
What natural convex mirror surpasses those produced by art?
What effect is obtained by convex surfaces of variable curvature?
How may the image of the person be caricatured by such an apparatus?
What description and explanation are given of the Chinese mirror with figured back?

tric circles to be similarly reflected by the light of the sun from polished steel buttons, which having been finished in a turning-lathe, the lines and rings had been formed on their surfaces by the action of the polishing powder or some similar cause, but too faintly to be visible except in the strongest light. Thus the figures on the back of the Chinese mirror were doubtless placed there merely to mislead the observer into a belief that he beheld them reflected through the metal, while he actually viewed the reflection of a duplicate of those figures lightly traced and concealed by the polish on the front surface.

Reflection from Concave Surfaces.

79. Concave mirrors exhibit a variety of phenomena depending on the situation of the object with respect to the mirror and to the observer, some of which are highly curious and interesting. "The concave mirror," says Sir David Brewster, "is the staple instrument of the magician's cabinet, and must always perform a principal part in all optical combinations."* Some of the most extraordinary optical effects in nature are also produced by reflection from concave surfaces, the properties of which therefore demand investigation.

80. The manner in which light is reflected from concave mirrors may be thus explained: let A C B, in the marginal figure, represent a mirror forming a part of a sphere whose centre is G, and G C, a radius; and suppose E to be an object far distant from the mirror, then its image will appear in front of the mirror at D, the central point of the radial line C G.



For any ray of light whatever, as E M, from the object E, falling on the surface of the mirror at the point M, will be reflected thence in such a manner as to pass through the point D; and when the eye is placed at N, the object will be seen at or near D; but this image will be to the object in the ratio of C D to M E, and consequently less than the object. If the object be made to approach nearer to the mirror, the image will recede from D towards G; and if it be placed there, the object and image will coincide; and the object still advancing from G, the

In what manner does Brewster suppose the effect to have been produced in that instrument?

How had Swinton previously explained it?

On what does the variety of appearances exhibited by the concave mirror depend?

Draw and explain a diagram by showing the manner in which light is reflected by a concave mirror.

* Letters on Natural Magic, p. 61.

image will retreat beyond it, till the object arrives at D, when the image will appear infinitely beyond E. But if the object be placed yet further forward, between D and C, the image will fall behind the mirror, and it will look larger than the object.

81. Thus it appears that when parallel rays fall on the surface of a concave mirror forming a portion of a sphere, they will be reflected and meet in a point at half the distance between the surface and the centre of concavity of the mirror. If the rays fall convergent on a concave mirror, they will be brought to a focus sooner than parallel rays; and the focus will be nearer to the surface of the mirror than to the centre of concavity. When the rays fall in divergent lines, the focus to which they will be re flected will be more distant than that formed by parallel rays.

82. There are three cases to be considered with regard to the effects of concave mirrors:

1. When the object is placed between the mirror and the principal focus.

2. When it is situated between its centre of concavity and that focus.

3. When it is more remote than the centre of concavity.

83. 1. In the first case, the rays of light diverging after reflection, but in a less degree than before such reflection took place, the image will be larger than the object, and appear at a greater or smaller distance from the surface of the mirror, and behind it. The image in this case will be erect.

84. 2. When the object is between the principal focus and the centre of the mirror, the apparent image will be behind the object, appearing very distant when the object is at or just beyond the focus, and advancing towards it as it recedes towards the centre of concavity, where, as already stated, the image and the object will coincide. During this retreat of the object, the image will still be erect, because the rays belonging to each visible point will not intersect before they reach the eye. But in this case, the image becomes less and less distinct, at the same time that the visual angle is increasing; so that at the centre, or rather a little before, the image becomes confused and imperfect; owing to the small parts of the object subtending angles too large for distinct

What results in this case from the gradual approach of the objects towards the surface of the mirror?

What relation exists between the focal distance of parallel rays from a concave mirror and that of its centre of concavity?

Will convergent rays meet nearer to or further from the concave mirror than parallel ones?

How will the comparative distances of the foci of parallel and divergent rays be found?

State the three cases of parallel and divergent rays.

What will be the relative size and distance of the object and the image in the first case?

Will the image be erect or inverted?

What will be the distance, positive and relative size of the image, in the second case?

vision, just as happens when objects are viewed too near with the naked eye.

85. 3. In the cases just considered, the images will appear erect; but in the case where the object is further from the mirror than its centre of concavity, the image will be inverted; and the more distant the object is from the centre, the less will be its image, and the further from the said centre, or the nearer the focus, and the converse; the image and object coinciding when the latter is stationed exactly at the centre, as noticed in the preceding case.

86. If an observer view his own image at a considerable distance beyond the centre of a concave mirror, the image will appear small, faint, and somewhat confused. This is owing to the smallness of the number of rays that can enter the eye; hence the apparent distance is augmented or rendered uncertain, so that the image is conceived to be beyond or within the mirror, and this misconception increases the confusion. As the observer advances towards the mirror, his image will gradually appear larger and brighter, and likewise draw nearer to him; but if he do not view it between himself and the mirror, it will continue still indistinct. At length he will arrive at the station whence the image assumes a determinate and correct figure, appearing perfectly distinct. After a few trials, the true place for viewing the image may be ascertained with tolerable accuracy; and it will continue distinctly perceptible when the observer moves a short distance backwards or forwards from the proper position: but advancing beyond it, the image will soon begin to appear indistinct, and this indistinctness will increase till he arrives so near the mirror as its centre of concavity, where the image will be lost in confusion. If he still advances, another image in an upright position gradually becomes visible, as explained in the preceding case.

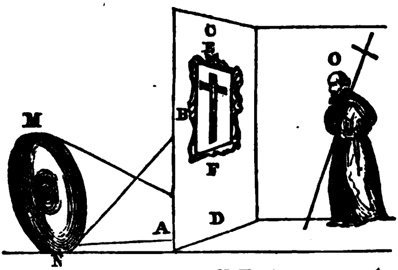
87. The most singular and curious effects of concave mirrors are those resulting from the position of objects at a greater distance from the mirror than its centre of concavity, as in the third case above described, when a diminished and inverted image will be formed in the air between the object and the mirror. In order that this may be seen to the utmost advantage, particular situations must be assigned both to the object and the observer, which will be regulated by the concavity of the mirror and its consequent focal distance. For the exhibition of such phenomena, however, spherical concave mirrors are not so well adapted as those of an elliptical figure, for the latter having double foci, any object placed in one focus of an elliptic concave mirror will form an accurate image in the other focus.

How will these three things be found related to each other in the third case?

Why is the image of a distant observer seen indistinctly in a concave mirror?

Which case of reflection by concave mirrors produces the most interesting phenomena?

What form of concavity ought the mirrors to possess for the exhibition of these phenomena?



88. The marginal figure exhibits a convenient mode of arrangement for producing optical images in the air by means of a single mirror. Suppose C D to be one side of a room, or a screen dividing one part of the room from another, and having in it a square aperture E F, the centre of which may be about five feet above the floor. This opening may be surrounded with a black border, or a gilt moulding, so as to resemble a picture-frame. A large concave (elliptical) mirror, M N, is then to be placed in an adjoining apartment, so that when any object is placed at A, in one focus of the mirror, a distinct image of it may be formed in the other focus at B, or in the centre of the aperture E F. This image will be inverted with respect to the position of the object; therefore if a small statue, bust, or plaster cast of any object be placed upside down at A, an observer in the apartment at O will behold an erect image of the object at B. In order to give the greater effect to this exhibition, the object should be white, or at least of a very bright colour, and should be strongly illuminated by a powerful lamp, the rays of which must be prevented from reaching the opening E F.

89. In this case, the image being formed, not in the single focus of a spherical concave mirror, but in one of the foci of an elliptical mirror, it will not be confused or reduced; but will be rather larger than the object. When the image appears in the air, as here described, it will be distinctly visible only from the point O, and a person placed at a little distance, on either side, will see nothing of it. If, however, the opening E F be filled with smoke, rising from burning frankincense or other perfumes, the cloudy vapour will serve as a screen to receive the reflected image, which may thus be rendered generally visible to persons within the room O.

90. Among the natural phenomena which appear to be caused by reflection from concave surfaces may be mentioned what is called in Germany the "Spectre of the Brocken," a gigantic figure sometimes seen at a distance upon the highest peak of the Harz Mountains, in the kingdom of Hanover. It has been ascertained, from careful observation, that the figure is a reflected spectrum of

Describe the arrangement of apparatus for exhibiting aërial images.
Will the images in this case be direct or inverted?
What will be the size and position of the image, with regard to those of the object?
How are reflections from concave surfaces applied to explain the spectre of the Brocken?

the observer, such as might be produced in certain situations by means of a concave mirror. A singular instance of atmospheric reflection, as observed in Sicily, from Mount Etna, has been noticed by a modern traveller. He says, "At the extremity of the vast shadow which Etna projects across the island, appeared a perfect and distinct image of the mountain itself, elevated above the horizon, and diminished, as if viewed in a concave mirror."*

91. Various forms may be given to mirrors besides those already described, and thus various modifications of the reflected images may be produced. Cylindrical, conical, pyramidical and prismatic mirrors are sometimes constructed, but they merely serve the purpose of creating amusement, by the singularity of the effects which may be exhibited by means of such instruments. A common method of displaying these optical phenomena consists in the rectification of distorted figures (drawn for the purpose,) by reflection from certain mirrors. These exhibitions are termed Anamorphoses;† and the rules for delineating deformed figures to suit the different kinds of mirrors, with directions for their proper arrangement, may be found in several works relating to optical instruments and phenomena.‡

DIOPTRICS.

92. Rays of light in passing to any distance through a medium of uniform density will proceed in right lines; but if a ray or pencil of rays be made to pass from one transparent medium to another, as from air into water or glass, its direction will be changed at the surface of the new medium, and it will afterwards proceed in a line varying more or less from that in which it passed through the air. Hence a ray is said to be refracted or bent, in consequence of its transit from one medium to another; the effect produced is termed refraction of light; and the laws by which the

To what use have cylindrical mirrors been chiefly applied?

By what name are the changes of figure produced by curved mirrors designated?

What difference exists between the course of a ray of light while traversing a *uniform*, and that which occurs while passing through a *variable* medium?

What is meant by refraction of light?

To what division of optics does this effect give rise?

---

* Travels in Sicily, Greece, and Albania. By the Rev. T. S. Hughes, 1830.

† From the Greek preposition Ανα, and Μορφωσις, an appearance: i. e, a reversed exhibition.

‡ V. Schotti Magia Universalis, p. i. lib. 3.; P. Dubreuil Perspective Pratique, t. iii. Trait. 5, 6, 7; Wiegleb's Natural Magic, (German); and Hutton's Recreations in Nat. Phil. vol. iii.

phenomena are regulated constitute the science, or branch of science, called Dioptrics.*

93. The effect just described may be easily subjected to observation, by laying a piece of money near the centre of the bottom of a china bowl, or basin, placed on a table or on the floor, and then retreating backward till the money is no longer visible, being hidden from the eye by the side of the bowl: if then water be poured into the vessel, the piece of money will become visible, just as if the bottom of the basin was raised above its real level. As this experiment may be readily repeated, and affords a convincing proof of the position above stated, it may be proper to observe that the money, or any other flat object which will equally well answer the purpose, should be fastened to the bottom of the basin with sealingwax, that it may not be moved from its place when the water is poured on it, and that the vessel must be filled to a certain height before the object can be seen.

94. The refraction of light may be exhibited more simply by plunging a straight cane or long ruler obliquely into a pond or a bucket of water, when it will appear bent at the surface of the water; that part of the cane held by the hand in the air appearing to be joined at an obtuse angle to the part under water.

95. There is, however, one case in which rays of light, in their passage from one medium to another of different density, will proceed without changing their direction; and that is when their direction is perpendicular to the connecting surfaces of the two mediums. Thus, if the eye be placed vertically above a piece of money in a basin, it will be seen in the same vertical line whether the basin be empty or filled with water; and for the same reason a straight stick held perpendicularly in water will not assume the bent figure which may be remarked when it is held obliquely.

96. If, from the point where a ray of light passes from one medium through the surface of another medium, we conceive a line to be drawn perpendicular to that surface, and prolonged indefinitely beyond it, the ray after refraction will either approach the perpendicular more than before refraction, or recede further from it than before. If the medium which the ray enters be more dense than that which it quits, it will approach the perpendicular; but if the second medium be rarer than the first, the contrary effect will take place, and the ray will recede from the perpendicular.

What simple experiment illustrates the effect of refraction?

What precaution is required to insure its success?

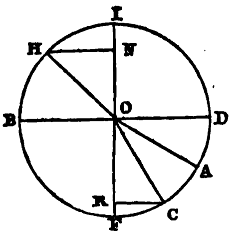
Why does a stick appear bent when plunged obliquely into the water?

Under what condition does change of density in the medium produce no change of direction?

What course will the incident and the refracted rays respectively take with reference to a perpendicular to the refracting surface?

Distinguish the case where the ray enters a rarer from that in which it enters a denser medium.

* From the Greek Διοπτομαι, to see through; or Διοπτρα, a mathematical instrument for measuring heights.



97. These effects may be illustrated by means of the marginal figure. Suppose O to be the point at which the luminous ray passes from one medium to another, and that the two are separated by the line B D, representing any surface either plane, concave, or convex; suppose the medium above B D to be more rare than that below it, and let H O represent the incident ray, and O C the refracted ray, and draw through the point O, I F perpendicular to the plane B D; then if the ray H O had preserved its direction after passing the plane, the angles H O I and F O C must have been equal; but the latter is more acute than the former, because the line of refraction O C approaches more to the perpendicular I F than the line of incidence H O. On the contrary, if the medium below B D had been rarer than that above it, the ray would have been less refracted than before, and would consequently have diverged further from the perpendicular I F than the ray H O does, and would therefore have formed an angle F O A more obtuse than H O I. From the point O as a centre describe the circle I D F B, cutting the directions of the incident and the refracted ray in the points H and C; from those points draw the lines H N and C R perpendicular to I F, which lines will be the sines of the angles H O I and F O C.

98. It has been ascertained from numerous observations that these lines are always in the same ratio, whatever be the angle of incidence at which the ray falls, provided the mediums through which it passes remain the same; for though there is no fixed relation between the angle of incidence and the angle of refraction, there is always a certain proportion between the sines of those angles. H N is called the sine of the angle of incidence, and C R the sine of the angle of refraction.

99. When a ray passes from air into glass, the sine of its angle of incidence will be to that of the angle of refraction, in the ratio of 3 to 2; if it passes from air into water, the ratio of the sines will be as 4 to 3; but these ratios will be inverted when light passes from glass or water into air; for in the former case the ratio of the sines will be as 2 to 3, and in the latter as 3 to 4. These ratios, as just noticed, are constant, whatever be the angle of incidence, for the respective mediums. But they differ considerably for different substances; and the refractive powers of a

Draw and explain the diagram relating to refraction.

To what trigonometrical lines are the refractive powers of bodies comparable?

What line on your diagram is the *sine* of the angle of incidence?

Which is the sine of the angle of refraction?

What relation will exist between these two sines when light passes from air into glass? from air into water?

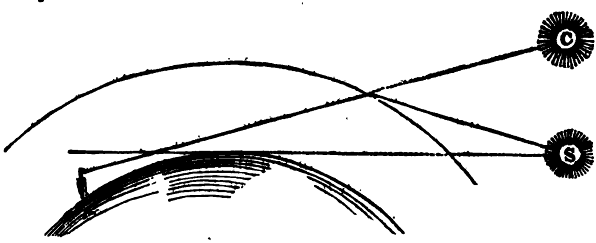
What will be their ratio when light passes from glass and from water respectively into air?

considerable number of bodies have been ascertained by experiment.*

100. No general principle has been discovered which connects the refractive power of bodies with their other physical properties; though it is usually highest in the densest transparent substances, and in such as are of an inflammable nature. Sir Isaac Newton having observed that several inflammable bodies possessed high refracting powers, and noticing a similar property in the diamond, ingeniously conjectured that gem to be an inflammable substance, long before its composition was known; and analysis has verified his idea, and shown it to consist of crystallized carbon.

101. As the effect of any transparent medium, in the refraction of light, generally increases with increase of density, so air and vapours when dense display greater power of refraction than when comparatively rare; and hence some curious and important phenomena depend on atmospheric refraction.

102. Light, on entering the atmosphere of the earth, encounters a medium less rare than the more ethereal space beyond it, and as the lower portion of the atmosphere is relatively the densest, rays passing through the air from objects far above us must be considerably refracted. From this cause the sun and other celestial bodies are never seen in their true situations, unless they happen to be vertical; and the nearer they are to the horizon, the greater will be the influence of refraction in altering the apparent places of any of those luminaries.



What relation have the refracting powers to the other physical properties of bodies?

What effect on refracting power has the increase of density?

What atmospheric phenomena depend on this refractive influence?

Explain by diagram the effect of refraction on the apparent place of the heavenly bodies.

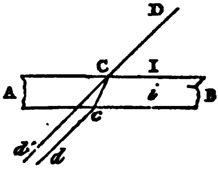
* The quotient found by dividing the sine of incidence by the sine of refraction is called, by optical writers, the *index of refraction*; and, as stated in the text, different bodies having different refractive powers will present different indices. The following are a few of the substances of which these indices have been experimentally determined:

Diamond	2.439	Amber	1.547	Water	1.336
Melted sulphur	2.148	Oil of Turpentine	1.475	Ice	1.309
Glass, 2 lead, 1 flint,	1.830	Olive Oil	1.470	Ether	1.057
Oil of Cassia	1.641	Alum	1.457	Air	1.000294
Quartz	1.548	Alcohol	1.372		[Ed.

103. Thus a spectator at A, in the annexed figure, would see the sun rise at C, when its real situation was at S; and so its apparent place would be relatively altered till it arrived at the zenith vertically above the point A; but it can be so situated only with respect to observers under the equator, or at least in the torrid zone. In consequence of this atmospheric refraction the sun sheds his light on us earlier in the morning and later in the evening than we should otherwise perceive it. And when the sun is actually below the horizon, those rays which would else be dissipated through space are refracted by the atmosphere towards the surface of the earth, causing twilight. The greater the density of the air, the higher is its refractive power, and consequently the longer the duration of twilight.

104. In cold climates, as near the poles, where the year is naturally divided into seasons of light and darkness, each lasting six months, the twilight of the circumpolar atmosphere diminishes the winter-night of those gloomy regions by a period equal to several days. Hence also terrestrial objects, viewed at a great distance, are affected by atmospheric refraction; and they therefore appear more elevated and nearer to the observer than they would if seen through a medium of uniform density.

105. Those optical phenomena depending on refraction, with which we are most familiarly acquainted, are such as are produced by the passage of rays of light from any medium, as air or water, into another more or less dense, and their entering again the former medium after they have traversed the more or less refracting medium. Thus objects seen through a common reading-glass or a pair of spectacles, if observed at certain distances, will be in some degree magnified; and glasses used by short-sighted persons have the effect of reducing the size of objects seen through them. And when any transparent substance is held between the eye and any object, the rays which render that object visible will be refracted in their passage from the air through the transparent substance, into the air again, before they reach the eye; and the effect produced will depend on the refractive power of that substance, and the figure of its surfaces.



106. The most simple case of this nature is when the denser or more refracting substance is terminated by plane surfaces parallel to each other. Suppose A B to be a section of a plate of polished glass, terminated by parallel surfaces I i, on which falls obliquely the ray D C at the point C, it will be refracted on entering the glass, and its direc-

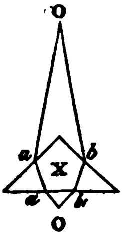
How is the duration of twilight affected by the density of the air?

What benefit do the polar regions derive from the refractive power of air?

What effect on the apparent position of objects, on the surface of the earth, is produced by refraction?

tion will be changed so as to approach nearer to a perpendicular to the plane of the glass, passing through it in the line C *c*; but on emerging at *c* it will be again refracted in the contrary direction, and will proceed in the line *c d*, parallel to D C *d'*. Thus rays being restored to their former direction after being refracted through plates of glass, or other transparent bodies with parallel surfaces, the effect is not perceptible; and hence the forms and situations of objects are not affected by viewing them through the panes of a glass window.

107. When the plane surfaces of a transparent substance are not parallel to each other, different effects will be produced. Let



X represent a section of a medium denser than that surrounding it, and terminated by inclined planes, across which pass rays of light, from the point O. Then the ray O *b* will be refracted in the direction *b b'*, and after emerging, it will pass in the line *b' o*; another ray O *a*, from the same luminous point O, will in the same manner be refracted from *a* to *a'*, and meet the former ray in the point *o*. If an eye be supposed to be placed at *o*, the luminous point O will be doubled; one image being formed by rays passing through the surface *b*, and another by those passing through the surface *a*.

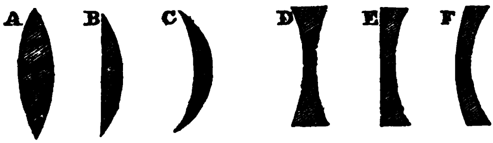
108. If, instead of *a* and *b* only, there were three, four, or any greater number of plane surfaces, the eye at *o* would perceive a light or other object at O, multiplied as many times as the number of facets into which the sides *a b* were thus divided. Hence also when glass is furrowed into a multiplicity of minute surfaces by grinding, the rays of light in passing through it are refracted as from innumerable small facets, and therefore objects are not perceived at all through it; for, if the images of them were formed in proper directions, they would be too diminutive to be visible. Such glass, forming a transparent screen, is sometimes used in the windows of offices and counting-houses, as the light passing through them is more generally diffused, and the shadows are very faint; and for these reasons, circular screens of ground glass are adapted to lamps, hence called sinumbral* lamps.

109. Glass and transparent crystals, but chiefly the former, are the substances generally employed in the construction of optical instruments for exhibiting the phenomena depending on the refraction of light; and having noticed the effects produced by transpa-

State some of the familiar optical phenomena depending on refraction
How are rays of light affected on entering obliquely and passing through a plate of glass with parallel surfaces?
Explain this by a diagram.
How will the effect be varied where the surfaces are not parallel?
What effect would result from multiplying the surfaces of incidence?
Why does a furrowed or ground surface not give distinct images?
Of what utility is the indistinctness produced by roughened glass?

* From the Latin *sine*, without, and *umbra*, a shadow.

rent bodies with plane surfaces, we shall now proceed to investigate the properties of glasses with curved surfaces. There are numerous varieties of such glasses, usually termed optical lenses; but they may all be arranged in two classes: (1.) convex lenses, or those which are thicker in the centre than towards their borders; (2.) concave lenses, or glasses thinnest in the centre.



110. Among convex lenses are the double convex, A, to which the appellation, lens, was originally applied, from its resemblance to a lentil-seed (*lens*, in Latin), being bounded by two convex spherical surfaces, whose centres are on opposite sides of the lens; the plano-convex, B, having one side bounded by a plane surface, and the other by a convex surface; and the meniscus, or concavo-convex, C, bounded on one side by a concave, and on the other by a convex surface; the former being a portion of a larger circle than the latter, and therefore the surfaces meet, when produced.

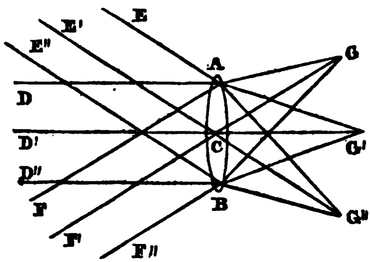
111. There are also three principal varieties of concave glasses; as the double concave, D, bounded by two concave surfaces, forming portions of spheres whose centres are on opposite sides of the lens; the plano-concave, E, bounded on one side by a plane, and on the other, by a concave surface; and the convexo-concave, F, bounded by a convex surface on one side, and by a concave one on the other, but these surfaces when produced do not meet.

112. The varieties of both classes of lenses admit of numerous modifications depending on the relative curvature of their several surfaces. The radius of a lens will be the radius of the sphere of which its surfaces form a part, if both surfaces have the same curvature; but otherwise each side will have a different radius. In all the various kinds of lenses there must be a point where the opposite surfaces are parallel; this point is termed the optical centre of the lens, and a line passing through it perpendicularly to the surface will be its axis. On this line will be situated the geometrical centres of the two surfaces of the lens, or rather of the spheres of which they form portions. A lens is said to be truly or exactly centred when its optical centre is situated

Into how many classes may lenses be divided?
How are they distinguished?
What names are given to the different varieties of convex lenses?
What to the three forms of concave lenses?
According to what circumstances in their construction do these forms vary in different glasses?
What is meant by the optical centre of a lens?
What line forms the axis of a lens?
When is a lens considered exactly centred?

at a point on the axis equally distant from corresponding parts of the surface in every direction; as then objects seen through the lens will not appear altered in position when it is turned round perpendicularly to its axis.

113. The general effect of those glasses which are styled convex lenses, or which are thickest in the centre, is to render rays which pass through them more convergent; and that of concave lenses, on the contrary, to render rays more divergent. The manner in which light is refracted by a convex lens may be illustrated by means of the annexed figure.

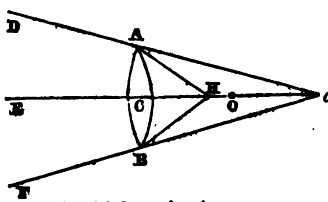


114. Suppose A B to be a double convex lens, the axis of which is D'C G', and C its optical centre, then the parallel rays D A, D'' B, will be so refracted at the two surfaces as to meet at G', which point is termed the "principal focus" of the lens. And the parallel rays E A, E' C, and E''B, and also F, A, F'C, and F'' B, falling obliquely on the lens, will in a similar manner be refracted, and have their foci at G and G'', at the same distance behind the lens.

115. It may be observed that the rays E' C G'', D' C G', F' C G, passing through the centre of the lens, do not alter their direction. C G' is termed the "focal distance" of the lens; and in a double convex lens, formed of equal spherical surfaces, its length will be that of the radius of the sphere of which those surfaces form portions. In a plano-convex lens the focal distance will be equal to double the length of the radius of its curved surface. If the lens be unequally convex, the focal distance may be found by multiplying together the radii of its two surfaces, and dividing the product by the sum of the two radii, the quotient being the focal distance required.

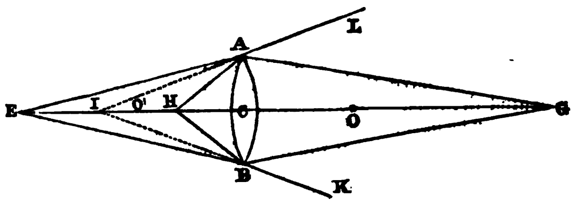
116. When converging rays, or those proceeding towards one point, as D A G, E C G, and F B G, fall on the surface of a convex lens A B, the principal focus of which is at O, they will be-

What test may be adopted of the accuracy of such centring?
What is the effect of convex and concave lenses respectively?
Illustrate the manner that parallel rays are refracted by a convex lens?
What is meant by the principal focus of such a lens?
What is meant by the *focal distance?*
How may this distance be known in spherical lenses of unequal convexity?
What will it be in a plano-convex lens?
How can it be found in lenses having curves unequally convex?
How does a convex lens affect converging rays?



come more convergent, and will therefore be refracted to a focus at H, nearer the lens than the point O. The more distant may be the point *a*, at which the rays would meet if uninterrupted, the further will the point H recede from the surface of the lens towards O, beyond which point it never goes; and the nearer the point *a* to the lens, the nearer will the point H advance towards it.

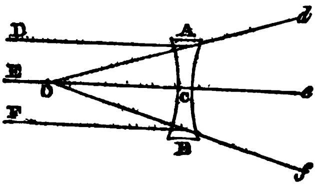
117. The points G and H are named "conjugate foci," because the place of one depends on that of the other, and though every lens has only one principal focus, it may have an indefinite number of conjugate foci, as rays may fall on it converging at innumerable angles. The conjugate focal distance, C H, may be found by multiplying the principal focal distance, O C, by *a* C, the distance of the point of convergence, and dividing that product by the sum of the same numbers, when the quotient will give the distance required C H.



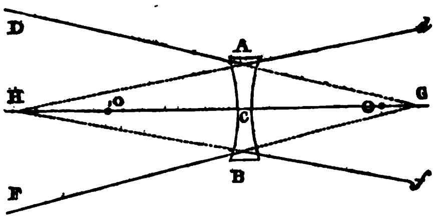
118. When diverging rays, or those issuing from one point, as E A, and E B, fall on a convex lens A B, the principal focus of which is at O, the refractive power of the lens will make them converge to a focus at G, beyond O. As the point whence the rays diverge recedes from the lens, the focus G will advance towards it, and when the point of divergence E is infinitely distant, the point G will coincide with the principal focus O, for rays issuing from a point at an infinite distance must be virtually parallel rays. If E approaches to O′, the focus G will recede from O, and when E coincides with O′, G will be infinitely distant, or

What are meant by the "*conjugate foci*" of a lens?
How is the conjugate focal distance for converging rays found?
In what position, with respect to the principal focus, will the conjugate focus of diverging rays be situated?
What effect will the indefinite distance of the point of divergence produce on the position of their focus?
With what point will it then coincide?
How may rays after refraction by a convex lens become parallel?
Where must the point of divergence be situated in order that they should be divergent after refraction?

the rays will become parallel after refraction. And when F is between O′ and C, as at H, the refracted rays will become divergent, as A L, B K, as if they had proceeded from a focus I, beyond O′ and in front of the lens. The points E and G are termed the conjugate foci, as before; and the conjugate focal distance may be found by multiplying the principal focal distance by E C, the distance of the point of divergence from the lens, and dividing the product by the difference of those numbers, and the quotient will be the required distance C G.



119. Rays of light passing through concave lenses will, in most cases, be rendered more divergent by refraction, whatever be their previous direction. Suppose A B to be a double concave lens, whose axis is E C *e*, and C, its optical centre; then the parallel rays D A, F B, falling on it, will be refracted into the lines A *d*, B *f*, as if they diverged from a point O, before the lens, which is its principal focus. The principal focal distance is relatively the same as in a convex lens, and may be ascertained in the same manner, whether the sides be of equal or unequal curvature.



120. When converging rays D A, F B, proceeding to a point G, beyond the principal focus O of a concave lens, fall on it, they will be refracted into the diverging lines A *d*, and B *f*, as if they issued from a focus H in front of the lens beyond O′. When G, the point of convergence, coincides with O, the rays will be parallel after refraction; and when the point G falls within the point O, the refracted rays will converge to a focus on the same side of the lens with G, but on the other side O. G and H are styled conjugate foci, and the situation of one of them, when the other is known, may be found by the rule given in the case of converging rays falling on convex lenses.

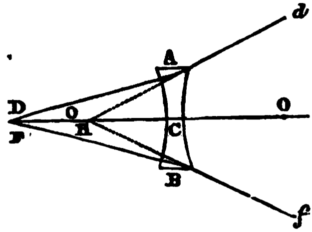
What directions will rays generally follow after refraction by a concave lens?

Where is the principal focus of such a lens conceived to be situated?

In what manner will the principal focal distance be ascertained?

How will converging rays be refracted, which, before refraction, converge to a point beyond the principal focus?

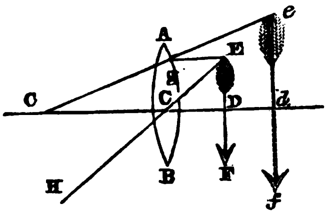
In what manner will they be refracted if converging directly towards the principal focus?



121. When diverging rays D A, F B, from any point F beyond the focus O′ fall on a concave lens A B, they will diverge in the directions A *d*, B *f*, as if proceeding from a point H, between O′ and C; and as F advances towards C, so will H likewise: that is, the more divergent the rays are before refraction the more will they diverge afterwards. When the distance F C or H C is given, the other point may be found by the rule for diverging rays falling on convex lenses.

122. Meniscus, or concavo-convex lenses, have the same effect on rays of light as convex lenses corresponding with them in focal distance. Convexo-concave lenses have the same effect as concave lenses agreeing with them in focal distance.

123. The manner in which images are formed by means of optical lenses may be readily conceived from the preceding figures and descriptions; and the effect of convex glasses, in magnifying the images of objects, may be further elucidated by reference to the annexed diagram. Let A B represent a convex lens, of which C *d* is the optical axis; and let E F be any object to be examined, placed between the principal focus and the surface of the lens; then a ray E *g* falling on the lens parallel to its axis will be refracted in the direction *g* C, and another ray E G H, from the same point, falling obliquely on the lens and passing through its optical axis, will be continued in the same direction without being affected by refraction, and the two rays will become more divergent after passing through the lens; whence it follows that if the ray E G H were prolonged beyond E, it would cut the line *g e* in the point *e*, and an eye placed behind the lens would see the extremity E of the object at *e*; and rays proceeding from every other part of the object being refracted in a corresponding manner, the image of the object E F will appear as at *e f*, and therefore be larger than the object.



What will be the directions after refraction of rays diverging from a point beyond the principal focus of a concave lens?

Can diverging rays ever become either parallel or convergent by the refraction of such a lens? Why?

What two rules apply for finding the focal distances of Meniscus lenses?

Draw and explain a diagram to illustrate the magnifying effect of convex lenses.

What effect is produced by refraction on rays passing through the optical axis of a convex lens?

124. But if the object be placed at the focus of the lens, the rays refracted being chiefly such as were parallel to its axis before refraction, the eye will not perceive a distinct image of the object. If we suppose the object E F to be placed beyond the focal distance, the rays E *g*, E G, from the same point E will become convergent after having traversed the lens, and will intersect each other below the axis, E G as passing through the centre of the lens not having its direction altered by refraction; all the rays from different points of the object will take analogous directions, and thus there will be formed on the opposite side of the lens a reversed image of the object. And if the lens be fixed in an aperture in a window-shutter, and all light but what passes through it be excluded, the image may be rendered visible, by placing a sheet of white paper opposite the aperture to receive it. A room thus fitted up would be literally a *camera obscura*, a darkened chamber.

The Organs of Vision.

125. The eyes of animals bear a certain analogy to the optical instrument called a camera obscura, just mentioned; for the images of external objects, within the sphere of vision, are actually formed or traced within the eye, in the manner that will be subsequently described.

126. In man and other animals destined to inhabit the surface of the earth, the eyeball is a mass nearly spherical, but somewhat flattened in front. Those animals that dwell in the water have eyes very much flattened, the eyeball in most fishes forming but half a sphere, and in the ray species, it is but one quarter of the thickness of a sphere. In those birds that soar to the higher regions of the atmosphere, the anterior part of the eye is sometimes flat, and sometimes in the figure of a truncated cone: the upper part forming a short cylinder, surmounted by a very convex eminence.

127. The eyes of spiders, scorpions, &c., are merely very minute points, which it would be difficult to recognise as organs of vision, if their functions had not been demonstrated by precise experiments. Millepedes, flies, &c., have eyes often very large in proportion to the bulk of the insect, and composed of a multitude of small facets, or plano-convex lenses united into a hemispherical form, with their axes directed to a common focus. Many insects have, at the same time, simple and compound eyes: this is the case with wasps, grasshoppers, and some others. There

Why does the eye not perceive a distinct image of an object at the principal focus of a convex lens?

In what position will the *image* appear when the object is beyond the principal focus? Explain the cause of this on the diagram.

In what manner may this position of the image be verified?

What is a *camera obscura*?

To what is the construction of the eye analogous?

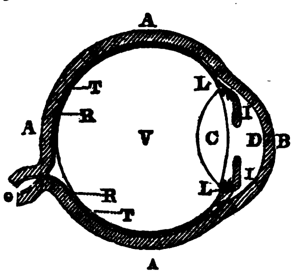
What relative sphericity have the eyes of land and of aquatic animals?

What peculiarity is found in the eyes of birds that soar to great heights? What, in those of spiders and scorpions?

exist likewise multitudes of animals, in which no organ of vision can be discovered; but it appears, that in such the sense of feeling is extremely delicate, and therefore supplies the defect of the other senses.

128. In the following descriptive notices of the organs of vision, and the phenomena depending on them, our attention will be restricted to the structure and functions of the human eye. But the eyes of some quadrupeds, as the ox or the sheep, so far resemble those of man, that sufficiently accurate ideas of the essential parts of the eye may be obtained by dissecting and examining an eye of either of those animals, and comparing its mechanism with the ensuing description.

129. The annexed figure exhibits a front view of the eye, or the anterior portion of the eyeball. The white part surrounding the centre is called the sclerotic* coat (*tunica sclerotica*), *a a*, and it is continued within the orbit, round the back part of the eyeball, being formed of a dense membrane, which includes, as in a bag, the other parts of the eye. It is perfectly opaque, and therefore is not continued over the front of the eye, but joins the transparent cornea, † *b*, which differs from it chiefly in being completely pervious to light, and therefore serves like a window to admit it to the interior of the eye for the formation of images. Within or behind the cornea may be perceived the iris,‡ *c*, a sort of coloured fringe, usually either of a dark brown or a grayish-blue tint; and hence the distinction between black, and blue or gray eyes: but there are persons with extremely light complexions and white hair (Albinos), who have red eyes, the iris being red, as in the eyes of a white rabit. In the centre of the eye, surrounded by the iris, is a dark circular space of variable dimensions, called the pupil, *d*, through which the rays of light pass into the chambers of the eye.



130. An horizontal section of the eye is represented in the marginal figure, in which the parts already described are shown, as well as those of the interior. It will be perceived that the eye is enveloped in four membranes or tunics, the sclerotic coat, A A A; the cornea, or horny coat, B B, connected with the former, in the front of the eye; the choroid coat,§ T T, which forms a lining to the sclerotic coat, and on its opposite surface is co-

* From the Greek Σκληρος, hard, firm; or, Σκληροτης, hardness.
† From the Latin *corneus*, horny, or like horn.
‡ So called from its being like the rainbow (*iris*), variously coloured.
§ From its resemblance to another membrane called, in Greek, Χοριον.

vered by a black pigment (*pigmentum nigrum*), on which lies the interior coat of the eye, called the retina,* R R, a delicate reticular membrane, expanded over the posterior chamber of the eye, and proceeding from the optic nerve, O, by which sensations are conveyed to the brain.

131. The interior of the eye, or the cavity surrounded by the coats just described, is filled by three substances called humours: the first, or the aqueous humour, D, is a fluid situated immediately behind the transparent cornea, and chiefly in front of the iris; the second in situation is the crystalline humour, C, directly behind the iris, being a solid, transparent lens, more convex behind than before; and the third is termed the vitreous humour, V, a kind of viscous solid mass, of a medium consistence compared with the other two, occupying the posterior chamber of the eye, supporting the other parts, and contributing chiefly to preserve the globular figure of the eye. Between C and D is the pupil or opening in the iris, I I, through which light is admitted into the eye; and behind the iris the crystalline humour or lens is suspended in a transparent capsule, by the ciliary processes, L L, which proceed from the iris.

132. The eyes are situated in basin-shaped cavities in the skull, called the orbits, and there are various muscles attached to the ball of the eye and to different parts of each orbit, which by their contraction give a certain degree of lateral or rolling motion to the eye, and thus assist in directing the sight towards particular objects. Eyelids, also moved by muscles, and fringed by the eyelashes, serve to guard the eyes from dust, and screen or shut them altogether from the access of too intense a light; and there are glands for the secretion of fluid to moisten the cornea, and by the motion of the eyelids keep its surface clear, and in a state adapted to yield perfect vision.

133. As already observed, the eye may be compared to a camera obscura, the rays of light from any object entering the pupil,

What appears to supply the place of the eye in animals which are without that organ?

From what quadrupeds may we obtain specimens, as substitutes, to demonstrate the structure of the human eye?

Where is the *tunica sclerotica* situated?

Where the *cornea?* the *iris?* the *pupil?*

What are the names and positions of the four coats containing the humours of the eye?

Between which two membranes is the *black pigment* found?

What substance occupies the front cavity of the eye?

What is the nature, form, and name of the body which separates this from the posterior cavity?

With what is the latter cavity filled?

Draw and describe a magnified section of the eye.

What is the purpose of the *ciliary processes?*

What name is given to the bony cavity in which the eye is placed?

---

* From the Latin *rete* a net, in reference to its resemblance to network.

and forming an image on the retina, which produces the perception of a visible object conveyed through the optic nerve to the brain. That a perceptible image is really formed in this manner on the retina, may be experimentally demonstrated by paring away the back part of the sclerotic coat of the eye of an ox, with a sharp knife, till it becomes so thin as to be transparent: it will thus be converted into a miniature camera obscura, and objects held before the cornea, will then be seen behind, delineated on the retina.

134. It may be imagined, that if a luminous point, or illuminated object be placed too near the eye, the rays proceeding from it will form an image beyond the retina, or rather the image they form on it will be confused and imperfect; so on the contrary, if the luminous point be too distant the image will be confused in consequence of the rays converging to a point before they reach the retina.

135. In order therefore that the image may always be formed distinctly on the retina, provision must be made for increasing or diminishing the refraction of rays within the eye, in proportion to the distance of the objects to be viewed. This seems to be effected by means of the crystalline humour or lens, which is composed of concentric laminæ of transparent fibres, by the action of which its form may be modified so as to adapt the eye to the distance of different objects. And in various animals the figure of the crystalline, and its situation with regard to the retina are varied so as to accommodate the powers of vision in each animal to its peculiar circumstances and mode of life.

136. The vision of objects at different distances may possibly also be further facilitated by the variable pressure of the muscles on the ball of the eye; though it must be concluded, from the experiments of Dr. T. Young, that their action cannot produce any alteration in the shape of the cornea. In viewing near objects, the pupil of the eye is contracted, fewer rays enter the eye, and such objects are thus distinctly perceived; while in viewing distant objects, the pupil dilates to admit more rays to fall on the retina. In obscurity, the pupil of the eye becomes dilated to admit as many rays as possible; and in a strong light its dimensions are much contracted, as may be observed by holding a candle near the eye of another person. Sudden exposure of the eyes to much light produces an uneasy sensation, from the quantity of rays admitted through the dilated pupil; and, on passing from

How can we prove that a perceptible image is formed on the retina at the back of the eye?

In what cases will images be indistinct?

What provision is necessary to render objects distinct at different distances?

By what part of the eye does the adjustment to distances appear to be effected?

What apparent effect on the exterior appearance is produced by efforts to distinguish very distant objects?

Whence arises the pain from sudden exposure to a glare of light?

open daylight into an obscure apartment, objects are not seen till the contracted pupil becomes enough dilated to take in a sufficient number of rays to render them visible.

137. An object may be seen distinctly and singly, though separate images of it be formed on the retina of each eye. This depends on those images occupying corresponding points on either retina, and thus the directions of the optical axes of the two eyes intersect each other, and a distinct image is perceived at that point. If, however, while a person looks steadfastly at any near object with both eyes open, he tries to direct his view to some rather more distant object, without suffering the first to escape attention, a double image will be perceived, one somewhat above the other; and, on ceasing the effort to look beyond the object, the images will coalesce into one. Similar effects may be produced by pressing with the finger on the ball of one eye, so as to displace its optical axis. Double vision is also in the same manner occasioned by intoxication or by frenzy. Many animals never see objects with more than one eye at a time; as most kinds of birds, lizards, and fishes; while there are some species of fish that can only see objects situated above them.

138. Though the perception of visible objects is certainly produced by means of their images formed on the retina, yet the manner in which the sensation is conveyed by the optic nerves to the brain is a mystery which we are utterly unable to penetrate. There are also some peculiar relations between the images of objects, and the manner in which they are perceived, which have given rise to various conjectures, and have never yet been clearly explained. Thus, it is certain that the image formed on the retina is always inverted with regard to the position of the object producing it; just like the images formed by a single lens in a camera obscura, as may indeed be ascertained by repeating the experiment on an ox's eye, previously mentioned.*

139. Some writers on optics content themselves with asserting that we really see all objects inverted, but that the judgment corrects the erroneous perception, a process of the occurrence of which no evidence can be produced. Others more philosophically attempt to explain this phenomenon by alleging the formation of a secondary image within the eye, reflected from that received on the retina to another plane, by means of which the

When are distinct images formed by both eyes producing a single impression on the mind?

On what does this distinctness depend?

How may the two eyes be made to see different images of the same object?

By what means other than voluntary effort may double vision be produced?

What peculiarities of sight belong to birds, reptiles, and fishes?

In what position is the image of an object formed on the retina?

---

* See No. 133.

position of the image is corrected.* But further investigation is requisite to enable us to explain the relation between the visible direction of objects, and the position of the images formed by them within the eye.

140. There are, however, some cases in which the judgment, with the aid of the other senses, enables us to correct erroneous perceptions produced by vision; and it is thus, by means of the sense of feeling and by habitual observation, that we ascertain the figures and relative distances of visible objects. It has been remarked, that persons born blind from the existence of cataracts † in the eyes, on being restored to perfect vision by a surgical operation, after arriving at years of discretion, believe at first that the objects they see are in immediate contact with their eyes, every thing appearing to them as if painted on a plain surface; and they are unable to recognize objects by sight alone, gradually acquiring that power by comparing their new sensations with the real objects by feeling them.

141. A person born blind and just restored to sight by the operation for the cataract, would not be able to distinguish a die or any other cube from a marble or a billiard-ball, without touching them; neither would he know the persons with whom he was most familiarly acquainted, or discriminate his father from his mother, or his brother from his sister, without examining their persons and dresses by the sense of feeling, or hearing their voices. Individuals thus situated acquire the correct sense of vision only by degrees, like infants; and it is by experience that they learn to walk about among the objects around them, without the continual apprehension of striking themselves against every thing they behold.

142. The processes by which we judge at all times concerning the dimensions and distances of visible objects are, in an analogous manner, the result of reasoning on visual phenomena; and thus experience modifies considerably the ideas we form of the size of any object and its position in space, according to the visual angle. For instance, in judging by the visual angle, a man would appear to us much smaller at three hundred paces distance than at one hundred; notwithstanding which we are able to form as exact a judgment of a man's height at one distance as at the other, provided there be other objects at hand which may serve as scales of comparison. Thus, we rectify the image formed under

What means have we of correcting the error of early impressions received through the eye?

What happens when persons of mature age are for the first time enabled to see?

How do such persons acquire the correct sense of vision?

How do we obtain accurate ideas of the dimensions and distances of remote objects?

---

* See a New Theory of Vision. By Andrew Horn. Also Encyclopædia Metropolitana—Mixed Sciences, p. 459.

† From the Greek Καταρρακτης, a cataract.

the visual angle by our preconceived idea of the common height of a man, comparing it in imagination with the door of a house, the trunk of a tree, or any other object in view, with the size of which we are acquainted. Hence, if we see a man three hundred paces off, upon a naked plain, as on a wide sandy level by the sea-side, he will look very small, and may be mistaken for a little child, as we can judge of him only by the visual angle, and have no other object near to rectify the erroneous perception.

143. Dr. Arnott has adduced an interesting example of the optical effect just illustrated. He says he "once sailed through the Canary Islands, and passed in view of the far-famed Peak of Teneriffe. It had been in sight during the afternoon of the preceding day, at a distance of more than 100 miles, disappointing general expectation by appearing then only as an ordinary distant hill rising out of the ocean; but next morning, when the ship had arrived within about twenty miles of it, and while another ship of the fleet, holding her course six miles nearer to the land, served as a measure, it stood displayed as one of the most stupendous single objects which, on earth, and at one view, human vision can command. The ship in question, whose side, showing its tiers of cannon, equalled in extent the fronts of ten large houses in a street, and whose masts shot up like lofty steeples, still appeared but as a speck rising from the sea, when compared with the huge prominence beyond it, towering sublimely to heaven, and around which the masses of cloud, although as lofty as those which sail over the fields of Britain, seemed still to be hanging low on its sides. Teneriffe alone, of very high mountains, rises directly and steeply out of the bosom of the ocean, to an elevation of 13,000 feet, and as an object of contemplation, therefore, is more impressive than even the still loftier summits of Chimborazo or the Himalayas, which rise from elevated plains and in the midst of surrounding hills."*

144. Various optical deceptions are produced when we are obliged to judge of the sizes and distances of objects merely by the visual angle. Thus, any person placed at one extremity of a long avenue, a gallery, or a rectilineal canal, will perceive the trees of the avenue diminishing in height as they are more distant, the two ranges of trees seeming to converge towards each other, and come to a point if the avenue is very long; and the two sides of a canal, and the floor and lateral walls of a gallery, in the same manner, become convergent, and meet in a point when greatly extended. These optical effects may be imitated by constructing

How are we liable to err in estimating the size of a person on a wide level surface?

In what case may the grandeur of an object be heightened by contrast?

What gives the Peak of Teneriffe its peculiar sublimity?

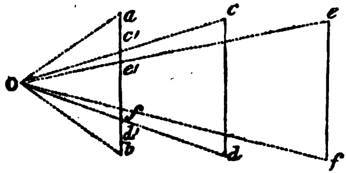
Why are the Andes and Himalayas less impressive than that peak?

In what cases may the imagination be deceived by an undue reliance on the eye?

---

* Elements of Physics, vol. ii. pp. 264, 265.

the sides of a canal or alleys of trees in converging lines, the more distant trees gradually diminishing in height; and thus the avenue or canal would appear longer than the reality.



145. The annexed diagram may serve to illustrate the apparent diminution of objects under different visual angles. Suppose *a b* to be any object, as a tree, to an eye situated at O, it will appear under the visual angle *a* O *b*, and the dimensions of the image on the retina will have a certain proportion; then, if another tree, *c d*, of the same height with the first, be placed as far again from it, the visual angle will be *c* O *d*, and the apparent height of the latter tree will be to that of the former, as *c' d'* to *a b*; and if a third tree be situated at a further distance, *e f*, its apparent height will be to that of the first, as *e' f'* to *a b*; that is, the spectator will see three trees really equal in height, as if they were three times at the same distance of the relative heights, *a b*, *c' d'*, and *e' f'*.

146. When objects are extremely distant it is impossible to judge correctly concerning their particular situations; and hence an irregular line appears to be an arc of a circle, because we suppose all the points to be equally distant from us; and thus when stationed in the midst of a plain, remote objects seem to form a circle around us. It is for the same reason that the heavens present the appearance of a concave hemisphere sprinkled with stars; for at first view the stars seem to be all equidistant from the observer. A small curved or polygonal line seen afar off appears to be a small right line; a polyedron cut in facets, or an irregular mass, at a distance, will look like a sphere, and yet further off will exhibit the contour of a flattened disk. This happens with respect to the sun and moon, which we see as circular disks.

147. Optical illusions take place in consequence of the figures of bodies in motion. If a sphere revolving on its axis be placed at a distance, it will be impossible to perceive the movement, unless there are on its surface spots or visible irregularities, the alternate appearance and disappearance of which may be observed; and it is thus only that astronomers have been enabled to ascer-

Illustrate by diagram the apparent diminution of objects by the effect of different visual angles.

How would a row of trees, of equal heights, and situated equidistant from each other, extending nearly in front of the spectator, be made to appear by the effect of perspective?

How could they be imitated in a picture?

In what instances may irregular forms be mistaken for those which are regular?

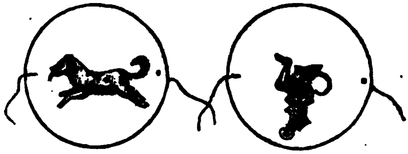
What appearance has a spheroidal figure when extremely remote from the observer?

What will enable us to judge whether such a body have a rotary motion or not?

tain the rotation of the sun and the planets, by observing spots on their surfaces.

148. A lighted candle or torch whirled in a circle, the plane of which passes through the eye, at a great distance, merely appears to come and go, in a line, from one extremity to the other of the diameter of the circle. The visible paths of the planets through the heavens, in their revolutions round the sun, thus have the appearance of right lines, from one extremity to the other of which each luminary seems, to a spectator on the earth, alternately to advance and return.

149. The impression of light on the eye is not merely instantaneous, but continues during a certain time after the luminous or illuminated object has been withdrawn. From the experiments of D'Arcy, it has been ascertained that the effect of light on the retina remains about 1-7 or 1-8 of a second after the light has actually been removed.* To this cause is to be ascribed the circle of light formed by whirling round a burning stick, a phenomenon with which every one must be acquainted. And on the same principle is constructed the amusing toy called the Thaumatrope,† contrived by Dr. Paris.‡



150. It consists of a number of circular cards, having silk strings attached to their opposite edges, as represented in the preceding figures. By these strings, one of the cards being twirled round with a certain velocity, both sides of it will be visible at the same time, and any objects traced on them, as a dog on one side and a monkey on the other, may be perceived simultaneously. Hence the parts of the picture being united, when it is whirled round, the monkey will be seen seated on the back of the dog. In this case the revolving card becomes virtually transparent, so that the objects on opposite sides of it may be viewed together,

How may a circle be mistaken for a straight line?
With what example of this does astronomy furnish us?
Does the image of an object vanish from the eye the moment the object is withdrawn?
For what length of time has D'Arcy found impressions to remain on the visual organ?
What familiar and amusing experiments owe their interest to the durability of visible impressions?
Describe the thaumatrope.

* See a Paper "On the Duration of the Sensation of Sight," in Memoires de l'Academie des Sciences, a Paris. 1765. p. 439.

† From the Greek Θαυμα, a wonder, and Τρεπω, to turn.

‡ Philosophy in Sport made Science in Earnest.

nearly as they would be if painted on the two surfaces of a plate of glass.

151. An improvement of the thaumatrope, as already described, has been made by the inventor, which consists in altering the axis of rotation, while the card is in the act of revolving, in order that the images on its opposite sides may be brought in different positions with respect to each other. This is ingeniously effected by affixing two strings to one or both sides of the card, which are so connected as to act on different points of the border, according to the degree of tension applied to them. The appearances exhibited are thus diversified, and rendered more amusing. A card, with a horse on one side and a jockey on the other, may by twirling it be made to show the rider in his saddle, then by merely tightening the string, while the card continues revolving, the jockey may be seen as if making a summerset over the head of his steed: on relaxing the string he will again appear in the saddle, and by various degress of tension other postures may be displayed.

152. Many singular effects may be produced by modifications of the machinery, all depending on the continuance of the impression of visible objects on the retina during the space of about one-eighth of a second, so that the figures on either side of the card, when it is made to revolve, are renewed before the preceding impression has ceased its action; and consequently the figures on both sides of the card are seen at the same time.

153. Another curious machine has been recently invented, called the Phantasmascope,* the effect of which further illustrates the phenomenon of the perception of visible impressions during a certain period after the objects producing them are withdrawn.

154. In this apparatus as modified by Mr. Faraday, figures are seen through revolving wheels, or circular disks of pasteboard, with deep narrow notches at their edges. If a transparent star, highly illuminated, be placed behind a disk of pasteboard or blackened tin plate, with a single narrow opening extending from the circumference to the centre, it will necessarily hide the whole of the star except that part immediately opposite the opening; but if the disk be made to revolve rapidly, the whole star will become visible; as may easily be conceived from what has been stated relative to the duration of impressions of light on the retina.

By what device has its action been varied?

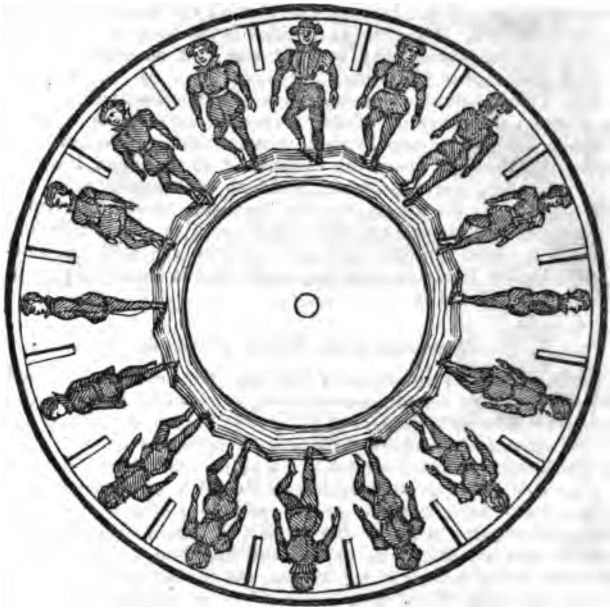
With what, as the least velocity, must this apparatus revolve, in order to exhibit its true character?

What other toy has been founded on the durability of impressions?

What is the arrangement by which figures are viewed in the phantasmascope?

How did Faraday contrive to render the whole of an illuminated object visible through a single line of opening?

* From the Greek Φαντασμα, a spectacle, and Σκοπεω, to view.



155. In the phantasmascope the pasteboard disks are painted with a variety of figures, in different positions, and the borders of the disks being cut into cogs or teeth, leaving openings between them, when made to revolve on a spindle, on looking at the objects as exhibited in a mirror, through the opening, they will display the most diversified and grotesque attitudes.

156. Thus the figures given in the preceding cut, when properly viewed, would all appear to be pirouetting like so many opera-dancers. By different arrangements of the openings, and varied designs, may be exhibited, in a similar manner, yawning figures, jumping frogs, creeping serpents, and a multiplicity of other strange combinations.

157. One of the most curious facts relating to the faculty of vision is the absolute insensibility to the impression of light at a certain point of the retina, so that the image of any object falling on that point would be invisible. When we look with the right eye this point will be about 15 deg. to the right of the object observed, or to the right of the axis of the eye, or the point of most

For what purpose is the mirror introduced in the exhibition of the phantasmascope?

Are all the parts of the retina equally sensible to the impressions of light?

distinct vision. When looking with the left eye the point will be as far to the left. The point in question is the basis of the optic nerve; and its insensibility to light was first observed by the French philosopher Mariotte.

158. This remarkable phenomenon may be experimentally proved by placing, on a sheet of writing paper, at the distance of three inches apart, two coloured wafers, then on looking at the left-hand wafer with the right eye at the distance of about a foot, keeping the eye straight above the wafer, and both eyes parallel with the line which joins the wafers, the left eye being closed, the right-hand wafer will become invisible; and a similar effect will take place if we close the right eye, and look with the left. According to Daniel Bernoulli, this insensible spot is about 1-7 part of the diameter of the eye.

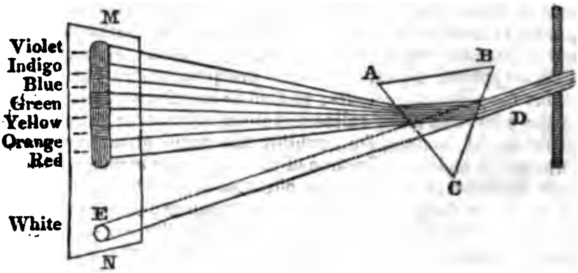
Chromatics, or the Theory of Colours.

159. Among the properties of light one of the most striking and curious is that of communicating colours to bodies. Popular language ascribes the existence of colours to some inherent qualities of the substance on whose surfaces we perceive them; and thus, in using the phrases a red brick or a green wafer, an uninformed person would conceive the redness of the brick, or the green tint of the wafer, to be as much peculiar properties of those bodies as the quadrangular shape of the one and the circular figure of the other. But we find, from experiment, that though colour partly depends on the texture of substances, and the nature of their surfaces, the essential efficient cause of colour is light, since not only are bodies destitute of colour in the absence of light, but, as will be subsequently shown, their colours may be altered by subjecting to certain modifications the light by which they are rendered visible. Hence it happens, that many coloured objects, the peculiar tints of which are discriminated without difficulty in broad day-light, appear to wear the same hue in the dusk of the evening, or by candle-light. It may therefore be properly stated, that *the colour of a substance is the effect of light on a surface adapted to reflect its peculiar colour.*

160. The influence of light in the production of colour is remarkably modified by refraction. This effect of light is most conveniently exhibited by means of a triangular prism of glass. If such a prism be held with one of its angular edges opposite to

What fact, in regard to this subject, was discovered by Mariotte?
How is the existence of a point of insensibility experimentally proved?
What is the size of the insensible spot?
What is the usual belief and the common language of mankind in regard to the existence of colours?
What is the efficient cause of colours?
How is this proved?
What is the true definition of colour?
What relation has colour to refraction?
How is the influence of refraction best exhibited?

the eye, the objects seen through it will not be doubled, as when viewed directly through one of the flat sides of the glass, but they will be more or less elongated, according to the angle at which the prism is held, and will also be clothed with all the colours of the rainbow.



161. The dissection of a ray of solar light into different colours, by refraction, may be more accurately displayed by admitting a ray through an aperture in a window-shutter into a darkened chamber, and causing it to fall on a diaphanous prism A B C, as represented in the preceding figure. A ray D thus entering, and suffered to pass unobstructed, would form on a plane surface a circular disk of white light E, but the prism being so placed that the ray may enter and quit it at equal angles, it will be refracted in such a manner, as to form on a screen M N, properly placed, an oblong image called the solar spectrum, and divided horizontally into seven coloured spaces, or bands of unequal extent, succeeding each other in the order represented: *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, *violet*.

162. These bands are not separated by distinct lines, so that it is difficult to determine where one ends and another commences, the several tints at their borders being blended, and each almost imperceptibly united with those next it; the whole spectrum exhibiting the seven principal colours, with intermediate shades or mixtures. Indeed some writers enumerate but six colours in the spectrum, omitting the indigo; and Dr. Wollaston observed, that when a very small ray was submitted to the prism, there were only four colours, namely, *red*, *yellowish-green*, *blue*, and *violet*. Bands of

Describe the effect of a prism of any transparent substance when placed near the eye.

How is the separation of white light into its constituent coloured rays most advantageously displayed?

What is the image of a beam of light refracted by a prism usually denominated?

Into how many and what spaces is the solar spectrum divided?

What are the two extremes of the spectrum?

What fact in regard to the number of colours was observed by Dr. Wollaston?

colours more precisely terminated may, however, be obtained by receiving the ray on a lens before it is allowed to fall on the prism; and the image thus formed will be more extended in length and very narrow.

163. Similar phenomena may be produced by means of other kinds of light as well as that of the sun; and all transparent substances, in masses not terminated by parallel surfaces, have in some degree the same effect as the glass prism. Hence the diamond, sapphire, topaz, and other precious stones cut in facets, display the prismatic colours; as also do angular crystals of quartz, Iceland spar, and many saline and stony substances; the cut-glass ornaments of lustres, &c., exhibit the same glittering tints, by lamp-light; and the refraction of the sun's rays in passing through drops of water produces a like effect in the rainbow.

164. From the preceding and many other experiments of a similar nature, Sir Isaac Newton was led to the construction of a theory relating to the cause of light and colours, which was, during a long period, almost universally received among men of science. The production of coloured spectra by the refraction or reflection of light had been observed long before Newton commenced his researches, and some imperfect attempts had been made to explain the phenomena; but he not only showed that these conjectures were wholly unsatisfactory, but also proposed a highly ingenious hypothesis, founded on the doctrine of the emanation of light, or that system which refers the phenomena of vision, light, and colours, to the presence and motion of an ethereal fluid, constantly issuing from the sun and other luminous bodies. "The sun's direct light," says Professor Maclaurin, "is not uniform in respect of colour, not being disposed in every part of it to excite the idea of whiteness which the whole raises; but, on the contrary, is a composition of different kinds of rays, one sort of which, if alone, would give the sense of red, another of orange, a third of yellow, a fourth of green, a fifth of light blue, a sixth of indigo, and a seventh of violet; that all these rays together, by the mixture of their sensations, impress upon the organ of sight the sense of whiteness, though each ray always imprints there its own colour; and all the difference between the colours of bodies when viewed in open daylight arises from this, that coloured bodies do not reflect all sorts of rays falling upon them in equal plenty; the body appearing of that colour of which the light coming from it is most composed."*

165. Hence, according to the theory of emanation, white light

By what means may distinctness between the coloured bands be obtained?

Is the presence of solar light necessary to the production of colours by refraction?

How did Newton explain the phenomena of the spectrum?

How did the Newtonian philosophers conceive light to be constituted?

Of what did they suppose white light to be composed?

* Maclaurin's Philosophy of Newton, 4to. b. iii. p. 318.

is an assemblage of molecules of various colours, which may be separated from each other by the action of a prism; and bodies, when exposed to the rays of the sun, display any given colour because they are so constituted as to absorb all the molecules except those of the rays of their own peculiar colour: thus perfectly white substances absorb none of the molecules, but reflect the white or compound light unaltered; black substances absorb all the rays, and therefore yield no colour; and red, yellow, and blue substances respectively reflect those rays alone by which they are distinguished.

166. The least that can be said in favour of this system is that it accounts for all the phenomena; but it must be admitted that the notion of material particles perpetually traversing space in all directions, with almost infinite velocity, is absolutely gratuitous, and hardly consistent with the simplicity and economy generally observable in the works of nature. The appearances likewise may be explained by having recourse to a different theory, advanced by Huygens, and advocated by Euler, which refers them to the excitement and propagation of undulations through an ethereal fluid pervading all space, which, by inconceivably rapid vibrations conveys white or coloured light to the eye, in a manner analogous to that in which musical and other sounds are brought by slower vibrations of the air to the ear.

167. "Every simple colour," according to this system, "depends on a certain number of vibrations which are performed in a certain time; so that this number of vibrations made in a second, determines the red colour, another the yellow, another the green, another the blue, and another the violet, which are the simple colours represented to us in the rainbow. If, then, the particles of the surface of certain bodies are disposed in such a manner, that being agitated, they make in a second as many vibrations as are necessary to produce, for example, the red colour, I call such a body red: and rays which make such a number of vibrations in a second may, with equal propriety, be denominated red rays; and, finally, when the optic nerve is affected by these same rays, and receives from them a number of impulsions, sensibly equal, in a second, we receive the sensation of the red colour.

168. The parallel between sound and light is so perfect that it holds even in the minutest circumstances. When I produced the phenomenon of a musical chord, which may be excited into vibration, by the resonance only of certain sounds, you will please to

What account did they give of bodies possessing a white colour? what of those which are black?

To what objections is the Newtonian theory of *emanations* liable?

What more simple view of the subject was entertained by Huygens, Euler, and others?

On what, according to that theory, do the several colours depend?

In what manner does this theory conceive coloured bodies to be adapted to produce the sensations belonging to their several tints?

What analogy has been traced between the seven colours and the seven notes of the musical gamut?

recollect, that the one which gives the unison of the chord in question is the most proper to shake it, and that other sounds affect it only in proportion as they are in consonance with it.* And it is exactly the same as to light and colours; for the differen colours [of the solar spectrum] correspond to the different musical sounds."†

169. It ought to be observed that while the phenomena of light and colours may be accounted for according to the system of emanation or that of undulation, it is not absolutely necessary to adopt either in reasoning concerning them; and it will be sufficient here to state that rays of light, whether they be trains of material particles, issuing from luminous bodies, or chains of undulations taking place in an ethereal medium, are always propagated in right lines till they enter or impinge on a refracting or reflecting medium, when they are either bent at certain angles, or returned in the same lines in which they advanced; and thus, when a luminous ray is refracted or reflected it still proceeds in a right line, though that line may not be parallel with its original direction.

170. If the coloured image obtained by means of a glass prism be extended longitudinally, by making it first pass through a convex lens, it will be found that the rays of different colours possess different degrees of refrangibility, or are some relatively more refracted than others. The red tint which forms the inferior band of the spectrum produced by the apparatus above described, consists of rays which have undergone a smaller degree of refraction than those which constitute the orange tint, the latter are somewhat more refracted than the yellow rays, the refraction is greater in the other rays successively, and most considerable in the violet rays, which therefore form the colour of the superior band of the spectrum.

171. If after the solar spectrum has been rendered more distinct, by subjecting a beam of light to a lens before it is refracted by the prism, an aperture be made in the screen, on which it is received, opposite to any one of the coloured bands, a small pencil of light similar to that of the band will pass through, and if it be refracted by a second prism, and even again by a third, and then received on another screen, it will not be decomposed any further, but will produce a circular image of a uniform colour corresponding with that of the band of which it originally formed a portion.

172. By a similar method the various refrangibility of the dif-

In what circumstances in regard to direction do rays of light resemble currents of sound?

What directions do rays always pursue after refraction?

How are the differently coloured rays found to be constituted in respect to refrangibility?

Which colour is the *least* refrangible? which the *most*?

What effect is produced on any one of the coloured bands of the spectrum, by an attempt to decompose it by a second refraction?

* See Treatise on *Acoustics*, No. 58, 59.

† Euler's Letters to a German Princess. Ed. 1823. vol. i. p. 85.

ferently coloured rays may be further demonstrated. For this purpose it is only necessary to make the first prism revolve slowly on its axis, and thus each part of the spectrum will transmit its rays successively through the aperture in the first screen, and form a succession of little circular images on the second, traced at different heights, the violet colour appearing strongest, the red weakest, and the intermediate tints varying as they are nearer to one or the other. Thus may be produced an ascending or descending procession of images on the screen, by turning the first prism in one direction or the other.

173. Rays of light, when reflected, exhibit properties analogous with those which they show when refracted; those coloured rays which are most refrangible being also the most reflexible; so that the violet is reflected more readily than the indigo, the latter more than the blue, and the others in succession becoming less and less reflexible, and the red least of all. This order of reflexibility explains in some measure the azure tint of the heavens; for the atmosphere being a reflecting medium, those rays most subject to reflection, namely, those which are violet, indigo, and blue, are reflected most abundantly, and hence the appearance of the unclouded celestial vault. To a similar cause is to be attributed the bluish tints of distant mountains, often imitated with great effect by landscape painters, in the display of aërial perspective.

174. As the decomposition of solar light into variously coloured rays may be exhibited by the means already stated, so there are methods by which white light may be composed by uniting the different colours of the solar spectrum into one image. This may be most perfectly effected by causing the spectrum to pass through a convex lens, and receiving the image on a card or screen placed in the focus of the lens, where a circular disk of white light will be formed. A mixture of seven powders tinted as the prismatic colours, and in the proportions of the breadths of the several corresponding bands will produce a whitish compound; and seven coloured wafers fixed at proper distances on the border of a circular piece of pasteboard would, when it was whirled round, on a pin passing through its centre, display a wheel or circle of a hue more or less approaching to white.

175. Instead of reuniting all the rays of the prismatic spectrum by means of a lens, certain parts may be united, a screen being placed to intercept the others, when the image produced will not consist of white light, but of particular tints resembling some of the simple colours of the spectrum. Thus the yellow and the blue will form a green, the yellow and red an orange, or the red

How may the degree of refrangibility belonging to each colour be verified by a second refraction?

What order do the colours follow in the degree of their reflexibility?

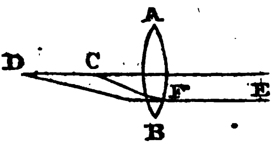
How is this principle applied to explain atmospheric and other colours?

How may a beam of white light be formed out of the constituent elements of different colours?

How may the compound colours be formed from the parts of the spectrum?

and blue a violet tint; but these artificial colours are distinguishable from the original colours corresponding with them by their susceptibility of decomposition into their constituent parts when transmitted anew through a prism. However, though certain colours thus reunited form coloured mixtures, there are other colours which when united by a second transmission through a convex lens reproduce white light; and these are termed complementary colours.

176. As the coloured rays that compose white light have different degrees of refrangibility, it follows that a pencil of rays of light, as E F, in the marginal figure, falling on a lens A B, the violet rays being the most refrangible will be brought to a focus sooner than the other rays, as at C, and the red rays which are the least refrangible will meet in a focus as at D, the intermediate rays meeting at relative distances between those two points. Hence the images which are formed at the focus of a lens will be surrounded by various colours constituting what is termed an iris. It is likewise obvious that those rays which enter the lens near its border will be more *dispersed* than those which pass through near its axis. Thus when an object is viewed through a single glass lens, the parts of it most distant from the centre will be deformed, and as just observed surrounded by a coloured irradiation.



177. It has been shown that rays of light in passing through different transparent mediums are more or less refracted or diverted from their original direction; and that the degree of refraction which light undergoes varies with the medium through which it passes. The manner also in which light is affected by being made to traverse a refracting substance the sides of which are not parallel to each other, as a prism of glass or crystal, has been stated; and the phenomenon of the production of coloured light, from the dispersion or analysis of the rays of white light has been generally illustrated.

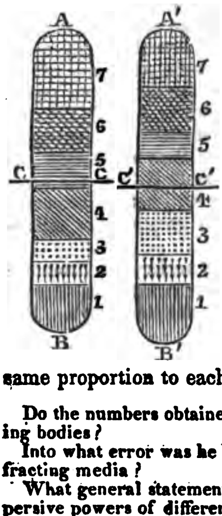
178. Sir Isaac Newton, in making his original experiments on solar light with a glass prism, ascertained that the relative breadths of the coloured spaces in the prismatic spectrum, supposing its whole extent to be divided into 360 parts, would be. for the red stripe, 45 parts; for the orange, 27; for the yellow, 48

Give some examples of this mode of producing intermediate colour.
What are meant by complementary colours?
What effect has the difference of refrangibility in the rays of light on the colour of an image formed behind a lens?
With what do such images appear to be surrounded?
What circumstance causes variations in the degree of refraction suffered by light?
What facts did Newton discover in reg[illegible] to the relative breadth of solar bands in the spectrum?

for the green, 60; for the blue, 60; for the indigo, 40; and for the violet, 80. These numbers, however, are by no means constant, depending on the peculiar nature of the refracting body employed to dissect a ray of white light; and it is a very singular circumstance, that though Newton made use of prisms composed of different substances in the prosecution of his researches, yet he neglected to observe that the dispersion or divergence of the differently coloured rays is greater when produced by one refracting medium than by another: he therefore erroneously concluded that the refractive and dispersive powers of bodies always corresponded; but that is far from being the case.

179. The effects of a considerable number of transparent solids and fluids on rays of solar light transmitted through them have been ascertained by Sir D. Brewster and other scientific inquirers, and tables of their dispersive powers have been constructed, from which it appears that the dispersive and the refractive powers of various bodies hold no definite proportion to each other.

180. The effect of prisms composed of different refracting substances on a ray of white light may be explained by reference to the following figures. Oil of cassia and sulphuric acid are transparent liquids which exhibit great diversity of dispersive power. Suppose A B to represent a spectrum, such as would be formed by transmitting a solar ray through a prism having its sides of glass, and filled with oil of cassia; and A′ B′, a similar spectrum produced by a prism filled with sulphuric acid. Then it will appear that the least refrangible colours, red, orange, yellow, numbered 1, 2, 3, will be more contracted in the spectrum A B, or that formed by the oil of cassia, than in A′ B′, or the spectrum formed by sulphuric acid; and that the most refrangible colours, blue, indigo, violet, 5, 6, 7, will be more expanded in the former spectrum than in the latter: the centre of one spectrum lying just within the blue space in the line C C, and in the other that line dividing the green space, but less unequally. Hence the coloured spaces bear not the same proportion to each other as the lengths of the spectra; and



Do the numbers obtained by him appear to be constant for all refracting bodies?

Into what error was he led in respect to the dispersive power of refracting media?

What general statement is true in regard to the refractive and the dispersive powers of different substances?

Construct and explain the diagram illustrating the difference between the dispersive power of a prism of sulphuric acid and one of oil of cassia.

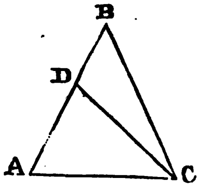
In which colour is the *centre of the spectrum* formed by the acid?

In which colour is the centre of that formed by the oil?

this want of correspondence is termed the irrationality of dispersion, or irrationality of the coloured spaces in the spectrum.

181. On this inequality of dispersive power among transparent bodies depends the construction of those optical instruments called achromatic,* or aplanatic,† telescopes; by means of which the coloured fringes and other defects in images formed by a single lens are removed, or prevented from interfering with the distinct observation of the object. The principle on which this is affected is by combining together refracting substances possessing different dispersive powers, in such a manner that the aberration caused by one shall be counteracted or neutralized by the opposite effect of the other.

182. Suppose a compound prism A B C, as represented in the diagram below, to be formed by joining two prisms A C D, and D C B, composed of the same substance; then if a ray of white light be made to fall on it, an image of the spectrum will be obtained, the colours of which will be less distinct than they would have been if the prism A C D alone had been employed, because the light decomposed by the first prism will be partially recomposed in passing through the second; and it would be entirely so, if B C were parallel to A B; because then the second prism having the same dispersive power as the first, would be so placed as to counteract its effect. If, instead of employing two prisms of the same kind, one of the prisms D B C, be composed of a substance the dispersive power of which is much stronger than that of the other, A D C, the rays dispersed in passing through the former prism will be re-collected by the second, and an achromatic prism will thus be formed. If the refringent power, likewise, of the prism D B C be the same with that of the prism A D C, the refraction will not be corrected; but if the refringent power of D B C is the greatest the refraction will be in some degree corrected.



183. It is practically impossible to form a perfectly achromatic prism, because the dispersive power of different transparent substances differs with respect to the differently coloured rays. But

What is meant by the *irrationality of dispersion?*

What advantage is derived from the knowledge of dispersive powers in the construction of optical instruments?

Explain the terms achromatic and aplanatic.

How may the dispersive power of a prism be counteracted?

Does it necessarily follow that the refractive effect must be overcome by a second refractor which restores the white colour of a previously refracted beam?

Why can we not form perfectly achromatic prisms?

---

* From the Greek α, *privative*, and χρωμα, colour: without colour.

† From α, *privative*, and πλανη, error or deception: without error.

the effect may be produced with regard to any two colours; and it is therefore usual to take the extremes of the spectrum, namely the red and violet, or the red and blue.

184. If, as Sir Isaac Newton too hastily concluded, the dispersive property and the refringent power had in all substances increased and diminished in the same ratio, the refraction, as well as the dispersion produced by one substance would be counteracted by another: the rays emerging after the double refraction would thus become parallel. It would hence have been impossible to achromatize a lens; for if a compound lens were formed by uniting a convex with a concave glass in such a manner that the rays should become deprived of colour after issuing from it, they would resume their original parallel direction: that is the colorization and the refraction produced by the convex glass would be destroyed both together by the concave one, and the rays could not, therefore, be united in a focus.

185. The effect of single convex lenses in producing an indistinct image with a coloured fringe, termed chromatic aberration, previously noticed, will be such that, "for parallel rays, the circle of least chromatic aberration, or of least colour, will have the same absolute magnitude, whatever be the focal length of the lens, provided the aperture remains the same. Now since in a telescope (with a given eye-glass) the image is magnified in proportion to the focal length of the object-glass, it follows, that by increasing the focal length the magnitude of the image increases, while that of the coloured border remains the same: by continuing, therefore, to increase the focal length we get an image so much magnified that the colour bears an insensible proportion to it. Hence, as long as simple lenses only were used, in order to correct the aberrations and secure a due quantity of light, it was necessary to have telescopes of very unmanageable length. Some of those constructed by Huyghens were of one hundred and even one hundred and fifty feet focal length."*

186. Newton, after numerous attempts to render refracting telescopes more portable and effective, found himself foiled, in consequence of the incorrect opinion he had formed concerning the correspondence of the dispersive with the refringent powers of bodies, and therefore inferring that "the improvement of the refracting telescope was desperate,"† he devoted his future attention

What would have been the success of such an attempt had Newton's supposition been true?

What is the effect of a single convex lens in producing an image?

In what proportion to the focal length of the object-glass will be the magnifying power of a telescope?

What inconvenience arose from the use of simple lenses in the construction of refracting telescopes?

---

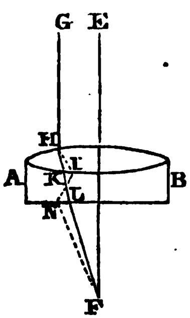
* Short Elementary Treatise on Experimental and Mathematical Optics. By the Rev. Baden Powell, M. A., F. R. S. Oxford, 1833. p. 101

† Optics. Lond. 1701, 4to. Part I. Prop. vii. Theor. 6.

to the construction of telescopes of a different kind, in which the images of objects are formed by reflection.*

187. But that which was despaired of by this great man has fortunately been accomplished by others. The merit of having first discovered the method of forming an achromatic refracting telescope appears to be due to Mr. Chester More Hall, a gentleman residing in Essex, England, who, about 1733, had completed several achromatic object-glasses, by the combination of lenses of different kinds of glass, having different degrees of dispersive power. In 1747, Leonard Euler published a paper in the Memoirs of the Academy of Sciences at Berlin, on the improvement of refracting telescopes. This attracted the attention of several philosophers to the subject, among whom was John Dollond, an eminent optician in London, who having fully ascertained the diversity of dispersive power in different substances, found that an achromatic lens might be formed by joining together crown glass, or that kind with which windows are glazed, with flint glass, or that of which cut-glass vessels and ornaments are made.

188. Peter Dollond, the son of the optician just mentioned, made a further improvement by forming an object-glass of three instead of two lenses, including a concave lens of flint glass between two convex lenses of crown glass. It is now, however, most usual to employ only two lenses, one, partly concave, of flint glass; and the other, double convex, of crown glass. These glasses have different curvatures, and are formed in such a manner that, after refraction, the red rays and the violet rays will become reunited at the same point: the intermediate rays will also be reunited at nearly the same point, it being impossible to reunite all the rays in precisely one point (as above stated), though they may be made to approach it sufficiently to prevent the usual effect of chromatic aberration.



189. In the marginal figure, representing the section of a compound lens, the ray E F falling on the centre of the lens A B, will pass through it without any alteration; but another ray G H falling on one side of the centre will be divided, and the violet ray, as being the most refrangible, will pass through the convex lens in the line H I, but the red ray in the line H K. The concave lens of flint glass will make both these rays diverge from the axis E F, the red taking the direction K L, and the violet the direction I N; and in passing again through the air to the focus, the red ray will take the direction L F, and

Who first succeeded in overcoming this difficulty? What two materials did Dollond employ for the formation of achromatic lenses?

* See subsequent part of this Treatise, relative to Optical Instruments.

the violet the direction N F: both consequently will be reunited at the point F.

190. Achromatic lenses thus constructed are still subject to imperfection, and hence subsequent attempts have been made to improve them, which have been attended with a considerable degree of success. Dr. Robert Blair, of Edinburgh, between 1787 and 1790, having conceived the idea of employing transparent fluids in the construction of compound lenses, at length succeeded, by inclosing muriatic acid, properly prepared, between glass lenses, in forming an object-glass by which the differently coloured rays were all bent from their rectilineal course with the same equality and regularity as by reflection. Other experimental philosophers have occupied themselves in analogous researches; and especially Mr. Barlow, of Woolwich, who has been very successful.* To the instruments thus constructed it has been proposed to apply the term *aplanatic*, or free from error, as possessing the utmost degree of accuracy.

191. Among the most interesting natural phenomena is that of the rainbow, the production of which wholly depends on the refraction and reflection of the sun's rays by clouds or drops of rain, and the consequent formation of prismatic colours; and the subject may therefore here be properly noticed. The bow in the heavens, as the French correctly term it (*l'arc-en-ciel*), is seen when the sun darts his rays on a cloud dissolving in rain, and the observer places himself opposite to it, with his back turned to the sun. Sometimes one bow only is perceived, but more usually there are two bows, the interior or lower one exhibiting brighter colours than the other, the tints of which are comparatively pale. Both present the colours of the prismatic spectrum; but in the interior bow the tints gradually ascend from the violet to the red, while in the exterior bow the violet is most elevated. Some writers remark that a third bow has been observed, but very rarely; and according to theory many bows must be formed, though all beyond the second must, in general, be utterly imperceptible.

192. The colours of the rainbow are the result of the decomposition of white light, in its passage through the globular drops of water forming a shower of rain. Each coloured ray produced

In what manner is it customary, at present, to arrange the parts of an achromatic lens?

Of what material is the double convex lens composed?

Which two rays are brought together at the focus of an achromatic lens?

Trace in the diagram the respective courses of the red and the violet rays.

What method was adopted by Blair and Barlow to form their aplanatic instruments?

On what principle is the rainbow formed?

In what order are the colours arranged in the double rainbow?

Whence do the colours of the celestial bow proceed?

---

* See Philosophical Transactions for 1828; or Abstract of Papers in Philos. Trans., vol. ii. pp. 333, 334.

by this decomposition traverses the globule, and is reflected in part at the opposite concave surface; it then traverses the globule again in a new direction, and presents itself to escape towards the observer. A part only, however, actually passes out, and the other part is again reflected and carried back into the interior of the globule. In this manner a multitude of successive reflections may be caused, at each of which some portion of the light will escape, but its intensity becomes more and more feeble with the increase of the number of reflections.

193. It is from those rays that thus first issue from the drop on the side towards which the observer is looking that the effect is produced. The rays which pass out from a globule after having suffered one or more reflections form a certain angle with their primitive direction. This angle is constant for all rays of the same nature that penetrate the globule at the same incidence, and which undergo within it the same number of reflections; but it varies for those rays the incidences of which are different, and which undergo a greater or smaller number of reflections.

194. It will appear from calculation that in a series of parallel rays of the same nature, which fall on a globule, and which undergo but one reflection within it, that the angle will be successively augmented, from the normal or direct ray, at which there will be no angle, to a certain limit, beyond which it will decrease till the ray becomes a tangent to the sphere or globule. Hence within those limits, the parallel rays entering the globule very near together, and undergoing deviation not very dissimilar, will remain sensibly parallel at their escape: and therefore an eye placed in the direction of such a bundle of rays will be affected with a sufficiently vivid sensation of colours; while elsewhere encountering only isolated rays, the sensation produced will be extremely inconsiderable. The rays which thus issue from a globule so as to form a small bundle capable of making a sensible impression, are termed *efficacious rays.*

195. It is the same with regard to rays which undergo two reflections, or a greater number, within the globule. There will always be certain limits within which several parallel rays, near together, issuing from the globule and remaining sensibly parallel, will produce a distinct sensation on the eye. These limits are not the same for all kinds of coloured rays, but vary with their refrangibility. Thus, with respect to the red rays, which are the least refrangible, when the ray issues after one reflection, it makes with the incident ray an angle of 42° 2′; this angle is succes-

How many reflections occur before the light leaves a drop of water to pass to the eye of the observer in constituting the primary rainbow?

What general fact can be stated in regard to the angle formed by rays passing out of a drop of water after undergoing one or more reflections?

What is meant by the *normal ray* in a beam of light?

Which of the rays reflected from rain-drops are termed *efficacious?*

What causes the difference in the position of the several sets of *efficacious rays?*

What angle with the incident ray, does the *efficacious red ray make?*

sively smaller for the other coloured rays, to the violet, which is the most refrangible, and for which it is 40° 17′. When the emergent ray undergoes two reflections in the interior of the globule, the limit in the case of the red rays will be at an angle of 50° 57′, and in the case of the violet rays, at an angle of 54° 7′.

196. The formation of the coloured bands of the rainbow may be thus explained: the sun, considered as a simple luminous point at an infinite distance, transmits to the shower a bundle of rays, of which each globule of water receives some. Hence on each of the globules fall some efficacious rays, which pass off to observers at different points. Thus, the first coloured ray which can come to an observer, after a single reflection in the globule, will be that which makes the smallest angle with its original direction; and will therefore be the violet ray, of which the angle is 40° 17′.

197. All the globules situated in the same circle, to the centre of which the axis of the bundle is incident, will produce the same sensation, and consequently form the first coloured line. The efficacious red rays which form with their original direction an angle of 42° 2′, will produce the last or highest line of the first bow; and between these extremes there will be the five other colours of the prismatic spectrum, in the order of their refrangibility. Such is the mode of formation of the first or principal bow: its dimensions will be the difference between 40° 17′ and 42° 2′, and therefore equal to 1° 45′.

198. Beyond the red rays the observer will only perceive those which have undergone two reflections, and their intensity will consequently be more feeble. The first rays in this case will now be the red, which make the smallest angle, equal to 50° 57′; forming the commencement of a secondary bow, at a distance from the first, corresponding with the difference between 42° 2′ and 50° 57′, and therefore equal to 8° 55′. The last or highest line of the second bow will be the violet, of which the rays will make with their original direction, an angle of 54° 7′, and between these extremes will be found the other colours. The dimensions of the second bow will be 54° 7′—50° 57′=3° 10′.

199. It may readily be understood from the preceding observations how three or more bows may be formed by successive re-

What angle is made by the *efficacious violet* with the incident ray, after a single reflection?

What are the angles respectively for these two rays after undergoing two reflections?

How is the formation of coloured bands in the rainbow explained?

What is the necessary limit to the breadth of the interior or *primary* bow?

What rays will come to the eye of the spectator beyond the red ray of that bow?

What order of colours will be observed in the exterior bow?

What is the breadth of band between the two bows?

What is the breadth in degrees of the secondary bow?

flections; and why also they must be too faint to be perceptible.* We have supposed the sun reduced to a luminous spot, and thus a circular line only of each colour would be produced; but as the sun has a sensible diameter, it follows that each band of the bows must have certain dimensions depending on the apparent diameter of the sun.

200. Lunar rainbows occasionally occur, but in most cases they are faint or colourless, from the inferior intensity of the moon's reflected light. Coloured halos are also sometimes seen, but they are among the more unusual meteorological phenomena. Clouds of rare colours, as green, have been noticed by some observers;† and the effect may be traced to the same causes with the more frequent and beautiful rainbow.

Why are not lunar bows generally distinguishable?

What other phenomenon analogous to the rainbow is occasionally observed in the atmosphere?

---

* Under peculiar circumstances, more than two rainbows, or rather iridiscent circles, may be formed by the refraction of the sun's rays, so as to be distinctly visible. A remarkable instance of such a phenomenon is related by Professor Winkler, from "L'Histoire General des Voyages," as occurring to the French and Spanish philosophers who were employed, in the last century, in measuring a degree of the meridian, in Peru. "As Don Antonio de Ulloa was with the French Academicians on the high and desert mountain of Pambamarca, in the kingdom of Quito, each of them saw his own image over against the side on which the sun rose, as in a mirror, and the head of each image encompassed with three rainbows, having all one and the same centre. The last or outmost colours of the one rainbow touched the first of the following. And externally, round all the three circles, but at some distance from them, a fourth bow appeared, which showed white only. When one of the spectators moved from one side to the other, the whole appearance followed him, in the like form and order. And though the observers were six in number, and stood quite close together, yet each could see only his own image, and not those of the others. As the figures of their bodies were portrayed in the middle space of the encompassing rainbow, the vapours of this space must have been in the state for the incident and reflected rays to form equal angles."—*Elem. of Nat. Philos. Delin.*, vol. ii. pp. 63, 64.

† The following instance of the occurrence of this phenomenon is derived from a diary kept by the person who witnessed it: December 24, 1812. Just before sunset, I observed a line of clouds, situated above the sun, tinged of a most beautiful pea-green colour. Above and below the green clouds were situated clouds of a dusky purple hue, intermixed with narrow stripes of orange. As the sun was sinking below the horizon the green belt of clouds became gradually lighter; and when the orb of day ceased to be seen, the green tinge also vanished. This appearance continued about a quarter of an hour."

Musschenbroek notices the occurrence of green clouds, and observes that "such were seen by Frezier, and are described in his 'Voyage to the West Indies.'"—*Elem. of Nat. Philos.*, translated from the Latin, by Colson. 1744. vol. ii. p. 241.

Colours of thin Plates.

201. The phenomena of coloured rings observed in the simple experiment of blowing bubbles of soap and water; in thin films of oil of turpentine or other essential oils floating on water; on the surface of polished steel when heated; and in general in thin plates of transparent substances, as quartz, Iceland spar, and mica, are extremely curious, as exhibiting a peculiar mode of the decomposition of white light. It may be most conveniently studied by examining what takes place when a very thin stratum of air or any other fluid is confined between two plates of glass; and the experiment may be advantageously made by placing a convex lens of small curvature upon a concave lens of a radius somewhat greater, and on pressing them together the colours will appear arranged in the form of rings round a central spot, which if the pressure be sufficiently powerful will be perfectly black, when viewed by reflected light, but when examined by transmitted light, as by looking at the sky through the glasses, instead of placing the eye between the light and the reflecting surface, the central spot will be white, and be surrounded by rings, the colours of which will be complementary to those seen by reflection. Hence it appears that the colours seen by reflection and by transmission of white light through thin plates, are those which form the greatest contrasts with each other.

202. The coloured rings are seen in the following order, proceeding from the centre to the circumference, forming different series of tints.

Colours of thin plates viewed by reflection.

1st series. BLACK, *blue*, *white*, *yellow*, *orange*, *red*.
2d series. *Violet*, *blue*, *green*, *yellow*, *red*.
3d series. *Purple*, *blue*, *green*, *yellow*, *red*.
4th series. *Bluish-green*, *red*.

Colours of thin plates viewed through the glasses.

1st series. WHITE, *Yellowish-red*, *black*, *violet*, *blue*.
2d series. *White*, *yellow*, *red*, *violet*, *blue*.
3d series. *Green*, *yellow*, *red*, *bluish-green*.
4th series. *Red*, *bluish-green*.

Under what different circumstances are transparent bodies capable of exhibiting coloured rings?

How is the appearance most conveniently studied?

In what different positions must the eye be placed with reference to the glasses to observe the two different classes of phenomena?

Of what colour is the central point in two conjoined lenses when it is viewed by transmitted light?

What difference do reflected and transmitted light respectively produce on every ring of the coloured surface?

What is the order in each of the four series of colours when viewed by reflected light?

What is it when viewed by transmitted light?

203. These tints are none of them identical with the simple prismatic colours. Sir J. Herschel observes, respecting the reflected colours, that "the green of the third order (or series) is the only one which is a pure full colour, that of the second being hardly perceptible, and of the fourth comparatively dull, and verging to apple-green; the yellow of the second and third orders are both good colours, but that of the second is especially rich and splendid; that of the first being a fiery tint passing into orange. The blue of the first order is so faint as to be scarce sensible, that of the second is rich and full, but that of the third much inferior: the red of the first order hardly deserves the name, it is a dull brick colour; that of the second is rich and full, as is also that of the third; but they all verge to crimson, nor does any pure scarlet or prismatic red occur in the whole series."*

204. The breadths of the rings are unequal, becoming narrower and more crowded, as they recede from the centre; and the extent of the rings or circles depends on the curvatures of the glasses between which they are formed. In order to make experiments with accuracy a proper apparatus is requisite. That used by Sir Isaac Newton, in experiments on this subject, consisted of a plano-convex lens, the radius of the convex surface of which was twenty-eight feet, and a double convex lens, the radius of whose surfaces was fifty feet; and the latter being placed on the convex surface of the former, they were held together, with any required degree of pressure, by three pairs of screws, fixed at equal intervals on their borders.

205. The colours may be shown by reflected light, by pressing together with the fingers a concave and a convex glass slightly differing in curvature, that of the former having the largest radius; but it is impossible by this means to maintain equable pressure, and the figures become distorted from circles into irregular ovals, or angular lines. Hence it will be obvious that no correct observations can be made on the dimensions of the coloured rings, unless the glasses can be subjected to uniform pressure. It is also necessary that the eye of the observer should always be similarly placed, or at the same angle of obliquity; for if the obliquity be changed,

How do the colours correspond with those of the prismatic spectrum? Which of the reflected colours is perfect in its kind?

What relations have the breadths of the several rings to their distance from the common centre?

On what do their actual breadths depend?

What were the forms and curvatures of the lenses used by Newton in experiments on coloured rings?

In what simple manner may the rings be exhibited by reflected light?

How must the apparatus be arranged and secured, in order to a correct appreciation of the nature of the rings?

What precaution is necessary in regard to the eye of the spectator? Why?

---

* Encyclopæd. Metropol.—Mixed Sciences, vol. ii. p. 458.

by elevating or depressing the eye or the glasses, the diameters (but not the colours) of the rings will change.

206. It is of importance to the explanation of this phenomenon to ascertain the thicknesses at which the respective tints, or the several points of greatest brightness and greatest obscurity occur. This may be done by means of Newton's apparatus; for the coloured rings being perfectly regular, by exactly measuring their diameter, may be found the thickness of the plate of air corresponding to each of them; for the interval between a plane and a spherical surface, the centres of which are brought into contact, will increase in the ratio of the squares of the distances from that point of contact.

207. Hence Newton found that in the most brilliant parts of the circles the thicknesses followed the progression 1, 3, 5, 7, 9; while in the darkest parts, commencing with the centre, they followed the progression 0, 2, 4, 6, 8. The same philosopher ascertained that when water is substituted for air between the glasses, the proportions of the diameters of the rings will be the same, but they will be relatively smaller; whence it follows that the plates of water reflecting any given colours must be more attenuated than those of air. It further appears that glass plates, to reflect the same colours, must be thinner than those of water; and it may be generally concluded that the thinness of the plates increases in proportion to the density of the bodies of which they are composed, or rather in proportion to their refracting powers.

208. Air in a plate but half a millionth of an inch in thickness ceases to reflect light; and the same is the case with water at three-eighths of the millionth of an inch, and with glass at one-third of the millionth of an inch. A plate of air two millionths of an inch in thickness, exhibits what Sir I. Newton terms "the beginning of black." A plate nine-millionths of an inch reflects the red of the first circle or series; one nineteen-millionths of an inch the red or scarlet of the second series; and tables have been calculated of the thicknesses of plates of air, water, and glass respectively, for each colour of each of the four series given above, and also for those of three more series, which may be observed extending in narrower circles beyond the preceding. Air seventy-

How may we ascertain the thickness of those plates of air which produce the different rings?

In what ratio do the distances between a plane and a sphere to which it touches, increase from the tangent point?

What did Newton ascertain to be the relative thicknesses of the strata at the brightest parts of the rings?

What progression of numbers represents the thicknesses of the darkest rings?

What law did Newton find to prevail when the space between his lenses was filled with *water* instead of *air?*

What result was given by *glass?*

What general conclusion was derived from a trial of various substances?

How much must the plates of each substance be diminished before they lose the power of reflecting light?

seven-millionths of an inch in thickness reflects a reddish-white colour, forming the boundary of the seventh or outer circle; and beyond that thickness it reflects quite white or undecomposed light.

209. As to the cause of the coloured rings formed by thin plates, Newton proposed an explanation founded on the doctrine of the emanation of light as consisting of molecules traversing space; and his hypothesis is deserving of notice as being in some degree applicable to the undulatory theory, which represents light as arising from the vibrations of an ethereal medium.

210. Having ascertained from experiment that the different rays become reflected at the successive thicknesses 1, 3, 5, 7, &c., and transmitted on the contrary, at the intermediate thicknesses 0, 2, 4, 6, &c., he regarded these laws as resulting from a particular disposition of the luminous molecules, which he denominated "fits of easy reflection," and "fits of easy transmission." Thus he concluded that any ray would be thrown into a fit of easy reflection on falling on a plate the thickness of which was one of the terms of the series 1, 3, 5, 7, 9, &c.; 1 being the first or least thickness at which it became susceptible of being reflected; and on the other hand, a ray would be in a fit of easy transmission when the thickness of the plate was one of the terms of the series 2, 4, 6, 8, &c.

211. Thus far Newton's hypothesis is little more than an enunciation of facts, but he also conjectured that the fits of easy reflection and transmission might depend on a sort of magnetic polarity belonging to the particles of light; to which supposition, however, it does not appear that the illustrious author himself attached any great importance.

212. According to the undulatory theory both of the surfaces of the thin lamina are concerned in the production of the colours; and the interference of the light reflected from the second surface with the light reflected from the first interrupts or facilitates the passage of the ray at certain intervals of thickness of the plate.*

213. "The colours of natural bodies in general are the colours of thin plates, produced by the same cause which produces them in thin laminæ of air, glass, &c.; viz., the interval between the anterior and posterior surfaces of the atoms, which, when an odd multiple of half the length of a fit of easy reflection and transmission for any coloured ray moving within the medium, obstructs its penetration of the second surface, and when an even, ensures it. The *thickness*, therefore, of the atoms of a medium, and of

What was Newton's explanation of the cause of coloured rings?
Explain by an example what he meant to express by "*fits* of easy reflection and of easy transmission."
On what what were the *fits* supposed to depend?
How is the undulatory theory applied to explain the coloured rings?
What is supposed to determine the colour reflected by surfaces receiving light with a perpendicular incidence?

* See Powell's Elem. Treatise on Optics, pp. 133—146.

the interstices between them, determines the colour they shall reflect and transmit at a perpendicular incidence. Thus, if the molecules and interstices be less in size than the interval at which total transmission takes place, or less than that which corresponds to the edge of the central black spot in the reflected rings, a medium made up of such atoms and interstices will be perfectly transparent. If greater, it will reflect the colour corresponding to its thickness."*

214. There are several very curious optical phenomena arising from the interference of the rays of light, besides the colours exhibited by thin plates; and among these may be included the variable colours of fine fibres and striated surfaces. "Fine fibres and striæ give beautiful colours by interference, when single, between rays reflected from their opposite sides; and when many are placed together, more complex colours are produced by their combined interferences.

215. "A striking example of this kind is seen in the *iris buttons*, invented by Mr. Barton, the surface of which is covered with minutely-engraved parallel lines, in some instances not more than one 10,000th of an inch apart. A phenomenon very similar is that of the colours exhibited by the surface of mother-of-pearl. This substance, when examined by a powerful microscope, is found to present a surface covered with minute striæ arranged in parallel waving lines."†

Double Refraction of Light.

216. Repeated instances have been already adduced of the appearance of double or multiplied images of bodies viewed through transparent media;‡ but these phenomena are all conformable to the common law of optics, which indicates the correspondence between the angles of incidence and of refraction or reflection, and the relation of their sines to each other.

217. There are, however, many cases in which a different effect is produced by the transmission of light through certain transparent substances, as some kind of salts and crystalline spars, plates

When would a medium be found perfectly transparent?

What other phenomena besides that of coloured rings depend on the interference of rays of light?

To what purpose in the arts has the colorific effect of grooved surfaces been applied?

What natural substance exhibits the effect of iridescence in consequence of possessing a striated surface?

In how many different ways may multiplied images be produced?

What is the peculiar effect of those substances which are denominated *double refracting*?

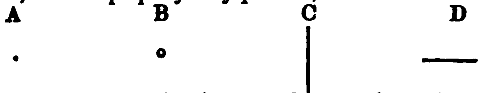
---

* Encyclopæd. Metropol.—Mixed Sciences, vol. ii. p. 580.

† Powell's Elem. Treatise on Optics, p. 150. See also Papers in the Philosophical Transactions, 1814 and 1829, by Sir D. Brewster; and Abstr. of Papers in Philos. Trans., vol. i. pp. 502—504; and vol. ii. pp. 378, 379.

‡ See 108, this treatise.

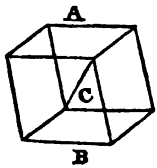
of which having parallel surfaces, when any object is viewed through them exhibit a double image, instead of a single one like similar plates of glass. Such bodies are called *doubly refracting substances*, and the property they possess, double refraction



218. This mode of refraction may be experimentally demonstrated by means of a small plate of Iceland spar, or crystallized carbonate of lime, not more than ¼ of an inch in thickness. If a plate of glass be placed over either or all the preceding figures, A, B, C, D, each will appear singly, as to the naked eye; but if a plate of Iceland spar be held above one of the figures, a double image will be perceived, as two dots, two circles, or two lines instead of one.

219. The distance between the two images will depend on the thickness of the plate of spar. If it be ¼ of an inch thick, the images will be so near together that the little circle B will look like a figure of 8. There is, however, another circumstance which will influence the relative separation of the images; and that is the position of the plate; for if it be laid flat on the paper and slowly turned round horizontally, one of the images will be perceived to revolve round the other; so that the circle will in one position appear thus 8, and in another thus ∞; and the lines will coalesce and diverge successively, as the plate is made to revolve.

220. In explanation of this phenomenon it may be stated that a ray of light on entering into the transparent spar becomes divided into two portions, one of which follows the ordinary law of refraction, as to the ratio of the sine of the angle of incidence to that of the angle of refraction, while the other undergoes a separate refraction, according to a new and extraordinary law. The Iceland spar consists of rhomboidal crystals, masses of which are always reducible by natural cleavage into exact rhomboids, having each of their faces equal and similar rhombs. These are the forms of the molecules into which the mass can be separated by continued subdivision; and in every one of these rhomboids the short diagonal is called the optical axis.



221. Thus in the annexed figure the diagonal line C represents the axis of the rhomboidal solid A B. Now if a ray of light is transmitted through a crystal in the line of its optical axis no double image will be formed, and the ray will be refracted simply according to the ordinary law of the proportional sines; for in this case the ordinary and extraordinary rays,

By what substance may this property be exemplified?
What kind of images are seen through plates of Iceland spar?
What circumstance determines the amount of separation?
On what do the relative positions of the two images depend?

as they have been termed, will coincide. But in all other cases the law is essentially different, the ray becoming divided, and one part of the pencil will be refracted, according to a law of a very singular and complicated nature.

222. A plane passing through the axis is called a principal section; and if a ray be incident, so that the ordinary refraction takes place in the plane of a principal section, then for all the incidences, the ordinary ray having its index of refraction constant, the extraordinary ray will also be in the same plane, though with an index of refraction which varies according to its position. If the ordinary refraction be in a plane perpendicular to the axis, the extraordinary ray will also in this case be in the same plane, and the index of refraction of the ordinary ray remaining of course constant, that of the extraordinary ray will also be constant.*

223. Hence it appears that both the ordinary and extraordinary rays have a certain relation to the optical axis of the crystal; "all the phenomena being the same, as though some power emanating from that axis had produced that extraordinary refraction, by separating a portion of the light from the original ray in its transmission through the prism, and attracting it towards the axis, or repelling it from it. Sometimes the extraordinary refraction is *negative*, or a deflection further from the axis, as in the Iceland spar; and sometimes it is *positive*, or a deflection nearer to the axis, as in common quartz crystal; but it is always with the axis that the angle of extraordinary refraction is made."†

224. A considerable number of crystalline substances are found to possess analogous properties, though with some modifications, depending on their peculiar structure. Thus some crystals have only one axis of double refraction, while others have two or more such axes. Dr. Brewster ascertained that all those bodies which crystallize in the form of the rhomboid, the regular hexaedral prism, the octaedron with a square base, and the right prism with a square base, have but one axis of double refraction; some, like the Iceland spar, having negative axes, as tourmaline, alum-stone sapphire, emerald, and phosphate of lime; while a smaller number, as quartz, zircon, and oxide of tin, have positive axes.

226. Among the crystals which have two axes of double re-

How is the phenomenon in question explained?
What is the form of crystal in the Iceland spar?
What is meant by the optical axis of such a crystal?
What is meant by its principal section?
How will the two refractions take place where the ordinary refraction is made the plane of a principal section?
How when it is made in a plane perpendicular to the axis?
When is the extraordinary refraction *negative*, and when *positive*?
How do crystals of different substances vary from each other in their doubly refracting power?
What forms of crystal have but one axis of double refraction?

---

* Powell's Elementary Treatise on Optics, p. 121.
† Readings in Science, p. 148.

fraction, are glauberite and sulphate of iron. But with respect to these bodies, as also the crystals with many planes of double refraction, and those with circular double refraction, the effects follow a very complicated law; and M. Fresnel made the remarkable discovery that in such cases neither of the images is refracted according to the ordinary law, but that both undergo a deviation from their original plane, exhibiting a sort of complicated double refraction.*

226. The property of double refraction was first discovered in the Iceland spar, by Erasmus Bartholin, a Danish philosopher, towards the close of the seventeenth century; it was particularly investigated by the celebrated Huygens; and the subject has in our own times acquired a peculiar interest in consequence of its intimate connexion with polarization.

227. Concerning the nature of *Polarization of Light*, we can only afford room for Sir David Brewster's concise account of the discovery of this property of light, which was made by M. Malus, colonel of the imperial corps of engineers, who, in 1810, published a most valuable memoir on double refraction, for which he gained the prize offered to the writer of the best work on that topic, by the Institute of France.

228. M. Malus, "having accidentally turned a doubly refracting prism to the windows of the Palace of the Luxembourg, which were at the time illuminated by the setting sun, he was surprised to observe that one of the double images of the windows vanished alternately during the rotation of the prism; and after various fruitless speculations on the cause of this singular phenomenon, he was conducted to the great discovery, *that light reflected at a particular angle from transparent bodies, is polarized like one of the rays produced by double refraction.*

229. "This singular result opened a wide field of inquiry to philosophers: and the successive labours of Malus, Arago, Biot, Fresnel, and Cauchy, in France; Seebeck and Mitscherlich, in Germany; and Young, Herschel, and Airy, in England—present a train of research 'than which,' as a distingnished philosopher remarks, 'nothing prouder has adorned the annals of physical science since the developement of the true system of the universe.'"†

What crystals have more than one axis of this kind?
What did Fresnel discover in regard to the two images formed by crystals with many planes of double refraction?
By whom was double refraction discovered?
From what is its greatest importance derived?
What investigation led Malus to the discovery of *polarization*?
What incident first opened the way to this discovery?
What is the general result at which he finally arrived?

---

* See Sir J. Herschel's Discourse on the Study of Natural Philosophy, pp. 30—33.

† Report on the recent Progress of Optics; by Sir D. Brewster, in Report of the British Association for 1832, p. 314. For further information

OPTICAL INSTRUMENTS.

230. There are two principal kinds of optical instruments; namely, those which may be more properly styled *dioptrical*, as they consist of one or more lenses, their effects depending on the refraction of light; and those called *catadioptrical* instruments, in the construction of which lenses and mirrors are combined, and hence telescopes of this description have been termed reflecting telescopes, to distinguish them from other telescopes, whose powers depend on refraction alone.

231. The perfection of these instruments must consist in the excellence of the lenses and mirrors of which they are formed, and of the accuracy of their arrangement, so that the axes of the respective glasses may be situated in a right line. They must be placed one behind the other, at distances exactly calculated with reference to their several foci. The eye must also be placed at a fixed point for observation. That lens in a telescope or microscope which is nearest the observer is named the eye-glass; and the lens or mirror which is turned towards the object to be examined is named the object-glass. The eye-glass is usually fixed in a tube, and so arranged that its distance from the object-glass may be varied according to circumstances.

Spectacles.

232. The employment of convex or common spectacles, or at least of single convex glasses to assist the sight, must have been coeval with the knowledge of the magnifying power of convex lenses. The invention of spectacles has been ascribed by some to Alessandro Spina, an Italian, who died in 1313; * and according to others the inventor was a Florentine nobleman, named Armato Salvini, who died in 1317.† It may not improbably be inferred, from these statements, that the mode of adapting two convex lenses to a frame, so as to form a pair of spectacles, originated about the close of the thirteenth century. But the magnifying

Into how many classes are optical instruments divided?
On what principles of construction is this distinction founded?
On what does their excellence depend?
In what positions must the several glasses of a telescope be placed in respect to each other?
What names are given to the several glasses?
At how early a period were spectacles invented?

relative to Double Refraction and Polarization of Light, the reader is referred to the Treatise on those subjects published by the Society for the Diffusion of Useful Knowledge; and to the very valuable Essay on Light, by Sir John Herschel, in the Encyclopædia Metropolitana, of which a French translation, enriched with Notes, by MM. Verhulst and Quetelet, has been printed at Paris.

* V. Redi Epistola ad Falconerium.

† V. Acta Lipsiensia, Ann. 1740.

properties of convex lenses or some similar transparent bodies was certainly known at an earlier period, though we are ignorant of the precise manner in which they were used.

233. There is a very remarkable passage in a treatise of Roger Bacon on "The Secret Works of Art and Nature," in which he says, "Transparent bodies may be so figured that one thing may be made to appear many, and one man an army; and several suns and moons may be rendered visible at pleasure. * * * * * * Thus also things which are afar off may be brought near, and on the contrary; so that from an incredible distance we might read very small letters, and distinguish the numbers of things collected together, though extremely minute; and make the stars appear when we please.* Thus it is thought that Julius Cæsar, from the sea-coast of Gaul, observed by means of very large glasses (*specula*), the disposition and site of the camps and towns of Britannia Major."†

234. This celebrated writer also thus expresses himself relative to the refraction of light, in his "Opus Majus:" "Greater things than these may be performed by refracted vision. For it is easy to understand, by the canons before-mentioned, that the greatest things may appear exceedingly small, and contrarily. For we can give such figures to transparent bodies, and disperse them in such order, with respect to the eye and the objects, that the rays shall be refracted and bent towards any place we please, so that we shall see the object near at hand, or at a distance, under any angle we please; and thus from an incredible distance, we may read the smallest letter, and may number the smallest particles of dust and sand, by reason of the greatness of the angle under which we may see them: and on the other hand, we may not be able to see the greatest bodies close to us, by reason of the smallness of the angle under which they may appear. For distance does not affect this kind of vision, except by accident, but the quantity of the angle does. And thus a boy may appear to be a giant, and a man as big as a mountain; because we may see a man under as large an angle as the mountain, and as near as we please. And thus a small army may appear to be a very great one, and though very far off, yet seem very near us; and contrarily. Thus likewise the sun, moon, and stars may be made to descend hither in appearance, and be visible above the heads of our enemies; and many things of a similar nature may be effected which would astonish unskilful persons."

235. From the manner in which Bacon, in the preceding passages, notices the effects of refracting substances in modifying the

What evidence is derived from ancient authors, proving that lenses were known before the invention of spectacles?

---

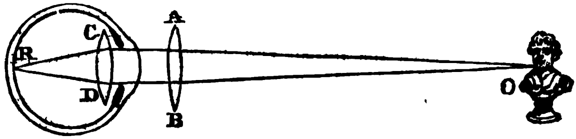
* This must apparently be understood of a telescope, or some such instrument, by means of which the stars may be seen in broad daylight.

† Epist. Fr. R. Bacon, de Secretis Operibus Artis et Naturæ, et de Nullitate Magiæ. Hamburg. 1572. Cap. 5. *De Experientiis Perspectivis Artificialibus.*

power of vision, it can hardly be doubted that single lenses, at least, were sometimes used for other purposes than those of mere experiment; though the general employment of spectacles to assist the visual organs of aged persons or others, may be dated from the beginning of the fourteenth century, or just after the period when they are said to have been invented at Florence.

236. There are two distinct kinds of spectacles, namely, those with convex glasses, which magnify objects, or bring their images nearer to the eyes; and those with concave glasses, which diminish the apparent size of objects, or extend the limits of distinct vision.

237. In old persons the transparent cornea becomes more flattened than in youth, and probably the crystalline humour undergoes a corresponding alteration, in consequence of which the rays coming from objects do not converge to a focus, so as to form a distinct image on the retina, unless they are relatively at a considerable distance from the eye. Hence it happens, as may be often observed, that aged persons when they attempt to read or examine a minute object, without spectacles, are usually obliged to hold the book, letter, or other object at arm's length. Such long-sighted individuals are termed *presbytes*.* The manner in which they may be assisted by convex glasses may be illustrated by the annexed diagram.



238. Let C D be supposed to represent a section of the crystalline lens, and A B a similar section of a spectacle lens, then the object O, at about six inches from the eye, will form a perfect image on the retina, at R; but if the latter lens be removed, the object at the same distance will become confused, and in order to obtain a proper view it must be withdrawn to treble or perhaps four times that distance, and if it be very small, the unassisted eye may not be able to distinguish it at any distance.

239. Those called short-sighted persons are such as have the transparent cornea unusually prominent, and therefore the rays

How are we to suppose that single lenses had been used before the time of Bacon?

How many kinds of spectacles are employed?

What is the effect on the size and apparent distance of objects of those which have convex glasses?

What is the effect of concave spectacles?

What parts of the eye undergo changes from age?

To what expedient do persons thus affected have recourse in reading?

What form of spectacle lenses do these changes render necessary?

Explain the figure illustrating the effect of such lenses.

* From the Greek Πρεσβυς, an old man.

from objects entering their eyes converge to a focus before they reach the retina, unless any object be placed very near the eye.* Where this peculiarity of vision exists but in a slight degree, it is rather an advantage than otherwise, as the individuals are thus gifted with a kind of microscopic sight; for they can see smaller objects than are commonly discerned by others, and are merely obliged to hold them relatively nearer to the eye. Distant objects, however, can only be seen confusedly; and hence the advantage such persons derive from concave spectacles. The nature of the assistance which these glasses afford will appear from considering the following diagram.

240. Let C D, as before, represent a section of the crystalline lens, then the rays from the object O will be rendered somewhat divergent in their passage through the concave glass A B, so that the effect of the prominent cornea on them will be diminished, and they will form a perfect image on the retina at R; whereas if the concave glass were removed, the rays would come to a focus before they reached the retina, and diverging again the image would be confused.

241. Common convex spectacles and reading-glasses, especially if they magnify considerably, have the defect of deforming more or less objects not viewed through the centre of the lens. For the rays which issue from distant objects and reach the eye through the borders of a lens, falling on it obliquely, are more refracted than the other rays, and hence the images become confused. To remedy this inconvenience Dr. Wollaston proposed employing concavo-convex lenses, with the concave sides turned towards the eyes; and spectacles thus constructed, called periscopic† spectacles, if accurately made, and adapted to the peculiar degree of long-sightedness which they are intended to relieve, will be found far superior to those constructed as usual with double convex lenses.

What is the cause of short-sightedness?
What advantage is possessed by short-sighted persons?
What inconveniences do they suffer?
Where is the image formed in the eye of a short-sighted person?
Draw and explain the diagram illustrating the effect of concave spectacles.
What defect have convex spectacles of high magnifying power?
How did Dr. Wollaston propose to remedy this defect?

* Short-sighted persons are called in Latin *Myopes*, from the Greek Μυω, to wink or half-shut the eyelids, and Ωψ, the eye.

† From the Greek Περι, about, around, and Σκοπεω, to look.

242. The Esquimaux, inhabiting a country covered with snow, would be subject to a weakness of vision approaching to blindness but for the method they take to guard their eyes from the constant stimulus of the bright white light reflected from the objects around them. For this purpose they use a sort of spectacles which they call *snow-eyes*, formed of small pieces of wood or bone, with a narrow slit in the middle, which are fixed near the eyes, by strings or thongs passing round the head, so that no light can reach the eyes, except that which enters through these apertures. These rude instruments not only protect the wearers from the excess of light, but also enable them to distinguish more readily distant objects.*

243. Persons whose sight is so much impaired that they find spectacles nearly useless may derive great benefit by viewing objects through conical tubes without glasses, but having only a small aperture at the end furthest from the eye, and blackened in the inside. Such tubes may be fitted into a frame and worn like spectacles; and they may be rendered more serviceable by being so constructed as to be lengthened or shortened, and have the apertures enlarged or diminished at pleasure.

The Microscope.†

244. The transition from the use of a single lens to assist vision to that of combinations of lenses for viewing small objects may be conceived to be by no means difficult; yet it appears that three centuries elapsed between the invention of spectacles and that of the microscope. Huygens attributes the invention of the latter instrument to Cornelius Drebbel,‡ about 1621; others to the famous Galileo, or to F. Fontana, a Neopolitan; and it is extremely probable that the idea may have occurred to different persons engaged in scientific pursuits, about the same period.

245. The simple microscope is merely a single convex lens of high magnifying power; and it may consist of a globule of glass, formed by holding a small fragment of flint glass on a piece of iron wire, flattened at the end, in the flame of a spirit-lamp, and letting it drop, when fused, on a sheet of paper placed to receive it. The globule must then be fitted into an aperture drilled in a small plate of brass; or if the glass fragment be placed in the first instance over such an aperture in a thin plate of platina, it

What expedient do the Esquimaux adopt to screen their eyes from the excessive light reflected from the snow?

What expedient may be adopted when the eyes are too much weakened to be aided by spectacles?

How long did the invention of spectacles precede that of microscopes?

To whom has the invention of the microscope been attributed?

What is the construction of the single microscope?

How may lenses for such a microscope be constructed?

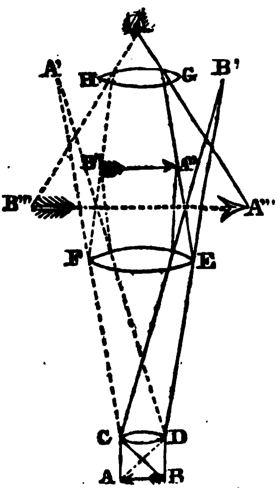
---

* V. Sigaud de la Fond Elem. de Phys., t. iv. p. 192.

† From the Greek Μικρος, minute, and Σκοπεω.

‡ See Treatise on *Pyronomics*, No. 51. Huygens Dioptrica, p. 221.

may be fused by exposing it to the flame, and becoming fixed in the little hole, it will form a microscope ready mounted. Such microscopes must necessarily have very short foci, and can therefore be used only for examining extremely minute objects. The magnifying power of lenses are inversely as their focal lengths: thus a convex lens whose focal distance is 2 inches, will increase the linear dimensions of the image of an object 5 times; and a lens the focal distance of which is 1-10 of an inch will magnify an object 100 times as to linear extent, and 10,000 times as to superficial extent.



246. The compound microscope must consist of two or more convex lenses. The object-glass is a small lens of very short focus; and there may be one or several eye-glasses. Among the most usual forms is the microscope with three glasses: but various modifications have been adopted, with a view to the improvement of these instruments, by forming both the eye-pieces and the *objectives* of two or more glasses.

247. The effect of the compound microscope may be described by means of the accompanying diagram, which represents the object A B placed a little beyond the object-glass C D; then the rays issuing from it would form an image at A′ B′, while the lens E F diminishes the convergence of these rays, whence it follows that the image is formed at A″ B″. This latter image becomes the immediate object of vision, seen by the eye through the lens G H, and therefore at A‴ B‴, greatly magnified.

*The Telescope.**

1. REFRACTING TELESCOPES.

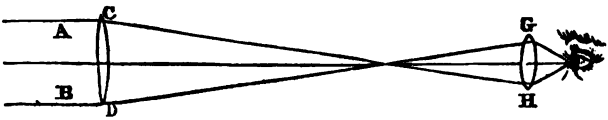
248. The invention of the telescope is usually stated to have taken place about 1590; but it is manifest from the writings of

To what purpose is the use of a microscope thus constructed necessarily limited?
Of how many lenses must the compound microscope be composed?
Which is the more common form of this instrument?
Draw and explain a diagram representing the essential parts of the compound microscope.
What is the purpose of the second lens?
In what position is the image seen with reference to that of the object?
How early did the invention of the telescope occur?

* From the Greek Τηλε, afar, and Σκοπεω.

Roger Bacon, already referred to, as well as from other sources of intelligence, that the effect of combinations of optical glasses must have been ascertained by experiment, long before that period, though the arrangement of them so as to form telescopes, and their general application to the purposes of science may be dated from the time just mentioned. Accident is supposed to have led to the discovery of this important instrument, which has been variously attributed to Zachary Jansen, or to John Lippersheim, who were Dutch spectacle-makers; and the improvements made on these perspective as they were styled, by Galileo, John Baptist Porta, Simon Marius, and others, may account for their being sometimes represented as the inventors of the telescope.

249. The most simple kind of refracting or dioptrical telescope is that termed the astronomical telescope, consisting of two convex lenses, an object-glass and an eye-glass, the foci of which concur in the same point



Let A B represent rays from some distant object, as a star, then the image formed by the object-glass C D, being viewed through the eye-glass G H, will have its apparent diameter magnified accordingly. Thus, if the object-glass have a magnifying power equal to 10, and that of the eye-glass be equal to 6, the object will be magnified to $10 \times 6 = 60$ times. With such a telescope the image will be formed inverted with respect to the object; but as it is only used, as its name implies, for surveying celestial bodies, this defect is of no importance.

250. The terrestrial telescope invented by A. de Rheita, differs from the preceding in being furnished with two additional eye-pieces, so that it has in all four glasses; and thus the images of objects appear erect, and the instrument is adapted for viewing ships, buildings, &c.

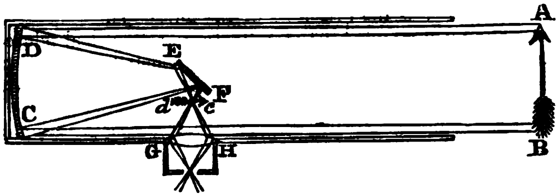
251. The effect of common lenses in producing spherical and chromatic aberration, and the consequent imperfections of such telescopes as those just described, have been already pointed out; as also the methods of correcting such errors, with reference to the principles on which achromatic lenses are constructed; and therefore the subject need not here be further noticed. For the description and developement of the properties of various modifi-

What name was given to the original instruments?
What is the simplest form of the instrument?
Represent this by a diagram.
How will the magnifying power of the simple telescope be computed?
How will the image be situated with respect to its object?
How does the terrestrial telescope differ from the celestial?
What is the purpose of the two additional glasses in this instrument?

cations of dioptrical telescopes, we must refer the reader to the works mentioned at the end of this treatise.

II. REFLECTING TELESCOPES.

253. Newton, as elsewhere stated, despairing of the discovery of a method of forming achromatic lenses, directed his attention to the improvement of the catadioptric telescope, invented by Professor James Gregory, in which an image formed by means of a concave mirror, or speculum, is viewed, after a second reflection, through a convex lens or eye-glass.



254. The preceding diagram shows the general construction and effect of the Newtonian reflecting telescope, in which the concave metallic speculum C D receives the rays issuing from the object A B, which it renders convergent, and thus forms a reversed image in the plane mirror E F, inclined at an angle of 45 degrees; and this image being reflected to *d c*, at the focus of the lens or eye-glass G H, is seen through the aperture before it by the observer.

254. In the original or Gregorian telescope, the image is viewed by looking towards the object, as in the refracting telescope; and there are other modifications of this instrument, as those of Cassegrain and Herschel; for descriptive notices of which the works mentioned at the end of the treatise may be consulted.

The Camera Obscura.

255. The manner in which images may be formed in a camera obscura, or darkened chamber, has been already described; but there is an instrument in a portable form, and adapted for immediate use, which bears the same designation, as its effects depend upon the application of the same principle to practice. There are also various modifications of the portable camera obscura, among the more convenient of which is that represented in the annexed figure.

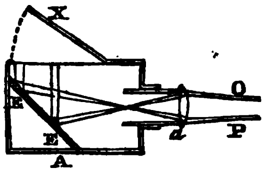
What led Newton to the examination and improvement of the Gregorian telescope?

What is the nature of that instrument?

Explain the diagram relating to the Newtonian modification of Gregory's instrument.

How is the portable *camera obscura* constructed?

What is employed as a screen to receive the images in this apparatus?



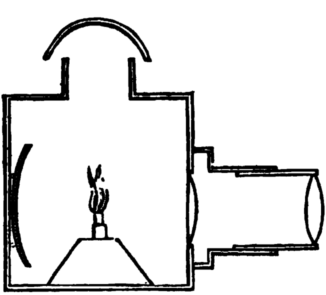
256. It consists of a square box A, with a circular aperture in front, into which is fitted a short tube, *a*, having at its extremity a convex lens. This tube is made to slide backward or forward, so that it may be adjusted to the proper point for near or distant objects. Then the rays O P, preceeding from any object passing through the lens, will form an inverted image in the posterior focus of the lens, which being received on a reflecting mirror E, inclined at an angle of 45 degrees, will be thrown on a plate of ground glass at the top of the box. The image thus formed may be traced on the rough surface of the glass, by a black lead pencil or crayon of red French chalk, and afterwards taken off on paper; or the figures may be drawn on tracing-paper placed on the ground glass, through which they will be readily perceptible. The lid of the box, X, has two side wings, which being raised when the instrument is in use, will exclude the superfluous light, and thus render the images distinct.

257. The *camera lucida*, invented by Doctor Wollaston, is an instrument analagous in its effects to the preceding, but of smaller dimensions, and therefore more convenient for many purposes, as for delineating distant objects, and for copying or reducing drawings. It consists essentially of a quadrangular glass prism, by which the rays from an object are twice reflected, and thus form an image on a plane placed below it. The prism is fitted horizontally to an axis on which it turns, so that it may be placed in a proper position; and the brass frame of the instrument has usually two lenses adapted to it, a concave and a convex one, the former to be used by short-sighted persons, and the latter for long-sights. There are various improvements and modifications of the camera lucida, the best of which appears to be that contrived by Signor Amici.

The Magic Lantern.

258. As an amusing as well as instructive optical machine, there is hardly any superior to the magic lantern, invented by Father Kircher. It is composed, as shown in the margin, of a square tin box, containing a lamp, behind which is placed a metallic concave reflector; and in front of the lamp is a plano-convex lens, which receives on its plane surface the reflected light of the lamp, and concentrates it on the object, which is mag-

How may the images be made permanent?
What purpose is effected by the lid and its sectoral side-pieces represented in the figure?
What are the essential parts of Wollaston's *camera lucida?*
By whom was the magic lantern invented?
What is the purpose of the mirror in this apparatus?
Which lens magnifies the image in this instrument?



nified by another lens fitted to the extremity of a tube projecting from the lantern. The objects are painted on thin plates of glass, which may be passed through a narrow opening in the tube between the two lenses. This tube must be double one end moving within the other, so that the tube carrying the outer lens may be drawn backward or forward, till the object is in the conjugate focus of that lens. Then if it be turned toward a vertical screen, a magnified image will be formed; and the further the lantern is withdrawn from the screen, the larger will the object appear; but when the distance is considerable it becomes indistinct.

259. Several years ago an exhibition took place, conducted by M. Philipsthal, and called the *Phantasmagoria*,* resembling in the general principle on which it was founded, the magic lantern, but rendered more imposing, by having the objects painted on a larger scale, and the figures being projected on a transparent curtain of gummed taffeta, by which the machinery was concealed from the spectators. Images to represent ghosts, skeletons, and other objects, singular or appalling, were thus displayed, and for a time formed an attractive source of popular amusement.†

The Solar Microscope.

260. This instrument differs from the magic lantern principally in the nature of the objects exhibited by it, and the manner in which they are illuminated. This purpose is effected by admitting the rays of the sun into a darkened room, through a lens placed in an aperture in a window-shutter, the rays being received by a plane mirror fixed obliquely, outside the shutter, and thrown horizontally on the lens. The object is placed between this lens and

On what are the objects painted?
What is the necessity for a sliding-tube in the magic lantern?
On what circumstance will the size of the image depend?
In what respects did Philipsthal's phantasmagoria differ from the magic lantern?
How are objects illuminated in the solar microscope?
By what means are the sun's rays rendered horizontal for the purpose of this exhibition?

---

* From the Greek Φαντασμα, a spectre, and Ἀγειρα, an assembly.

† See Young's Lectures on Natural Philosophy, 1807, vol. i.; Brewster's Natural Magic; and likewise the Repertory of Arts and Manufactures, First Series, No. 95, in which is a copy of the specification of the phantasmagorian machinery, for which M. Philipsthal took out a patent.

another smaller lens, as in the common microscope; and the magnified image thus formed is to be received on a screen, as in the case of the magic lantern. The mirror is sometimes kept in its due position to reflect the sun's rays in a constant direction by a species of clock-work called a *heliostat*.

261. Mr. George Adams, an eminent optician, invented an instrument, which he called the *lucernal microscope*, so constructed as that objects could be illuminated by the light of the lamp; and thus the microscope could be used at any time, or in any situation. An improvement on this mode of displaying highly magnified images of minute objects has recently been adopted, by employing the splendid light produced by the combustion of oxygen and hydrogen gases on lime; and instruments have been fitted up for public exhibition, presenting some of the most curious and interesting phenomena with which optical science has made us acquainted.

How can the beam of solar light be kept steadily on the object, since the sun is itself apparently in motion?

What is the peculiarity of the lucernal microscope?

How is the oxy-hydrogen blow-pipe applied to microscopic exhibitions?

Works in the department of Optics.

Powell's Treatise on Experimental and Mathematical Optics. Oxford. 1833.

Cambridge Physics, treatise on Optics, by Prof. Farrar.

Brewster's Treatise on Optics, with an Appendix by Professor Bache. Philadelphia edition, 1833.

Library of Useful Knowledge, treatise on Optical Instruments

Brewster's Treatise on New Philosophical Instruments.

Coddington's Treatise on Optics, part ii.

Loyd on Light and Vision.

Herschel's Treatise on Light.

Biot Traité de Physique, tom. iv

ELECTRICITY.

1. Among the physical sciences, there is, perhaps, no other so immediately and completely the result of the researches of modern, and especially of contemporary philosophers, as Electricity. It is true that the ancients were acquainted with one of its grand characteristic phenomena, namely, the property which some bodies, under certain circumstances, possess of attracting various other bodies. Thus Plato, Theophrastus, Dioscorides, Pliny the Elder, and other Greek and Roman writers, state that Amber* may be made, by rubbing it, to attract very light substances, much in the same manner as the loadstone attracts iron. They were even aware that a similar property belongs to jet, belemnite, the emerald, jasper, and some other precious stones.† And notices occur in the writings of the ancients concerning other natural phenomena now known to depend on electricity; but all these are reported as isolated facts, which they never referred to a common cause, nor proposed any theory to explain and illustrate them.

2. The first attempt towards a generalization of phenomena which had been so long before observed, and to so little purpose, was made towards the end of the sixteenth century, by Dr. William Gilbert, a physician who wrote a very curious and original treatise on the Magnet, and being led by analogy to make experiments on the attractive property of amber, he found that the power it possessed of attracting light substances, was one which might be induced by friction in several other bodies; and he therefore regarded it as originating from a common cause.

3. In the following century the subject was further investigated by Boyle, Otho Guericke, Sir I. Newton, and others; but though they accumulated facts, they were not such as were of a nature on which to found general principles; and what was known of electricity by no means deserved the appellation of science.

4. In the early part of the last century, Dr. Hauksbee, a physician, made many electrical experiments, from which he ascertained that glass was a substance in which the property of electric attraction could be most readily excited by friction; and that some other bodies, especially metals, treated in the same manner, manifested no electric power whatever.

What fact concerning electricity appears to have been known to the ancients?
From what does the science derive its name?
In how many substances had the ancients observed electrical properties?
Who first attempted a generalization of electrical phenomena?
What names occur among the cultivators of electricity in the seventeenth century?

---

* From Ηλεκτρον, the Greek name of Amber, the term Electricity is derived.

† V. Musschenbroek Institutiones Physicæ, 1748, 8vo, pp. 198, 199.

5. But the grand discovery, which led to the classification of all material bodies under two divisions, as being either conductors or non-conductors of electricity, was made by Mr. Stephen Grey, a pensioner at the Charterhouse, London, who died in 1736. This gentleman, having occupied himself with various experiments, partly suggested by the researches of Hauksbee, in attempting to ascertain how far the electric influence could be propogated vertically by means of a line connecting two bodies, found that when an ivory ball was suspended from an electrified glass tube, by a silk cord, the electric influence would be distinctly manifested by the ball at the distance of more than 700 feet; but when a metal wire was used to suspend the ball, it gave no signs of electricity whatever.

6. It likewise appeared that glass, horsehair, amber, and resin, as well as silk, and in general all those bodies which can be rendered electric by friction, also possess the property of insulation, or preventing the escape of electricity; while metals, wood, linen, and water, have no such effect, suffering electricity to escape through them into any other bodies with which they may come in contact.

7. It had been previously observed that light was often given out in the passage of electricity from one body to another through the air, when, in 1744, Dr. Ludolf, of Berlin, discovered that ether could be set on fire by sparks produced by friction from a glass tube: and in 1746, the discovery was accidentally made at Leyden, that the electric influence could be accumulated in a bottle partly filled with water; and, by making a communication between the water and exterior surface of the bottle, what is termed an electric shock might be communicated: whence a bottle or jar with a metallic coating, which has the same effect with water, has been termed the "Leyden Phial."

8. These discoveries led the way to those of Dr. Franklin, who experimentally ascertained what had been before conjectured, that lightning is an electrical phenomenon. The mode in which he conducted the investigation was by raising a kite, during a thunder-storm, in June, 1752, and having attached a key to the lower end of the hempen string, and insulated it by fastening it to a post by means of silk, he found that when a thunder-cloud had appeared for some time over the kite, electricity was received by it and conveyed through the string to the key, which gave out

Who first divided bodies into conductors and non-conductors?

By what experiments was Grey led to his great division of natural bodies?

Enumerate the bodies of each class as he arranged them.

How early was it discovered that electricity might inflame combustibles?

When and where was the principle of electrical condensation discovered?

What name was given to the apparatus by which it was effected?

Who discovered the identity of lightning and electricity?

Describe the manner in which this was effected.

electric sparks, on the knuckles of the hand being presented to it. Science is also indebted to Franklin for the construction of a theory to account for the phenomena of electricity, which, with some modifications, is still regarded as affording the most satisfactory mode of explaining them.

9. The exhibition of phenomena apparently depending on electricity, by the voluntary action of animals, in the case of the torpedo and some other fishes, which communicate a kind of electric shock to those who touch them, had long been known, when Galvani, professor of anatomy at Bologna, in 1790, observed that the contact of metals with the nerves and muscles of a frog, recently killed, produced convulsive motions, which might, for some time after the death of the animal, be renewed at pleasure, by repeating the application of the metals. These singular phenomena, with others of an analogous kind, were at first supposed to depend on some peculiar action of metals and some other bodies on the nerves of animals; and regarded as constituting the foundation of a new science, to which, in honour of the original discoverer, was appropriated the appellation of Galvanism.

10. Some philosophers, noticing the apparent connexion of these appearances with the benumbing power of the torpedo, and the relation that seemed to exist between the effects and those arising from electricity, ascribed the former to some peculiar modification of the electric influence, to which they gave the designation of animal electricity. However, the important discovery by Professor Volta, of Pavia, of the electric effect of certain arrangements of different metals, forming what has been since called a voltaic pile, and sometimes a Galvanic pile, and that of the similarity of the effect of electricity accumulated from bodies excited in the usual manner by friction, with the effect of such a pile, in causing the chemical decomposition of water and metallic oxides, contributed to the introduction of more correct views of the nature of electrical and galvanic phenomena, as all depending on the various operation of the same causes, and as belonging to the same science.

11. Among the latest discoveries in natural philosophy are certain singular and important facts which afford grounds for extending the theory of electricity so as to include the rationale of all those phenomena previously regarded as belonging to the separate science of magnetism, which, however, from its connexion with

What did Franklin effect for the general explanation of electrical phenomena?

What knowledge of electric action excited by animals had preceded the discoveries of Galvani?

How early did this philosopher make his grand discovery?

In what elementary facts did that discovery consist?

What name was at first applied to the phenomena observed by Galvani?

What investigations led to the change of views in regard to the true nature of Galvanism?

What has the science of electricity been of late years extended to comprize?

the art of navigation, and its application to practical purposes, will form in some measure a distinct subject of investigation.

12. The term electro-magnetism has been adopted to designate this class of phenomena; and that of electro-chemistry has been used with reference to the effect of the electric influence on the chemical composition of bodies: the manner in which bodies are affected by the irregular distribution of heat, inducing in them or dissipating electricity or magnetism, has been made the subject of research, and provided with a peculiar appellation, in that of thermo-electricity; there seems also to be some mysterious connexion between the electric or magnetic influence and light: so that it must be obvious that the science of electricity affords a most extensive field for research; and that it is so intimately connected with other branches of natural philosophy, as to claim the closest attention from those who are interested in the progress of physical science.

13. Within the limited space to which this sketch is restricted, it will be impossible to attempt more than a cursory view of the most striking and essential phenomena of electricity or electro-magnetism, with a few illustrative experiments and observations which may furnish correct ideas of the present state of our knowledge, and enable the young inquirer to study with advantage works of greater extent and deeper research.

14. Electricity may be investigated under several points of view. 1. With reference to the sources of electric influence. 2. With respect to its cause, including the developement of the hypothesis of electric fluids, and the properties ascribed to them. 3. The distribution of the electric fluid in bodies imbued with it. 4. The action of electrified bodies on those which are in their natural state; and the phenomena of accumulated electricity. 5. The production of electricity by the contact of different substances; or, Galvanic electricity. 6. The production of electricity by heat; or, thermo-electricity. 7. The phenomena of electric currents; or, electro-magnetism.

15. To these might be added several other heads of inquiry, as regarding the effect of electricity on the living bodies of animals, in health or disease; the investigation of the natural electricity of marine animals, as the torpedo and gymnotus electricus; the chemical effects of electricity; and the nature of atmospheric electricity, or the causes of lightning, hail, the northern lights, and other meteorological phenomena.

The Fundamental Properties or Mode of Action of the Electric Fluid.

16. Some of the usual effects of electric influence, such as the attraction of light bodies by glass tubes excited by friction, the

What is meant by the terms electro-magnetism and electro-chemistry?
What is meant by the term thermo-electricity?
Under how many and what aspects may electricity be regarded?
What incidental inquiries are connected with its main branches of investigation?

production of sparks of fire under certain circumstances, and other phenomena, have been mentioned as owing their origin to a common cause, the investigation of which forms the subject of that branch of natural philosophy, constituting the science of electricity. Like the essential causes of light and heat, that of electricity can only be inferred from observation and experiment.

17. But in order to trace with accuracy the operations of this powerful agent, and elucidate its mode of action, some hypothetical principle may be advantageously assumed, by means of which the phenomena may be connected and accounted for, as resulting from its influence under any given circumstances. Hence the existence of an ethereal fluid, either identical or analagous with that on which depend the phenomena of light and heat, may be admitted; and the term electricity or electric fluid may be employed to designate it.

18. But we should carefully avoid considering it as a palpable form of matter, the existence of which can be directly demonstrated. Instead of which, it should be regarded as merely a convenient method of explaining certain appearances, and showing their mutual relations, so that we may be enabled to contemplate them in connexion with each other.

19. Dr. Franklin advanced a theory of electricity by means of which he accounted for the phenomena as depending on the action of a particular fluid, existing in all bodies, and of which each, according to its capacity, possessed a relatively greater or smaller quantity. When this fluid is in a state of equilibrium, or equally distributed among two or more bodies in communication with each other, it is quiescent, and no particular effects are perceived; but if the equilibrium be destroyed, as by the contact of a body in a different electrical state, a new distribution takes place, and various phenomena may arise from the passage of electricity from one body to another. Thus the phenomena were supposed to depend on the excess or defect of the electric fluid; those bodies which were overcharged with it having a tendency to impart it to others, and those in which it might be less abundant to receive it.

20. It further appeared that bodies in a similar state of electricity, whether of excess or deficiency, always attracted each other; while bodies similarly electrified constantly repelled each other; the terms *positive* and *negative electricity* were therefore adopted to designate the states of bodies as to the quantities of electric fluid contained in them; those in which it was supposed to exist in

How can we arrive at a comprehension of the cause of electrical phenomena?

What assumption is it necessary to make in speaking of electric action?

How are we required to restrict the meaning of the term *electric fluid?*

What supposition was adopted by Dr. Franklin to account for electrical effects?

What was meant by electrical equilibrium, according to that theory?

What obvious phenomenon was observed to occur between bodies in the two opposite states?

When was a body said to be *positively* electrified? when *negatively?*

excess being termed positively electrified bodies, and those in which the quantity was relatively deficient negatively electrified bodies.

21. This theory accounts satisfactorily for some of the most important phenomena, but there are others to which it appears to be inapplicable; in consequence of which, though once generally received, it is now almost entirely abandoned, and has been replaced by an hypothesis originally proposed by Mr. Symmer, an American philosopher, who ascribed the appearances observed to the existence of two kinds of electric fluid, and their separate or united influence under various circumstances.

22. According to this system all bodies in nature contain electric fluid; and the earth itself is to be regarded as an immense reservoir of electricity. This fluid is supposed to consist of a combination of two distinct ethereal essences, which neutralize each other; and it is only when they are separated that electrical phenomena are observed. They may be separately collected, and thus made to display their distinct properties; but they manifest a strong disposition to reunite, and it is principally at the instant of reunion that the most striking appearances are exhibited; for their combination paralyzes their several powers, and the compound fluid becomes perfectly quiescent and ineffective.

23. To these fluids English philosophers have generally given the names of *positive* and *negative* fluids, borrowing in part the phraseology of Franklin. In France, however, the former has been termed the *vitreous fluid*, because it is that which is commonly produced by the friction of glass; and the latter has received the designation of *resinous fluid*, as it is in the same manner exhibited by the friction of resin or sealing-wax: though, as will be subsequently shown, the positive or vitreous fluid may be rendered active by rubbing resin, and the resinous fluid on the contrary produced from the friction of glass; the effects depending partly on the nature of the substances applied to the glass or resin respectively, and being modified by the relative temperature of bodies, and other circumstances.

24. One of the most simple yet at the same time important experiments to show the effect of bodies in different states of electricity may be performed by means of a glass tube, about three feet in length, and three-quarters of an inch in diameter; on rubbing which with a dry silk handkerchief, it will become excited with positive electricity; and if a light downy feather, quite clean and dry, suspended from a silk thread, be held near the

How does the system of Symmer differ from that of Franklin?

What tendency have the two opposite electricities in regard to a neutral condition?

What names do English writers commonly apply to the two electricities?

What terms are in use in France and other countries on the continent of Europe?

What experiment demonstrates the effect of oppositely electrified bodies?

tube, it will be immediately attracted and adhere to it; but if it be then withdrawn, still held by the silk line, and not suffered to come in contact with any other body, it will be found, on again bringing it near the tube, to be repelled, instead of being attracted as before.

25. These appearances are to be explained, as depending on the feather having been imbued with negative electricity in the first instance, and therefore becoming attracted by the positively electrified tube, which having communicated a portion of its electricity to the feather, sufficient to neutralize its former electricity, and bring it into the positive state, both bodies become similarly electrified, and therefore mutual repulsion takes place, manifested by the feather, as being by far the lighter body, flying off from the tube.

26. Let a large stick of red sealing-wax be rubbed with dry warm woollen cloth, and it will be perceived that the suspended feather presented to it will be first attracted and then repelled, as in the former case. But if the feather, after having been positively electrified by contact with the excited glass tube, be presented to the sealing-wax, it will not be repelled, as it would be by the tube, if again presented to it, but would be more strongly attracted by the sealing-wax, than when in its natural state, plainly demonstrating that since it has been positively electrified by the glass, the sealing-wax which now attracts it must be in a negative state. This experiment may be reversed by presenting the feather in its natural state to the excited sealing-wax, and then bringing it near the glass tube, by which it would be instantly attracted; for having been negatively electrified by contact with the sealing-wax, it attaches itself to the positively electrified tube.

27. It has been observed that whenever electricity is excited by the friction of one body against another, both kinds are produced, the one body becoming negatively, and the other positively electrified. Thus when glass is rubbed by silk or flannel, negative electricity is excited in the rubber, while the glass becomes positive; and if sealing-wax or resin be rubbed with flannel or woollen cloth, the negative electricity excited in the rosin or wax will be accompanied by the developement of positive electricity in the woollen. Polished glass acquires positive electricity from friction with almost all substances except the back of a cat, which renders it negative; but if ground glass be rubbed with silk or any of those substances which excite positive electricity in smooth glass, it will become negatively electrified, and the rubbing bodies

In what manner is the experiment to be explained?

What difference in the electric state of a light insulated body will be manifested after touching it with excited sealing-wax, from that which arises from the use of a glass tube?

What two effects must always be produced when two bodies are rubbed together to produce electricity?

Enumerate some of the substances which, when used together, take opposite electrical states.

What substance may render polished glass negative?

will be positively electrified. So sealing-wax, when rubbed against an iron chain, if the surface of the former be smooth, it will be excited with negative electricity; but if its surface be previously roughened with scratches, it will become positively electrified.

28. Hence it appears that the excitement of one kind of electricity or the other depends much on the surfaces of bodies; and therefore it may be conceived that the electric fluid is chiefly disposed on the external parts of solid bodies. As two surfaces rubbed against each other acquire opposite kinds of electricity, it might be expected that they would attract each other, and that is always found to be the case. If a black and a white ribbon, each about a yard in length, and perfectly dry, be applied together, and then drawn several times between the finger and thumb, so as to rub against each other, they will be found to adhere, and if separated by pulling one end from the other, they will fly together again. While they remain united they manifest no sign of electricity; for being in opposite states, they neutralize each other; but if completely separated, each will exhibit its peculiar electricity, those bodies being attracted by the one ribbon which are repelled by the other.

29. When the experiment is made in a dark room, flashes of light are perceived from the surfaces of the ribbons, together with a rustling noise. The black ribbon in this case will be found to be negatively electrified, and the white ribbon positively. By taking ribbons from the same piece and of equal length, and drawing one of them lengthwise at right angles across the other, the former will acquire positive and the latter negative electricity. The friction of liquids or gases against solid bodies will excite electricity; and the effects of contact, pressure, or friction of any one body against another will in some degree produce the same effect, the appearances being variously modified according to circumstances.

30. The following substances become positively electrified if rubbed with either of those mentioned after them, and on the other hand when one of these substances is rubbed with either of those named before it, the substance rubbed becomes negatively electrified: 1. The back of a cat. 2. Polished glass. 3. Wool and woollen cloth. 4. Feathers. 5. Dry wood. 6. Paper. 7. Silk. 8. Gum lack. 9. Ground glass.

31. It has been already stated that some kinds of substances freely transmit electricity to bodies in contact with them, or suffer it to escape through them; while others retain it, or prevent its

On what does the particular state which any body shall take, when rubbed, appear to depend?

How may the developement of electricity by differently coloured ribbons be exhibited?

Why will not two pieces of silk, when oppositely electrified and placed together, show signs of electricity?

How may liquids and aëriform bodies be made to excite electricity?

State the order in which the several electrics become either positive or negative according to the substance with which they are rubbed.

passage: the former are named *conductors* of electricity, and the latter *non-conductors*.

32. Among solid bodies, the metals are generally excellent conductors, and yet they appear to be very unequal as to their powers of conduction; linen, straw, and wood charcoal are likewise good conductors; while glass, resins, sulphur, silk, wool, sugar, fat, and various other substances are either non-conductors, or possess the conducting power in a very imperfect degree. Most kinds of wood when quite dry, and animal fibres deprived entirely of the juices they naturally contain, become nearly absolute non-conductors; but in their fresh state they conduct electricity freely, doubtless in consequence of the liquid matter with which they are penetrated. Hence the bodies of men and other animals suffer the electric fluid to pass through them with great facility.

33. All liquid substances, except fat oils, are good conductors, though not equally so; for essential oils, and spirit of wine do not conduct electricity so readily as water; and the latter fluid has its conducting power augmented by combination with acids or saline substances.

34. Air and all gaseous fluids, when free from moisture, are bad conductors, and the more dense they are the greater will be their resistance to the passage of electricity through them. Atmospherical air, therefore, in dry weather becomes a non-conductor; but when charged with moisture, as from a fog, the electric fluids traverse it more readily. Temperature also, as might be concluded, influences its conducting power, which is greatly augmented by heat.

35. Those bodies which are good conductors of the electric fluids may be excited by friction as well as the non-conductors, but the effects produced will depend on the circumstances in which they are placed. Thus a cylinder of brass, or any other metal, grasped by the hand, if rubbed with silk or flannel, will be perfectly inert, not displaying any attractive power, like rubbed glass or sealing-wax, when brought near to a light feather. But if a handle of baked wood or glass be fixed to a metal cylinder, so that it may be held without touching the cylinder itself, and the latter be rubbed with a dry silk handkerchief, or piece of flannel, it may be readily excited, generally manifesting negative electricity, and it will act on the feather accordingly. In such a case the electricity is prevented from passing off from the metal, through the body of the person who

What gives rise to the distinction of bodies into conductors and non-conductors?

What bodies are among the best *conductors*?

What are some of the bodies which may change their character according to the state in which they happen to be tried?

What liquids are bad conductors of electricity?

What power of conduction has dry air?

What influence has heat on the conducting power of air?

Under what circumstances may a metallic cylinder be excited by rubbing?

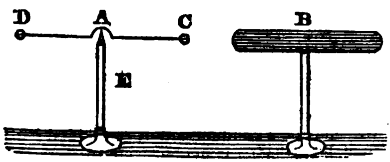
holds it, by the insulating or non-conducting handle of dry wood or glass.

36. From the power which the most perfect non-conductors possess of preventing the escape of the electric fluids from conductors supported by them, they have been termed *insulators*, and as they most readily exhibit electricity by friction, they have also been called *electrics*, while the appellation of *non-electrics* has been applied to the metals and other freely-conducting substances. These terms, however, can hardly be considered as correct, since bodies differ more essentially in their power of retaining electricity than in their capacity for receiving it; and hence the more obvious distinction between conductors and non-conductors.

37. In making experiments relative to the accumulation or transfer of the electric fluids, it is necessary to use instruments so constructed as that a conducting body may be supported and thus insulated by means of a non-conductor. On this principle is formed that necessary part of electrical apparatus called *the prime conductor*, usually consisting of a brass cylinder fixed horizontally by one or more rods or thick tubes of glass to a wooden stand.

38. It may be inferred from the experiment with a glass tube and an insulated feather, that any body capable of free motion, on approaching another body powerfully electrified will be thrown into a contrary state of electricity; and thus a feather brought near to a glass tube excited by friction is attracted by it, and therefore previously to its touching the tube negative electricity must have been induced in it: and on the other hand, if a feather be brought near excited sealing-wax it will be attracted, and consequently positive electricity must have been induced in it before contact. Hence it appears that electricity of one kind or the other is generally induced in surrounding bodies by the vicinity of a highly excited electric. This mode of communicating electricity by approach is styled *induction*.

39. When an electrified body thus causes electricity in another by induction, the effect extends only to that part of the surface of the latter body immediately opposite to the former, while the other extremity will exhibit a contrary state of electricity.



This may be shown by means of a brass wire A, in the annexed figure, moving freely on a pivot, and supported by a glass tube E; and a brass cylinder or conductor B, similarly sup-

Whence has the term *insulator* been derived?

To what is *electric* applied?

How are we to arrange conductors and non-conductors for the purpose of showing the accumulation of electricity?

Into what electrical state is any body brought by being placed near one which has already been electrified?

How is this exemplified?

ported, and placed within a few inches of the extremity of the wire C, carrying a small ball of pith of elder.

40. If the conductor be positively electrified, the ball C will become negative, as may be shown by approaching to it an excited stick of sealing-wax, by which it will be repelled; while the ball D will be attracted by the sealing-wax, and must therefore be in a positive state of electricity. In this case the wire A is said to be in an *electro-polar state*, having a negative pole C opposite to the positively electrified conductor, and a positive pole D, at its opposite extremity. Such an arrangement might be carried to any extent. Thus if another brass wire similarly insulated and armed with pith balls were to be placed near the extremity D, the ball opposite to it would be negatively electrified, that at the other end positively, and so on.

41. The instrument above described, or mounted brass wire with its balls, forms a convenient electroscope,* to indicate the electrical states of bodies; and as such it was proposed by the French philosopher, Hauy. On the same principle depends the action of the more simple electroscope, consisting of two small pith balls suspended by a fine linen thread or silver wire to the extremity of an insulated conductor. When such an instrument is electrified, the two balls necessarily acquiring the same kind of electricity will separate from each other; and the nature of their electricity may be ascertained by presenting to them an excited glass tube, which, if they are positively electrified, will make them more divergent, if negatively will draw them nearer; and with a stick of excited sealing-wax, the reverse effects would take place.

42. A more delicate instrument for estimating the kind of electricity is that called Bennet's gold-leaf electrometer, composed of two small slips of gold leaf suspended within a glass jar, which by their divergence or collapse on the approach of an electrified body to a brass ball connected with them by a wire passing through the neck of the jar, indicate that its electricity is similar or contrary to that of the gold leaves. An arc of a circle graduated may be so placed as to show the relative extent of the divergence of the leaves, according to the degree of electricity in the body presented to the electrometer.

43. Another very delicate electrometer is that called the electric balance, invented by M. Coulomb; in which the force of electri-

What name is given to this mode of exciting electricity?
In what state are the opposite ends of a conductor thus electrified?
Describe the apparatus by which this effect is demonstrated.
In what state is the body electrified by induction said to be?
Can a body electrified by induction communicate an electrical excitement to another insulated body?
What use did Hauy make of the wire and balls insulated on a pivot?
What other similar apparatus depends on the same principle?
Describe Bennet's gold-leaf electrometer.

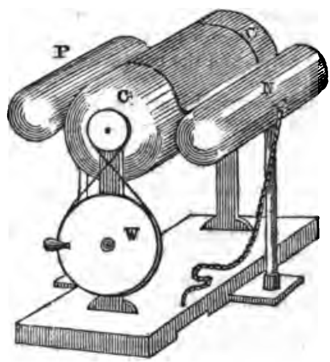
* From the Greek Ηλεκτρον, (see p. 418), and Σκοπεω, to observe.

cal repulsions and attractions, is measured by the torsion of a wire; and others have been contrived, by means of which the amount of electric repulsion may be ascertained and measured on a graduated scale. From experiments with the electric balance it has been concluded that the influence of electricity, like that of gravitation, is in the inverse ratio of the squares of the distances of the acting bodies

Electrical Instruments and Experiments.

44. Electricity is usually developed, in order to show its effects, by the friction of glass. The earlier electricians, in the prosecution of their researches, merely used glass tubes or other non-conductors, held in one hand and rubbed with silk or flannel. Dr. Hauksbee made an improvement on this tedious process, by arranging a glass globe so that it might be made to revolve continually on an axis; and Professor Winkler of Leipsic, contributed greatly to render the apparatus useful and convenient, by affixing a cushion of soft leather stuffed with horsehair, so that by the pressure of a spring it might rub against the revolving globe.

45. Such an arrangement as that just described constitutes an electrical machine; but subsequent experimentalists have made many alterations; and among the most simple and yet advantageous modifications of this instrument may be reckoned that invented by Mr. Nairne, a mathematical instrument maker, as represented in the following figure. It consists of a glass cylinder, C C, from



10 to 16 inches in diameter, and about twenty inches in length, supported, so that it may turn on its axis, on two pillars of glass, fixed to a wooden stand. Two metallic conductors, P N, equal in length to the cylinder, and about one third of its diameter, are fixed parallel with it, on either side upon two glass pillars, which are cemented into two separate pieces of wood, sliding in grooves so that they may be respectively adjusted at any distances from the cylinder required. To one of these conductors, N, is attached a cushion an inch and a half wide, and about as long as the cylinder, against which it may be made to press by means of a bent spring; and to the upper part

On what principle was Coulomb's torsion balance constructed?
How is electricity most commonly developed?
How was this effected by the early electricians?
What improvements were made by Hauksbee and Winkler?
Describe the essential parts of Nairne's electrical machine.

of it is sewed a flap of oiled silk, which extends loosely over the cylinder, to within an inch of a row of brass pins or pointed wires proceeding from the side of the opposite conductor. The conductor to which the cushion is attached is called the negative conductor, and the other, which by means of its points collects electricity from the glass, is named the positive conductor, and also the prime conductor. The cylinder may be made to revolve, in the direction of the silk flap, simply by a winch fitted to it, or by a multiplying wheel, W.

46. In order that the machine may be worked with the greatest effect, the cylinder and every other part must be made perfectly clean and dry; and as may be supposed, it displays the greatest power when the air around it is quite free from moisture. To augment the efficacy of the machine, it is usual to apply to the cushion an amalgam of zinc and tin, made by melting together one part of tin and two of zinc, and mixing them in a heated iron mortar with six parts of hot quicksilver; and after the compound has been reduced by trituration to a powder, it must be made into a stiff paste, with pure hog's lard.

47. When it is requisite to obtain positive electricity, the cushion or negative conductor must be connected with the wooden stand of the machine by a chain or wire; and thus the electric equilibrium of the rubber is restored, by the earth, as fast as it is disturbed by the action of the machine; but the opposite positive conductor being insulated cannot return to a state of equilibrium except by the action of the wire. If it be required to produce negative electricity, the cushion must be insulated by removing the chain, and attaching it to the prime conductor P, whence the positive electric fluid will pass to the earth, and the conductor N will become negatively electrified.

48. There is another form of the electrical machine, consisting of a circular glass plate, fitted up so that it may be made to revolve between two rubbers. It is a powerful instrument; and, when properly made, is easily adapted for producing positive or negative electricity. In both forms of the machine the quantity of electricity developed in a given time will depend, other things being equal, on the extent of surface rubbed, and the goodness of the insulation by which the reunion of the two electricities can be prevented. The intensity or striking distance of electricity, in a machine of either form, must depend on the distance between the

What names are given to the two conductors with which that machine is furnished?

What is the object of the wheels and band in this apparatus?

What precautions are necessary to insure the efficacy of an electrical machine?

What substance is applied to augment the action?

What adjustment of parts will yield positive electricity?

How may the negative electricity be exhibited?

On what will the *quantity* of electricity depend, in any machine of a given form?

To what will the *intensity* be proportioned?

rubber and the collecting points, that is, in general, on the *diameter* of the plate or cylinder.*

49. M. Beudant has described a machine that has the advantage of being less costly than those of glass, and exempt from injury by accident. It may be constructed by taking two yards of varnished taffeta, and sewing together firmly, with a flat seam, the two ends, so as to make it like what is called a jack towel; and it is then to be stretched over two wooden rollers, one of which being turned with a winch, the taffeta will pass continuously over them, cushions of hare or cat skin being placed so as to rub against it; and a conductor with points may be placed near its surface to collect the electricity produced.†

50. When an electrical machine, as above described, with a glass cylinder, has been properly prepared, and during a dry state of the atmosphere, if the cylinder be made to revolve with a certain degree of velocity, sparks and vivid flashes of light will be perceived passing over the surface of the glass, from the cushion to the conductor; and if the knuckle be presented to the conductor, sparks, with a sharp report, will proceed from it to the knuckle, causing a peculiar and slightly disagreeable, but momentary sensation. The light is supposed to be occasioned by the sudden compression of the air, by the transit of the electric fluid; and it is accompanied by the developement of heat, for gunpowder, alcohol, fulminating silver, and other highly inflammable bodies may be set on fire by means of the electric spark.

51. The operation of the electrical machine depends on the glass becoming positively electrified by friction against the rubber, when the cylinder or plate is put in motion, and the rubber or cushion consequently becoming negatively electrified. The positive electricity thus acquired by the glass is regularly attracted and carried off by the metallic points of the prime conductor, in which it becomes accumulated. But if both conductors be insulated, so that the cushion connected with the negative conductor cannot continue to derive electricity from the earth or surrounding objects, it will soon cease to afford electricity to the other conductor by means of the glass cylinder. In order, therefore, that the supply may be kept up, it is requisite that either the cushion or the con-

What construction has Beudant proposed for an electrical machine?
What is supposed to be the cause of electrical light?
On what does the operation of the machine depend?
What takes place when both conductors are insulated?

---

* For an experimental investigation of this and other subjects connected with the action of electrical machines, the reader is referred to the 25th volume of Prof. Silliman's American Journal of Science, p. 57. —ED.

† Traite Elem. de Phys., p. 570. The idea of Beudant is sometimes realized in the action of machinery driven by broad leather bands moving rapidly over pullies. As there is a considerable amount of friction, and as both leather and wood become dry and warm, electrical sparks may be obtained.—ED.

ductor should communicate with the earth, or with the floor, by some good conducting medium, as a metal chain or wire.

52. Hence it appears that the electricity of either conductor must be extremely weak, when both of them are insulated; that if one conductor alone be insulated, the power of the other will be proportionally augmented; that the cushion and the glass must always be in opposite states, the one being positive and the other negative; and that the opposite electricities are exactly in that proportion which will cause them when combined to neutralize each other. The effects produced by the positive conductor, or that opposed to the cylinder, will be similar to those of an excited glass tube; and the effects of the negative conductor, or that connected with the cushion will correspond with those of an excited stick of sealing-wax.

53. If two suspended pith balls be attached to either conductor, they will be observed to repel each other, manifesting the same kind of electricity; but if one ball be attached to the positive, and another to the negative conductor, they will attract each other. If, however, the two conductors be connected by a metal rod, their opposite electricities will neutralize each other, and no signs of either state will be exhibited.

54. The passage of a spark indicates the annihilation of the opposite states of electricity previously existing in the bodies between which the spark passes, and which has been already shown to be the effect of induction on the approach of bodies towards each other. Thus, the knuckle, when presented to the positive conductor, becomes negatively electrified; and when the opposite electricities thus induced become sufficiently intense, the appearance of the spark announces that the state of excitation is terminated.

55. The most important phenomena depending on the principle of induction are those arising from the accumulation of electricity. This is what takes place in using the electrical jar, or, as it has been termed, the Leyden phial, the property of which was accidentally discovered by Professor Musschenbroek, of Leyden, or, according to some writers, by M. Cuneus. Its mode of action may be readily exhibited by taking a glass bottle nearly filled with water, and placing it in a basin of water; a chain or rod of metal must be passed into the bottle below the surface of the water, and continued from it to the positive conductor of an electrical machine, and another chain must have one end immersed in the water of the basin surrounding the bottle, and the other end trailing on the floor, or connected with the cushion.

What will be the electrical condition of both conductors when both are insulated?

In what proportion are the opposite electricities always found?

What phenomenon will two pith balls exhibit when suspended to either conductor of the machine?

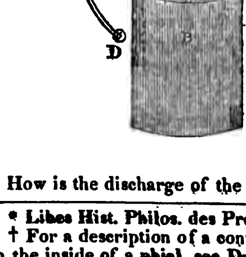
What does the passage of a spark indicate?

How may the Leyden phial, in its simplest form, be exhibited?

56. On turning the machine, the electrical fluid received by the conductor will pass from it by means of the chain or rod to the interior of the bottle, where it will be accumulated; and in order to discharge it, a communication must be made between the rod or chain proceeding from the bottle, and that immersed in the basin; and thus the confined electricity will make its escape. A person grasping the latter chain with one hand, and touching the other or the conductor with which it is connected with the other hand, would receive the whole charge of the phial, constituting what is termed an electric shock.

57. It was in this manner that Musschenbroek undoubtedly became practically acquainted with the effect of accumulated electricity; and the sensation he experienced so strongly impressed him that, in a letter on the subject which he addressed to Reaumur, he said the crown of France would be but a feeble inducement to expose himself to the hazard of receiving such another shock.* The sensation caused by the discharge of an electric jar is not, however, so formidable as might be supposed from the alarm of the alleged discoverer; and unless the jar be large and highly charged, the shock will only occasion a momentary painful feeling, much resembling that caused by suddenly striking the elbow against a hard substance, but more transient.

58. A more convenient form of the Leyden phial than that just described consists of a wide mouthed jar, coated outside and inside with tinfoil, to within about two inches of the top; having a wooden cover, fitted into the mouth like a cork, and pierced so that a strong brass wire may pass through the cover, terminating below in a chain in contact with the inner coating of the jar, and having at the other end a brass knob or ball. A jar or bottle with a narrow neck, as represented in the margin, may be used, but as



in that case it can be coated only on the outside, it must be filled with some metallic substance, as mercury, or steel filings, as high as the coating B reaches; or moderately warm water may be poured into it whenever it is wanted for use.†

59. A jar may be electrified by placing it near the positive conductor of a machine, with which the knob A must be in contact; and then, on turning the cylinder, the electric fluid will pass from the conductor to the jar, in which it will become accumulated; and in order to dis-

How is the discharge of the phial to be effected?

* Libes Hist. Philos. des Prog. de la Physique, t. iii. p. 141.

† For a description of a convenient method of fixing a metallic coating to the inside of a phial, see Dr. Olinthus Gregory's Lessons, Astronomical and Philosophical, 6th edit. 1824, p. 127.

charge it a bent or jointed wire must have one extremity placed against the outer coating of the jar, and the other being advanced towards the knob, nearly the whole charge will escape from the inside of the jar, through the wire, to the outer coating. A curved brass wire, called a discharger, is sometimes fitted up with a knob at each end, C,D, and a glass handle; but the jar may be safely discharged by the bent wire only, as the fluid will pass wholly through it without affecting the person who uses it. In charging the jar care must be taken that the *exterior* coating be allowed to take the state opposite to that of the *interior*. This may be perhaps most conveniently effected by connecting the outside of a jar or battery when undergoing the operation, immediately with the rubber of the machine; then connecting the prime or positive conductor with the interior the charging will proceed with entire success, though the jar, the machine, and even the person who works it be perfectly insulated from the ground. By connecting the rubber with the interior, and the positive conductor with the exterior, the battery will be charged internally with negative electricity.

60. As the effect of the electrical jar will be proportioned in part to the quantity of coated glass it contains, and in part to the thinness of the glass, it must be obvious that its power will greatly depend on its size. Very large jars, however, would be awkward, inconvenient, and liable to be broken by slight shocks if very thin, as well as highly expensive. Hence means have been contrived for combining any number of jars, so that they may be all charged at the same time, and discharged with equal facility as a single jar. This may be effected by forming a connection between all the wires proceeding from the interiors of the jars, and also connecting all their exterior coatings; and such an arrangement is styled an electrical battery. The discharge of electricity from such a combination is accompanied by a loud report; and when the number of the jars is considerable, animals may be killed, metal wires be melted, and other effects be produced by the discharge of the battery, analagous to those of lightning.

61. By means of an electrical machine a vast number of curious and interesting experiments may be performed, a few of which may be here described.

The effect of electricity in producing the divergence of tufts of hair is sufficiently amusing. This may be shown by placing a person on a stool with glass legs, so that he be perfectly insulated,

What account did the discoverers of the Leyden phial give of their sensation on receiving the shock?

What form of this apparatus is most convenient in practice?

How may such a jar be charged?

What apparatus may be used in the discharge?

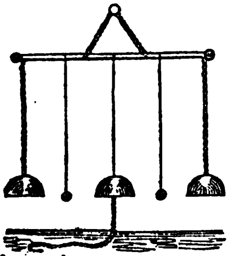
On what two circumstances in the construction of a jar will its efficiency depend?

How is the necessity of using very large jars obviated?

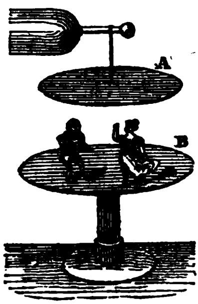
What is an electrical battery?

and making him hold in his hand a brass rod, the other end of which touches the positive conductor; then on turning the machine, the hairs of the head will diverge in all directions. The same effect may be more perfectly exhibited by means of an artificial head, of small dimensions, with hair glued to it, and fixed on a brass wire, which is to be placed on the conductor.

62. The electrical bells (*carillon electrique*, as designated by the French) consist of a number of small bells, as represented in the annexed figure, suspended from the conductor by brass chains, with a ball to act as a clapper hanging by a silk thread, between every two bells, one of them being connected with the table, so that its electricity is neutralized as fast as it is received. Thus the insulated ball will vibrate backwards and forwards alternately striking the electrified and non-electrified bell, when the machine is put in motion.



63. The dancing figures, as shown in the margin, may be cut out of writing paper; and such figures, or any other light bodies, placed on a brass plate B, connected with the ground, and having another brass plate A, suspended at a little distance above it, from the prime conductor, will rapidly dance when the upper plate is electrified.



64. The effect is obviously caused by the figures being attracted by the electrified plate and immediately after repelled, and being robbed of their acquired electricity by the lower or non-electrified plate, they rise again to receive a new charge, and thus the dance is continued.

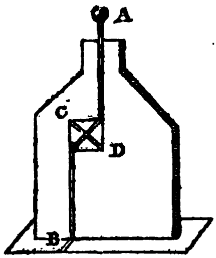
65. The manner in which buildings are injured when struck by lightning, or the accumulated electricity of the atmosphere, may be instructively elucidated by means of the apparatus delineated in the following figure, called a Thunder-house. It consists of a triangular piece of mahogany, which may represent one end of a house or barn: in the centre a small square piece is fitted loosely into a corresponding cavity; and diagonally across the moveable square passes a brass wire, C D. When this instrument is used, the brass knob A must be brought near to the

How is the divergence of the hair, and similar effects on the person, produced by electrification?

Describe the electrical chime of bells.

How is the electrical dance to be explained?

What apparatus illustrates the effect of lightning on objects which it encounters?



knob of a charged jar, with the outside of which is connected a chain attached to the brass wire B; thus the jar will be discharged, and its electricity will pass through the knob and wire A to B; but the interruption occasioned by the position of the square in the centre will cause it to be forcibly driven from its place. If, however, its position be altered, so that the wire C D may communicate with A and B, forming a part of the same electric circuit, the fluid will pass through the wire C D without displacing the square.

66. It is thus that the highest point or points of a building being struck by lightning, if the passage of the electric fluid be interrupted, by non-conducting or imperfectly conducting bodies, they may be displaced with violence, injured, or destroyed; but if the electric fluid can pass readily through a good conductor, as a thick metal rod, it will be conveyed into the earth without hazard of the safety of the building. Hence the utility of conductors affixed to towers and other lofty edifices. In practice, the lightning rod must be furnished with a sharp point instead of the ball exhibited at the top of the model.

GALVANISM.

67. The effects of electricity depending on the accumulation of the electric fluids by the friction of non-conducting bodies having been pointed out, we shall next attempt to explain those phenomena which appear to be caused by circulating currents of those fluids, produced by the contact of bodies in different states of electricity, and especially by the contact of metals and other good conductors. Phenomena of this nature constitute the objects of that branch of physical science termed Galvanism or Galvanic electricity, from the discoveries of Professor Galvani of Bologna; and sometimes Voltaism, or Voltaic electricity, from the subsequent researches of Professor Volta of Pavia, who made great additions to our knowledge of the subject, with reference both to facts and theory.

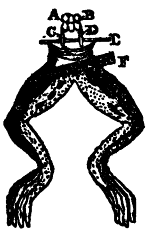
68. The earliest notice which has been observed of any phenomenon attributable to Galvanism, occurs in a work entitled "A

In what form must the termination of a lightning rod be?
What is meant by galvanism?
From whom does that science derive its name?

General Theory of Pleasures," published in 1767, by John George Sulzer, a German writer of some eminence on philology and metaphysical philosophy. He states that when two pieces of different metals are applied to the upper and under surfaces of the tongue, and then brought into contact, a peculiar taste will be perceived. Sulzer made an abortive attempt to account for this curious fact, which seems to have attracted no particular attention till a later period, when further discoveries led to the inference that it ought to be regarded as depending on electricity.

69. Professor Galvani, already mentioned, about 1790, accidentally made the discovery that the transmission of a small quantity of electricity through the nerves of a frog, shortly after the death of the animal, would excite muscular contractions in its limbs. And he afterwards found that similar contractions could be produced, by touching the muscles of the leg of a dead frog with one metal, and the nerves belonging to them with another, and then bringing the metals into contact.

70. This singular effect of electricity may be experimentally exhibited, by preparing the hind limbs of a frog as represented in the margin. The skin being removed, the crural nerves, C D, may then be perceived issuing from the spine, A B, and resembling two white threads; a silver wire, E, is to be passed under the nerves, and a small plate of zinc, F, to be laid on the muscles of the thighs; then on bringing the metals into contact, either directly, or by a bent silver wire passing from one to the other, the limbs will be effected with convulsive twitchings, which may be re-excited at pleasure for some time, by suspending and renewing the contact of the metals.



71. Similar phenomena may be produced by treating in this manner any animals; but cold-blooded animals, as frogs, toads, serpents, and fishes retain their excitability longer than those with warm blood, though experiments made with the latter, under proper arrangements, have a more imposing appearance. Live animals also display signs of sensibility to the influence of galvanism; and experiments may thus be made with live flounders, which may readily be procured in any place near the sea-coast. If a flounder be laid in an earthenware plate, on a slip of zinc, and a piece of silver or gold placed on its back, on connecting the zinc with the other metal, by a bent wire, strong muscular contractions will be excited in the fish.

What phenomena attributable to electric currents excited by metals were observed by Sulzer?

What was the nature of Galvani's original discovery?

What was the second point ascertained by his experiments?

How may this be exhibited?

What classes of animals are best adapted for exhibiting the effect of muscular contraction after death?

How may the Galvanic effect be produced in the case of a living animal?

72. In these and analagous experiments it is requisite that the separate pieces of metal should be of different kinds; and the effects are most striking when one metal is readily soluble in acids, as is the case with zinc, and the other difficultly soluble, as silver, gold, or platina. Hence two insoluble metals, as gold and platina, applied as above directed, have hardly any effect; while gold, platina, silver, or copper, may be advantageously opposed to zinc, tin, or iron, to form a galvanic circuit. It must be observed that the effect is chiefly momentary, and the convulsive motions take place at the instant of the contact of the metals; but the phenomena may be renewed by separating the metals and repeating their contact with each other.

73. Sulzer's experiment before noticed, may be performed by placing a piece of silver, as a half dollar, upon the tongue, and a disk of zinc under it, and on bringing together the edges of the metals while their flat sides remain in contact with the tongue, a peculiar taste will be perceived, and a sensation approaching to a slight electric shock, especially if the metallic plates have rather extensive surfaces. In that case, also, a flash of light will sometimes pass before the eyes; but this latter phenomenon may be more certainly excited by placing one of the metals between the upper lip and the gums, and the other on the tongue, and bringing their edges in contact as before.

74. It has been found that when two metals are brought into contact, and then separated, they will exhibit opposite states of electricity. Thus if an insulated disk of zinc be laid on one of silver or copper, and then removed by means of some non-conducting substance, the zinc, on being applied to a delicate electrometer, will show positive, and the silver or copper, on the other hand, negative electricity. Whence it may be inferred that a portion of free electricity had been developed by the metals, and to the passage and reunion of the two opposite kinds are to be attributed the convulsions of the muscles of animals when their nerves are in contact with them placed in a galvanic circuit.

75. The effect of the contact of different metals may be exhibited by placing on the cap of a gold-leaf electrometer, a large plate of any metal, and sifting over it zinc filings through a copper sieve, insulated by a glass handle; when it will be found that the leaves will diverge with positive electricity, and the sieve will become negatively electrified. On repeating the experiment, but using a zinc sieve to sift copper filings, the effect will be reversed, and the electrometer will show that the copper filings are negatively electrified, while the zinc sieve will display positive electricity.

What characteristic properties of the metals employed, favour the success of this experiment?

How may Sulzer's experiment be conveniently repeated?

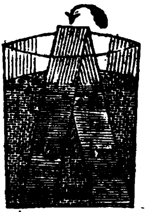
What effect may it produce on the organ of sight?

In what states are two metals left after having been in contact with each other?

How are the convulsive motions to be explained?

In what other manner may the effect of contact be exhibited?

76. A simple galvanic circle may be formed, by the apparatus represented in the margin, consisting of a plate of zinc, Z, and one of copper, C, immersed to a certain depth in sulphuric acid greatly diluted with water, contained in a glass vessel. Then, when the upper edges of the metals are brought in contact, a current of electricity will take place, the positive electric fluid circulating from the zinc to the acid, from the acid to the copper, thence again to the zinc, and so on in the direction indicated by the darts; the negative current being in the opposite direction.



77. Various modifications of this arrangement may be contrived: thus, instead of making the metals communicate immediately, as above, a wire of any metal may be attached to the upper extremities of each plate, and when the wires are brought together the circuit of electricity will go on, but when they are separated, it will be interrupted. By this means the electric currents may be directed through any bodies, by placing them between the wires, so that they may form a part of the circuit, and various effects may be produced. The wire connected with the zinc in this case is called "the negative wire," and that connected with the copper "the positive wire." By some writers they have been denominated positive and negative rheo-phores.*

78. The effects of such an arrangement as that just described, at least with small metal plates, will be but inconsiderable. Hence Professor Volta conceived the idea of forming what may be termed a compound galvanic or voltaic circle, by arranging a number of disks of different metals, as zinc and copper, with cloth or pasteboard soaked in some acid or saline solution between them; as thus the effect might be indefinitely augmented, according to the number and size of the disks.

79. The apparatus may be fitted up as represented in the annexed figure, consisting of an equal number of silver or copper coins, or flat pieces of either metal, and of similar pieces of zinc, arranged one above another, with wet pasteboard between them in the following order: zinc, copper, wet pasteboard, denoted by the letters Z, C, W, in successive layers throughout the series. One end of the pile must terminate with a zinc plate, and the other with one of copper, with each of which wires may be connected; and the whole should be made steady by fixing the

Which electrical state is taken by the copper in a simple galvanic pair or circuit?

In what manner may the effects of such a circuit be displayed?

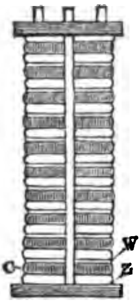
What different names are given to the conductors usually attached to the opposite extremities of the galvanic arrangement?

In what manner did Volta undertake to augment the power of the galvanic apparatus?

Describe the *pile* of Volta.

---

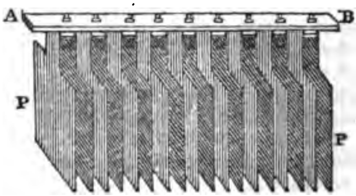
* *Current-bearers*, from Ρεον, a current, and Φερω, to bear.

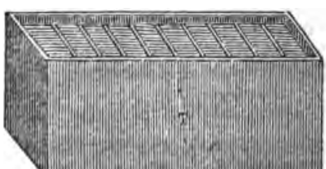


disks between three vertical glass rods, properly varnished, and cemented into two thick pieces of wood, one of which serves as the base and the other as the cover of the pile. Any number of such piles may be united so as to constitute a Voltaic battery, by making a metallic communication between the last plate of one pile and the first of another, to any extent.

80. The Voltaic pile will be found highly efficient, and forms a convenient instrument, so long as the cloth or pasteboard disks between the metals retain their moisture; but when they become dry, the pile is rendered comparatively inactive. Volta, therefore, contrived a different arrangement, to which has been given the French designation *Couronne de Tasses*, as consisting of any number of glasses partly filled with diluted acid, with a plate of zinc and another of copper in each as before described; and the zinc plate in one glass being connected with the copper one in the next, throughout, the circuit might be completed by wires attached to the terminating plates.

81. But this instrument, though not liable to the same objection with the pile, was inconvenient, and therefore has been superseded by various other arrangements, among which we select for description the Galvanic trough, or as it also is termed, the Galvanic battery of Mr. Cruicshank. It may consist of a trough, T, constructed of baked mahogany, with partitions of glass in the interior; or it may be formed of Wedgwood ware, with interior cells,





How is the efficiency of the *pile* limited in regard to the time of its action?
What other arrangement of the elements was devised by Volta?
What is the construction of the *couronne de tasses*, or "*crown of cups?*"
Describe the Galvanic battery.

each trough containing ten or twelve. The metal plates P P adapted to them are united by a bar of baked wood A B, so that the whole set may be let down into the trough, or lifted out together.

82. The cells are to be filled with water or diluted acid when the instrument is to be used, and the plates placed in them, each cell will contain a zinc and copper plate, and the circulation of the electric fluid will take place throughout the whole, while wires proceeding from the last zinc plate on one side, and from the last copper plate on the other, any bodies, by being placed between the wires, will form a part of the circuit, and be subjected to the action of the electric fluid. When the necessary experiments are completed, the plates should be lifted out of the trough, that they may not be too hastily corroded by the acid.

83. Several such troughs may be combined like voltaic piles, after the manner before stated; and if very large plates be employed to form the battery, its power will be exceedingly increased. One was constructed, for the use of the Royal Institution in London, consisting of two hundred separate parts, each part composed of ten double plates, and every plate containing thirty-two square inches. The whole number of double plates amounts to two thousand, and their entire surface to 128,000 square inches, or 888 square feet.

84. Several forms of Galvanic apparatus have been invented and applied in the United States, some of which manifest great energy, combined with facility in manipulation. Among them, those of Dr. Hare, denominated the *deflagrator* and the *calorimotor*, deserve particular mention. The former is composed of two troughs, in one of which the zinc and copper plates are arranged across the trough, so that each pair forms, when united, a separate partition for a cell, and the whole thus adjusted throughout a length of ten feet, is to receive the acid liquor when the trough is to be put into action. To one edge of this trough is attached another of the same length with the plane of its open side or mouth forming a right angle with that of the trough which contains the cells. This is to receive the acid when the action of the deflagrator is to be suspended. These troughs thus united are hung on an axis passing longitudinally through the line which unites their edges so as to allow the liquor to be, by the quarter of a revolution, transferred from one trough to the other. Many of the brilliant and important experiments exhibited by Dr. Hare, are shown by means of this apparatus.

With what are the cells to be filled?

What advantage attends this apparatus in regard to the corrosion of the metals?

How may the power of this sort of batteries be augmented?

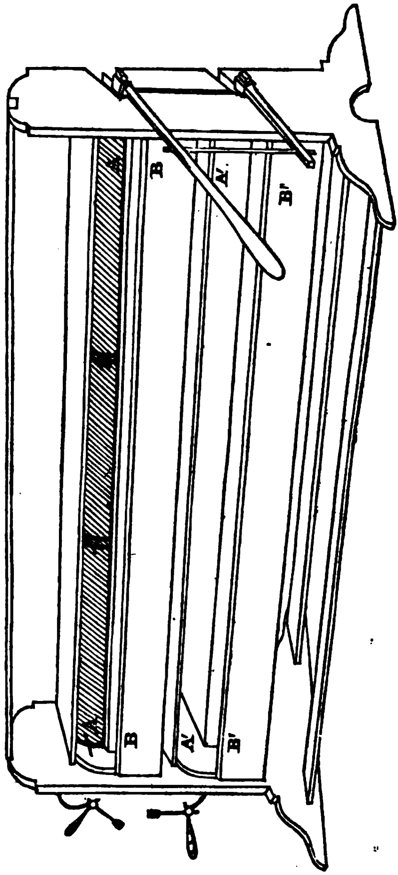
What was the size of that belonging to the Royal Institution?

What is the construction of Hare's deflagrator?

By what means is the acid brought to act on the metallic plates in this apparatus?

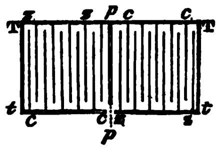
How are the metals disposed in the calorimotor?

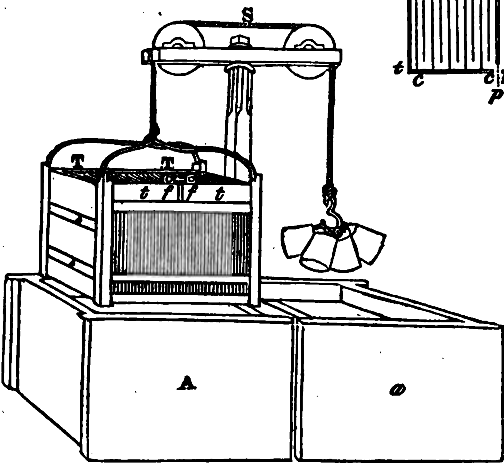
85. The accompanying figure represents the deflagrator. The two troughs containing the plates are seen at A A and A′ A′. When the open mouths of these two are in a vertical position, as seen in the figure, those of the other two, B B and B′ B′, containing the acid liquor, are in a horizontal one; on raising the handle at the right of the figure, so as to give each pair of troughs half a revolution, the aid will be decanted from its receptacle, and flow into the trough containing the plates.



86. The calorimotor in which a great quantity of heat accompanied by little electrical *tension* is produced, consists of such an arrangement of the elements as to form in fact but one, or at most, *two* pairs of separate plates; for all the zinc plates in one half of the apparatus being connected together constitute but *one* plate, while all the copper ones being united, afford *another*. The plates are, however, arranged in an alternating series, so as to present their surfaces to each other without occupying too great a space.

The accompanying figures represent the arrangement of parts in the calorimotor. A and *a* are the cubical boxes containing the one acidulated and the other pure water; *b b b b* is the wooden





frame containing the zinc and copper plates alternating with each other, and from ¼ to ½ an inch apart, T T *t t* are masses of tin cast over the protruding edges of the sheets which are to communicate with each other. The smaller figure, representing a horizontal section through the plates, shows the manner in which the junction between the several sheets and the tin masses is effected. Between the letters *z z* the zinc only is in contact with the masses. Between *c c* the copper alone touches the tin. At the back of the frame ten sheets of copper between *c c*, and ten sheets of zinc between *z z* are made to communicate by a common mass of tin, extending the whole length of the frame between T T; but in front, as shown in the larger figure, there is an interstice between the mass of tin connecting the ten copper sheets, and

What relation has the electric tension in the calorimotor to that of the pile or trough?

Describe the several parts of the calorimotor.

that connecting the ten zinc sheets. The screw forceps, *f f*, may be seen on each side of this interstice, holding the wire which is to undergo ignition. A wooden partition, *p p*, separates the two sets of plates of which the apparatus is seen to be composed. The swivel at S permits the frame to be swung round after being taken out of the acid in A and to be lowered into the pure water in *a*; this is for the purpose of washing off, after an experiment, the acid which might otherwise too rapidly corrode the plates.

88. The inventor regards this as furnishing an extreme case of great heating power with low electric intensity, and also as showing that the *quantity* of heat evolved in single large pairs is greater, but its intensity less than that given out by an equal quantity of metallic surface arranged in several successive pairs.

89. Though the most efficient voltaic circles, whether arranged as piles or troughs, are such as consist of plates of different metals and layers of fluid matter containing oxygen, as already described, yet combinations may be formed of various kinds of matter, besides, metals and acids, manifesting analogous effects, though, in most cases, with far inferior energy.

90. Dr. Baconio of Milan, constructed a voltaic pile entirely of vegetable substances; using disks of red beet root, two inches in diameter, and similar disks of walnut-tree, the latter deprived of their resinous matter by masceration in a solution of cream of tartar in distilled vinegar. With such a pile, using a leaf of scurvy grass as a conductor, he is stated to have produced contractions of the muscles of a dead frog. Other experimentalists have formed voltaic piles wholly of animal substances.

91. MM. Hachette and Desormes composed piles of layers of metallic plates separated by masses of common paste made of flour and mixed with marine salt (muriate of soda). This, which has been improperly called the dry pile, appears to owe its efficiciency to the attraction of moisture from the air by the salt contained in the layers of paste. Professor Zamboni of Verona, made a pile with disks of paper gilt on one side, and coated on the other with layers of black oxide of manganese made into a paste with honey.

92. The most simple arrangement of this kind is that called Deluc's electric column, consisting of disks of paper covered with gold or silver leaf, and similar disks of laminated zinc, properly arranged. Mr. G. J. Singer constructed an instrument in this manner composed of twenty thousand pair of disks inclosed in a tube of glass of suitable diameter, having at each end a brass cap, perforated by a screw for the purpose of pressing together the

What does it demonstrate with respect to the heat furnished by a single pair compared with that given out by the same amount of metal in other arrangements?

What materials were used by Baconio in the construction of his battery?

What materials did Hachette and Desormes employ?

What were adopted by Zamboni? what by Deluc?

What account is given of Singer's column?

disks, a wire being attached to either screw, so that one might be in contact with the zinc, and that at the other end with the other metal. Each extremity or pole of such a column will affect the electrometer, and exhibit electrical attractions and repulsions.

93. If two upright electrical columns be placed near each other with their poles in opposite directions, and their upper extremities connected, while a small bell is attached to the lower end of each column, and a brass ball is suspended between them, it will alternately strike either bell, and the ringing thus caused may be kept up for a great length of time. Sir J. Herschel mentions his having seen such an apparatus in the study of Deluc, which had continued in action for whole years.*

94. Some of the remarkable phenomena produced by the agency of the electric fluids, through the voltaic pile or battery, have been already noticed; and a few additional experiments may be adduced which will serve more strikingly to illustrate the mode of action of voltaic electricity, and demonstrate its similarity to common electricity.

95. Among the effects of the voltaic pile may be mentioned the production of sparks and brilliant flashes of light, the heating and fusing of metals, the deflagration of gunpowder and other inflammable substances, and the decomposition of water, saline compounds and metallic oxides.

96. The most splendid exhibition of light may be obtained by fixing pieces of pointed charcoal to the wires connected with the opposite poles of a voltaic battery. When the charcoal points are brought almost into contact, a vivid light and intense heat will be excited; and on gradually withdrawing the points from each other, a continued discharge of electric fire will take place, forming an arch of light of the most dazzling brightness. If the wires be introduced into a tube partially exhausted of air, and the charcoal points be made to approach and then recede as before, the effect will be heightened, and the arch of light will assume a beautiful purple colour.

97. Wires of metal introduced into the voltaic circuit may be raised to a red or white heat; and wires of moderate dimensions, composed of the least fusible metals, as platina, speedily become melted. The same effect is produced on some of the most refractory substances, as quartz, sapphire, magnesia, and lime; while fragments of the plumbago or of the diamond are dissipated, undergoing a real combustion.

How may such columns be employed to maintain oscillation?
What is related of the durability of the electric effect in such columns?
What are some of the effects produced by the voltaic pile?
How may electrical light be best exhibited by the galvanic apparatus?
What peculiar effect is observed when the experiment is made in vacuo?
What refractory substances are fused by the battery?

---

* See Discourse on the Study of Natural Philosophy, p. 343. On the principle of Deluc's column is constructed the electrical clock mentioned in the Treatise on *Mechanics*, No. 256.

98. The chemical powers of the voltaic battery have afforded the means for some of the most remarkable discoveries of modern times, among which it will be sufficient to mention the decomposition of potash and soda, and the exhibition of their metallic bases, by Sir Humphry Davy. But for an account of his researches, and of the modes of effecting various other chemical analyses by means of voltaic arrangements, we must refer the reader to the treatise on Chemistry, in the second part of the Scientific Class Book.

99. The decomposition of water by the voltaic battery may, however, be shortly noticed as one of the most simple yet important processes exhibiting the chemical influence of electricity. If two wires of platina connected with the opposite poles of a battery be passed through corks into the extremities of a glass tube filled with water, on suffering the electric current to traverse the fluid between the ends of the wires, it will be decomposed into oxygen and hydrogen gases; and if one of the wires be of iron, or any other easily oxidable metal, the oxygen will combine with the iron as fast as it is evolved, and the hydrogen only will appear in the form of gas. By a proper modification of the apparatus with two platina wires, both gases may be separately collected; and on examination it will be found that they are produced exactly in the proper proportions to form water.

100. The spontaneous evolution of electricity observable in some animals, and particularly in certain kinds of fishes, has been ascribed to galvanism; but though the electrical phenomena exhibited by the torpedo and a few other marine animals, have much analogy with the effects of the voltaic pile or battery, the researches of philosophers have not hitherto enabled us to ascertain how far the structure of the electrical fishes may be assimilated to the arrangement of bodies in different states of electricity, forming the galvanic pile. The production of electric sparks and other phenomena of a similar nature lead to the conclusion that electrical excitement is a concomitant property of animal life in general.

101. Many instances are recorded of the spontaneous display of electric light issuing from the skin of the human body, and the production of electricity by friction, as from the back of a cat, is a common and well-known phenomenon. Cardan mentions a Carmelite friar, from whose hair sparks issued whenever it was stroked backwards. Scaliger gives a somewhat similar account of a

What remarkable discoveries have been effected by its aid?

In what arrangement is the decomposition of water effected by galvanic electricity?

In what proportion are the elements oxygen and hydrogen found to be when separately collected?

To which class of artificial electrical phenomena does that of electrical fishes bear the strongest analogy?

What general facts indicate a relation between electricity and the existence of animal life?

What examples of electrical developement in the human body, and the bodies of other animals, have been recorded?

woman at Caumont, whose hair emitted fire when combed in the dark. Ezekiel di Castro, an Italian physician, in his treatise "De Igne Lambente," relates of Cassandra Buri, a lady of Verona, that when she touched her body but lightly with a linen cloth, it gave forth sparks in abundance. Scaliger, above quoted, mentions a white Calabrian horse, whose coat when combed in the dark emitted lucid sparks. Various instances of a similar nature are recorded by Bartholin, Beccaria, Saussure, and other writers; and those cases of spontaneous combustion which have been related by physicians were probably owing to the evolution of electricity; but of these further notice will be taken in the treatise on Chemistry.

102. The electrical animals already alluded to display much greater powers in the developement of electricity than those exhibited by human beings; and the production of the electric shock appears in these creatures to be dependent on the will, and the power of producing it to be bestowed on them in order that they may be enabled to defend themselves from their enemies, or to take the prey necessary for their subsistence. Among these animals the most noted is the torpedo (*raia torpedo*), the peculiar powers of which were known to the ancients, and are mentioned by Pliny, Oppian, and other writers. These phenomena have also been noticed by Redi, Koemper, and other modern authors; but Dr. Bancroft appears to have first conjectured that the influence of the torpedo depended on electricity, and Mr. Walsh made some important experiments which served to confirm this conclusion. The subject has since been more fully investigated by John Hunter, Spallanzani, Humboldt, Volta, and other philosophers.

103. The torpedo is an inhabitant of several different seas, being found on the coast of England, in the Mediterranean, and in Table Bay, at the Cape of Good Hope. The weight of the animal when full grown is about eighteen or twenty pounds. It gives a benumbing sensation, like an electric shock, when touched, and these effects are renewed by repeated contacts. The shock may be conveyed, like common electricity, through an iron rod or a wet line, but not through non-conductors. The greatest shock the torpedo can give is never felt above the shoulder, and rarely above the elbow-joint; its strength depending more on the liveliness of the animal than upon its size. The electric discharge is generally accompanied by an obvious muscular action in the animal, with an apparent contraction of the superior surface of the electric organs, and by a retraction of the eyes.

On what does the production of electric shocks in animals appear to depend? For what purpose is it generally employed?

What was known to the ancients respecting the powers of the torpedo?

By whom was the true nature of those powers first explained?

In what parts of the globe is the torpedo found?

How may the benumbing effect of this animal be transmitted to the person without an actual contact?

On what does the force of the shock depend?

By what effort does it appear to be produced?

104. These fish appear to be greatly weakened by the emission of electricity, and those that give shocks most readily soon become exhausted and die. From dissection of the torpedo it is found to be provided with peculiar organs, placed on each side of the head and gills, and connected with the nervous system. It has been ascertained, however, from the researches of M. Geoffroy St. Hilaire, that a similar organic structure is found in other animals of the raia genus, which nevertheless exhibit no electrical power.

105. The gymnotus electricus or electrical eel, is a fish having similar powers with the preceding. It is a native of the intertropical regions of Africa and America, being frequently found in the rivers and lakes of Surinam; and it was first described in 1677 by M. Richer, who was sent by the Academy of Sciences of Paris, to make philosophical observations at Cayenne. This fish (which was dissected by Mr. Hunter), like the torpedo, possesses peculiar electric organs, which consist of divisions, formed by thin plates or membranes, ranged transversely, so that in the space of one inch there were two hundred and forty of these transverse membranes. These organs are copiously supplied with nerves, and their too frequent use occasions debility and death. It seems, however, that they are not essential to the existence of these animals, which live and thrive after the organs have been removed.

106. Humboldt, in his "Tableau Physique des Regions Equatoriales," describes a curious method of taking the gymnoti, by driving wild horses into a lake which abounds with those fish. Some of these are very large, and capable of giving most powerful shocks, by which some of the horses are paralyzed and drowned; but the eels, at length, being exhausted by their own efforts, are taken without difficulty. This philosopher states, that the gymnotus in giving shocks does not make any motion of the head, eyes, or fins, like the torpedo.

107. Three other electrical fishes have been mentioned besides the foregoing, namely, the silurus electricus, found in the Nile; the trichiurus Indicus, which inhabits the Indian seas; and the tetraodon electricus, discovered off the island of Joanna. Little is known concerning the two latter; but they all appear to possess the same general powers of evolving electricity with those already described.

108. That the various phenomena of common electricity and galvanism, to which may be added those of magnetism, depend on the operation of a common cause, may now be regarded as an

What is the effect of repeated discharges on the fish itself?
Where is the gymnotus electricus found?
What peculiar organs has it in common with the torpedo?
By what method are the gymnoti captured?
What other fishes hitherto discovered possess the property of giving electrical shocks?
What remarkable chemical effects have been produced by the voltaic battery?

established principle of physical science; but the investigations which have led to this conclusion are only of recent date, though the experiments on which it is founded appear to be perfectly satisfactory.

109. In the progress of his electrical researches, Dr. Faraday found it necessary, for their further prosecution, to establish either the identity or the distinction of the electricities excited by different means; and in a paper of great value, which has been published, he has established beyond a doubt the identity of common electricity, voltaic electricity, magnetic electricity, thermo-electricity, and animal electricity. The phenomena exhibited in these five kinds of electricity do not differ in kind, but merely in degree; and in this respect they vary in proportion to the various circumstances of quantity and intensity, which can be at pleasure made to change in almost any one of the kinds of electricity, as much as it does between one kind and another.

110. Dr. Faraday was anxious to determine the relation by measure of ordinary and voltaic electricity; and after various excellent experiments he found as an approximation, and judging from magnetical force only, that two wires, one of platina and one of zinc, each 1-18 of an inch in diameter, and placed 5-16 of an inch apart, and immersed to the depth of 5-18 of an inch in acid consisting of a drop of oil of vitriol and four ounces of distilled water, at a temperature of about 60°, and connected at the other extremities by a copper wire 18 feet long and 1-18 of an inch thick (being the wire of the galvanometer coils), yielded as much electricity in 8 beats of his watch, or 8-150 of a minute (3.2 sec.) as the electrical battery (of 15 jars) charged by thirty turns of a plate machine 4 feet in diameter, and in excellent order. The same result was found to be true in the case of chemical force.*

111. It further appeared, from the experiments of Dr. Faraday, that a great number of bodies which when solid were incapable of conducting electricity of low tension, acquired by liquefaction or fusion the power of conducting it in a very high degree. Such are water, and several saline and other substances; but sulphur, phosphorus, camphor, spermaceti, sugar, and various other bodies, including *some* salts, acquire no conducting power when melted.

What have recent investigations proved with regard to the phenomena of Electricity, Galvinism, and Magnetism?

In what respect did Faraday find the different kinds of electrical action to differ?

State the relation in point of *magnetic force* and of *chemical action* between a four feet plate machine and a single Galvanic pair, with the conditions of the experiment.

What is the general effect of liquefaction on the conducting power of electrics?

What bodies remain non-conductors when melted?

---

* Encyclopædia Britannica, 7th edition, 1834, pp. 574, 575.

MAGNETISM.

112. It was long since conjectured by some philosophers that a connection exists between electricity and magnetism, and that electric and magnetic phenomena arise from the same cause. The discovery of the effects of the contact of metals and other voltaic combinations tended greatly to render the analogy more striking; but the grand discovery of the power of electric currents to induce magnetism was made only in 1819, by Professor Oersted of Copenhagen; and Mr. Faraday has more recently demonstrated the similarity of electricity and magnetism, by ascertaining a method of eliciting electrical sparks from the magnet.

113. The power of the natural magnet or loadstone to attract iron was known to the ancients, though they did not avail themselves of it for any useful purpose. The loadstone is an ore of iron, originally found in the country of Magnesia, in Asia, whence it derived its name;* but it is by no means uncommon in various parts of the world. The principal varieties are those called by mineralogists natural loadstone, earthy loadstone, and magnetic iron ore, all which are oxides of iron; and meteoric iron, or those masses which appear to have fallen from the atmosphere,† principally composed of metallic iron and nickel, are in general found to be strongly magnetic. All these bodies, as well as some other iron ores, have long been known to possess the property of attracting metallic iron when brought nearly in contact with it. The magnetic property is capable of being communicated to steel by touching it with a natural magnet; and in this manner artificial magnets are formed for various purposes. When steel is touched by a magnet it acquires permanent magnetism; but soft iron treated in the same manner, though it also becomes magnetic, loses its virtue as soon as it is separated from the magnet.

114. Other metallic bodies besides iron and steel are susceptible of magnetism. This is found to be the case with nickel, cobalt, and brass; the first mentioned of these metals especially being observed sometimes to manifest a high degree of magnetic power. Nor is this property confined to metals, for many other substances belonging to the mineral kingdom, as the emerald, the

What conjecture was formerly made respecting electricity and magnetism?

What is meant by loadstone? Where was it originally discovered?

What particular varieties of minerals belong to the magnetic species?

In what manner and to what materials may the magnetic property be communicated?

What difference arises in magnetizing soft iron from that of hard steel?

What other substances besides steel and iron are susceptible of being artificially magnetized?

---

* In the Greek language the loadstone is called Μαγνης.

† See Treatise on *Mechanics*, No. 88.

ruby, the garnet, and some other precious stones are stated by Cavallo* to be susceptible of magnetic attraction. More recent researches have led to the detection of magnetism in a great variety of bodies, including glass, chalk, bone, wood, and other kinds of animal and vegetable matter. And since it may be concluded that magnetic attraction is only a peculiar mode of action of the electric fluid or fluids, there can be no reason to doubt that its influence in particular circumstances must be as extensive as that of electricity, and consequently that all kinds of matter are subject to it.

115. The attraction of iron is to be regarded as only one of the peculiar effects of magnetism, but there is another which though less imposing and obvious, is highly important: namely, the polarity of magnetic bodies, or that tendency they possess, when capable of free motion, to assume such a position that one particular part, as one extremity of an iron rod suspended horizontally, shall be directed towards the northern regions of the earth, and the opposite extremity towards the southern regions. On this property depends the utility of the mariner's compass, which essentially consists of a magnetic needle suspended on a pivot, so that it may turn horizontally without obstruction. Such a needle, if the box containing it be placed on a level surface, will generally be observed to vibrate more or less, till it settles in such a direction that one of its extremities or poles will point towards the north, and the other consequently towards the south. If the position of the box be altered or reversed, the needle will always turn and vibrate again, till its poles have attained the same directions as before.

116. All magnets and magnetic bars have a north and a south pole; and if the north pole of one magnet be presented to the south pole of another, attraction takes place between them; but if two north poles or two south poles of different magnets be made to approach, they repel each other. If the north pole of a common bar magnet be presented to the south pole of the needle of a compass, the latter will be attracted, and may thus be drawn from its proper direction, which it will recover as soon as it is left at liberty; and on the contrary, if a similar pole be presented, as the north pole of the magnet to the north pole of the needle, the latter may be repelled, and thus driven from its true direction, to which it will return when the disturbing object is withdrawn.

What general conclusion follows the researches of recent experimenters on this subject?

What effect besides simple attraction is an attendant of magnetizing?

What practical purpose is subserved by this property of magnetized bodies?

Describe the manner in which this is applied.

How do poles of the same and those of opposite names respectively affect each other?

---

* See Philos. Trans. for 1786 and 1787; and Cavallo's Treatise on Magnetism, 1787, p. 73.

117. When a piece of iron not magnetic is brought in contact with a common magnet, it will be attracted by either pole; but the most powerful attraction takes place when both poles can be applied to the surface of the piece of iron at once. It is on this account that artificial magnets are often bent into the form of a horseshoe, the north pole being usually marked by a line or point to distinguish it.

118. Having thus stated the most common phenomena of magnetism, the reader will be prepared to understand the nature of the connexion between electricity and magnetism as deduced from the researches of Oersted, Ampère, Faraday, and other philososhers. It appears that a metallic wire forming a part of a voltaic circuit exercises a peculiar attraction towards a magnetic needle. Thus if a wire connecting the extremities of a voltaic battery be brought over and parallel with a magnetic needle at rest, or with its poles properly directed north and south, that end of the needle next to the negative pole of the battery will move towards the west, and that whether the wire be on one side of the needle or the other, provided only that it be parallel with it.

119. If the connecting wire be lowered on either side of the needle, so as to be in the horizontal plane in which the needle should move, it will not move in that plane, but will have a tendency to revolve in a vertical direction, in which, however, it will be prevented from moving in consequence of the manner in which it is suspended, and the attraction of the earth. When the wire is to the east of the needle, the pole nearest to the negative extremity of the battery will be elevated, and when it is on the west side that pole will be depressed. If the connecting wire be placed below the plane in which the needle moves, and parallel with it, the pole of the needle next to the negative end of the wire will move towards the east; and the attractions and repulsions will be relatively contrary to those observed in the former case. The connecting wire will be equally efficient whatever be the metal of which it is composed; and even a small tube filled with mercury will answer the purpose. The interruption of the circuit by water, unless it be carried to a great extent, does not prevent the action of the connecting wire; and its influence, like that of common magnetism, penetrates all bodies not too thick, whether conductors of electricity or non-conductors.

120. If an unmagnetized steel needle be placed parallel with the connecting wire of a voltaic battery, and nearly or quite in contact with it, the two sides of the needle become endued with

Under what circumstances is the most powerful exertion of magnetic force displayed?

What form must be given to the magnet in order to exhibit this?

What effect proceeds from placing over a compass needle, and parallel with its direction, a wire connecting two poles of a voltaic battery?

In what direction will the two poles of the needle move when the wire is on a level with the needle and parallel in direction?

What change of tendency will arise from carrying the wire below the needle?

opposite kinds of magnetism; one side being attracted by the north pole of a magnet, and the other side by the south pole. But if the needle be placed at right angles to the connecting wire, it will become permanently magnetic, one of its extremities pointing to the north pole and the other to the south, when it is suspended and suffered to vibrate undisturbed.

121. Magnetism may be communicated to steel by means of electricity from an electrical machine, evidencing the identity of the cause of attraction in the different cases; but the voltaic battery is more conveniently adapted to the purpose of rendering steel magnetic.

122. Among the various arrangements for the superinduction of magnetism in steel bars, one of the most efficient and useful is by inclosing the bar within the coils of a conducting wire twisted into a helix or corkscrew form, by wrapping it round a glass tube. It will then in some degree represent a polar magnet, and a bar of steel introduced into the central cavity of the helix will speedily become highly magnetic. The wire should be coated with some non-conducting substance, as silk wound round it, as it may then be formed into close coils without suffering the electric fluids to pass from surface to surface, which would impair its effect. If such a helix be so placed that it may move freely, as when made to float on a basin of water, it will be attracted and repelled by the opposite poles of a common magnet, forming a kind of voltaic magnet. M. Ampère describes such an apparatus under the appellation of an Electrodynamic Cylinder.

123. If a magnetic needle be surrounded by coiled wire covered with silk, the transmission of a very minute quantity of electricity through the wire will cause the needle to deviate from its proper direction. A needle thus prepared, therefore, forms an instrument adapted to indicate trifling degrees of electricity produced by the contact of metals, by slight changes of temperature, or by any chemical action of one body on another. The magnetic needle thus applied has been termed an Electro-magnetic Multiplier.

124. Professor Henry and Dr. Ten Eyck have availed themselves of the influence of voltaic electricity on iron, under the arrangement above described, to form magnets whose powers are most extraordinary. Those gentlemen first constructed an electro-magnet capable of supporting the weight of about 750 pounds; and they have since formed another which will sustain

Through what substances may the voltaic current be transmitted without affecting its influence over the magnet?
How may magnetism be communicated by the electrical current?
Is the magnetizing power limited to electricity from any particular source?
What arrangement gives the greatest facility in producing the magnetism of steel bars?
How may the voltaic magnet be constructed?
What name has Ampere given to that apparatus?
How is the electro-magnetic multiplier formed?

2063 pounds, or nearly a ton. It consists of a bar of soft iron bent into the form of a horseshoe, and "wound with twenty-six strands of copper bell-wire, covered with cotton threads, each thirty-one feet long: about eighteen inches of the ends are left projecting, so that only twenty-eight feet of each actually surround the iron; the aggregate length of the coils is therefore 728 feet. Each strand is wound on a little less than an inch: in the middle of the horseshoe it forms three thicknesses of wire, and on the ends, or near the poles, it is wound so as to form six thicknesses."

125. With a battery of 4.79 square feet, the magnet supported the weight already stated, 2063 pounds. The effects of a larger battery were not tried. It induced magnetism in a piece of soft iron so powerfully as to raise 155 pounds. When two batteries were employed, so that the poles could be rapidly reversed, it was observed that while one of the batteries was removed, the armature, with the weights suspended from it, amounting to 89 pounds, did not fall, though the magnetic influence must for a moment have been interrupted. This seemingly surprising phenomenon is readily explained by adverting to the obvious consideration, that the interruption and renewal of the voltaic circuit, and consequent magnetic attraction, occupied too short a space of time to admit of the armature becoming sufficiently detached from the poles of the magnet for it to sink beyond its influence, before the circuit was again completed; whereas, in general, its action ceases as soon as the circuit of electricity is entirely broken, affording a striking illustration of the nature and causes of magnetism.*

126. If any further evidence had been requisite to prove the analogy between electricity and magnetism, it might be derived from the discovery recently made by Mr. Faraday, of the possibility of eliciting electric sparks from the common magnet.

127. One arrangement for effecting this, consists of twelve sheer-steel plates, connected together, in the form of a horseshoe; with a keeper or lifter made of the purest soft iron. Around the middle of the keeper is a wooden winder, having about 100 yards of common threaded bonnet-wire, the two ends, composed of four lengths of the wire twisted together, being carried out with a vertical curve of about ¼ of a circle; one of these twisted ends passing beyond each end of the keeper, and resting on the re-

What extraordinary results have been obtained in the induction of magnetism by voltaic currents?

What apparent anomaly was observed by Messrs. Henry and Ten Eyck after breaking the voltaic circuit?

How is it to be explained?

What discovery illustrates most forcibly the analogy between electricity and magnetism?

What form of magnet has been found most convenient for this purpose?

Under what arrangement and operation of the apparatus are electric sparks elicited by the magnet?

* Silliman's American Journal of Science.

spective poles of the magnet. A small wooden lever is so fixed as to admit of the winder and keeper being suddenly separated from contact with the magnet, when a beautiful and brilliant spark is perceived to issue from that extremity of the wire which first becomes separated from the magnet. By means of this electro-magnetic spark gunpowder may be inflamed.

128. Some researches have been made relative to electro-magnetism by Dr. Ritchie, Professor of Natural Philosophy in the University of London. One of his experiments was the continued rotation of a temporary magnet on its centre by the action of permanent magnets. This effect is produced by suddenly changing the poles of the temporary magnet, and thus at the proper moment converting attraction into repulsion. The instrument used consists of a series of soft iron cylinders, having ribbons, or rather bands, of copper surrounding them, in a similar manner as in the apparatus for showing the detonation of oxygen and hydrogen gases by the electro-magnetic spark. The cylinders are made to revolve rapidly opposite the poles of the permanent magnet, so that before one current of electricity ceases the other commences its action. By a peculiar arrangement of the apparatus, Dr. Ritchie succeeded in obtaining a series of sparks from the common magnet, forming a complete circle, appearing in the dark like a lucid ring of the finest diamonds.*

129. The magneto-electrical machine of Mr. J. Saxton, an ingenious mechanic of Philadelphia resident in London, has been constructed by Mr. I. Lukens of Philadelphia, in a very neat and portable form, and serves to demonstrate the nature of the reaction between magnets and electrical currents. It consists of a horseshoe magnet capable of supporting about 10 pounds laid horizontal with the two poles at the same level. Through the bend of the magnet and between the two poles passes horizontally a spindle, carrying at the posterior part, next to the bend, a small toothed wheel acted upon by another of larger diameter turned by a crank. This spindle also carries at the anterior, and just beyond the poles of the magnet, a piece of soft iron bent into the form of a horseshoe, the arms of which are at the same distance apart as those of the stationary magnet. This is connected to the spindle through the intervention of a disk of brass, so that in revolving the soft iron magnetic poles come successively in contact with those of the permanent magnet.

130. The former is thus successively magnetized and neutralized, each complete revolution performing the operation twice over, reducing its two ends to the condition of north and south poles alternately.

What method was employed by Ritchie to produce continued rotation of a temporary magnet?

In what manner is the electric spark elicited in Saxton's apparatus?

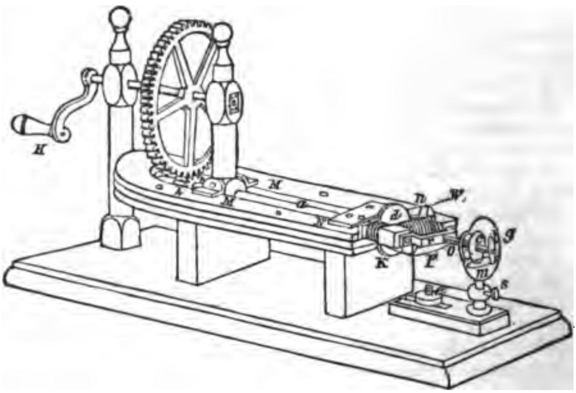
What is the succession of magnetic states in which the keeper is found in this apparatus?

---

* New Monthly Magazine for July, 1833, p. 366.

The means of manifesting these two states consists of a wound copper wire encircling the keeper, and having its two ends terminating, the one in a copper disk on the spindle exterior to the keeper, and the other in a small cross-head upon the same axis. The disk revolves, having a small part of its lower rim immersed in mercury. The cross-head alternately dips its two ends into the same cup, and at the moment of rising out of it exhibits a brilliant spark. The whole is supported on a neat mahogany frame.*

131. The accompanying figure represents Mr. Saxton's magneto-electric machine.



M is the horseshoe magnet, composed of three flat magnets united, and is about 9 or 10 inches long; *a* is the axis on which revolves the keeper K, to which it is connected through the intervention of the brass disk *d*, and at the other end the pinion *h* set in motion by the tooth wheel and winch H. Round the keeper K are wound several coils of wire, *w*, all terminating in the two separate polar wires *n* and *p*, of which the former is made to pass longitudinally through the wooden axis *o* on a line with *a*, but connected with the keeper by the rectangular piece of brass *r*, and then serves as an attachment for the little cross-head *t*, while the latter passes along the outside of the wooden axis, and joins the copper disk *c*.

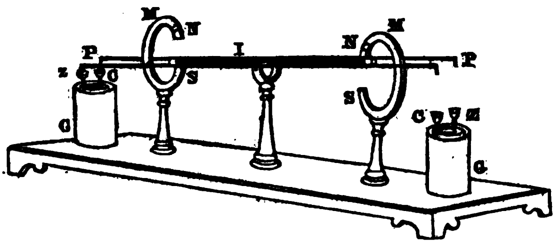
g is a nearly spherical glass cup, 2½ inches in diameter, with its mouth turned towards the magnet to receive the end of *o* with the copper disk and cross-head. This cup is supported on a stem of glass moveable up and down, and capable of being fixed at the

By what method is the spark made to pass between one part of the apparatus and the other?

* For a description of Saxton's apparatus see Journal of the Franklin Institute, vol. xiii. p. 155; and for Dr. J. Green's experiments with it, see the same volume, p. 269.

required height by the screw *s*, the lower part of the cup at *m* contains mercury; *e* is a nut and screw to keep the cup and stand in place.

132. Professor Henry of Princeton, New Jersey, has constructed an apparatus for exhibiting in a temporary magnet a reciprocating motion, the soft iron magnet with its coils of wire being suspended like the beam of a steam engine, on an axis, and furnished with projecting wires which dip into mercurial cups connected with a voltaic battery at each end of the apparatus. The wires are so arranged as to change the poles of the soft magnet at every alternation in the movement. Each end of the soft iron bar, I, plays between the poles of a permanent magnet curved into an elliptical form as seen at M M in the figure.



133. The north poles of the permanent magnets are both upward, and when the projecting wires at either end dip into the cup, the corresponding end of the soft iron becomes a south pole, and is repelled by the south pole of the magnet below it, while the elevated end being made a north pole is likewise repelled by the north pole of the other permanent magnet. These repulsions are so vigorous as to raise the wires out of the cups, and the momentum given to the bar throws the apparatus beyond the horizontal position, so that the wires at the opposite end dip into their appropriate cups, and the magnetism of the soft iron bar being instantly reversed, the operation is repeated.* The zinc element of each galvanic pair is marked *z* and the copper *c*. The poles of the two elliptic magnets are indicated by N and S respectively. It will be understood that the coil of wire is continuous, and all

In what manner has an alternating motion been produced by combined voltaic and magnetic influence?

To what states are the poles of the temporary magnet successively reduced?

How is the soft magnet made to raise its connecting wires from the mercurial cups in Prof. Henry's apparatus?

What is the best form of apparatus for exhibiting vivid galvanic sparks? On what circumstances does its efficacy appear to depend?

---

* See, for a description of this apparatus, Silliman's Amer. Journal of Science, vol. xx. p. 342. The above figure was kindly furnished to the editor by Prof. Henry.

in the same direction, and that one of each pair of projecting wires is the immediate prolongation of the *helix*, while the other, a straight line, comes from the opposite end of the bar, being soldered to the wire which *there* terminates the coil. The *reversing of the magnetism* will easily be understood from observing that each end of the helix, as P P, dips alternately into a cup from the copper, and then into one from the zinc element of the galvanic pairs G G. This neat and ingenious apparatus will continue in action for a long time, limited indeed only by the durability of materials in the galvanic circuits, and their power of furnishing a supply of electricity. It is far more energetic than Deluc's pendulum, or any similar apparatus depending on the action of what is called the dry pile.

134. Professor Henry has also made some interesting observations on the power of voltaic conductors to exhibit sparks proportioned to their lengths, breadths, and relative arrangement of parts, from which it appears that a ribbon of copper coiled into a spiral* gives a more intense spark than any other arrangement yet tried, and that an increase of length and of breadth in the ribbon gives an increase in the effect, but the limits of this increase are not yet ascertained.†

135. The identity of the electric influence under its various modifications—whether as arising from the excitement of electrics on non-conductors by friction, from the contact of bodies in different states, the one being positively and the other negatively electrified, from the action of heat, from compression; and in its more anomalous forms, as in the production of meteorological phenomena, of animal electricity, or of magnetism, from circulating currents of the electric fluids—may be regarded as having been satisfactorily demonstrated, in consequence of the experimental researches and important discoveries of modern philosophers.

136. Most of the topics of inquiry just mentioned have been already noticed in this treatise, the plan of which prevents the introduction of more detailed information, for which the reader may have recourse to works of greater extent, and to such as are exclusively appropriated to the discussion of the branch of science now under review. But the peculiar effects of currents of electricity on metallic substances, and especially steel, inducing magnetic attraction and repulsion, and the application of the magnetic needle to the purposes of navigation, demand some further notice, without which this compendium of science would be imperfect.

137. The general properties of the magnet, whether natural or artificial, and the affinity between contrary poles, and antipathy

What general truth, in regard to the different kinds of electricity, may now be considered as demonstrated by modern experiments?

---

* See Treatise on *Mechanics*, No. 202, note.

† See Journ. of Franklin Inst., vol. xv. p. 170.

between those which are similar, as in the case of bodies positively and negatively electrified, have been already noticed. Natural magnets or mineral loadstones, though sometimes possessing strong magnetic power, are not in all respects so well adapted for practical purposes as bars of steel artificially magnetized; and the latter are therefore used in the construction of the mariner's compass, and other instruments.

138. There are many methods of inducing permanent magnetism in steel; but one of the most simple and effectual consists in passing a strong horseshoe magnet over bars previously hardened and prepared. "If bar magnets are to be produced, the bars must be laid in a longitudinal direction, on a flat table, with the marked end of one bar against the unmarked end of the next; and if horseshoe magnets are required, the pieces of steel, previously bent into their proper form, must be laid with their ends in contact, so as to form a figure like this , observing that the marked ends come opposite to those which are not marked; and then, in either case, a strong horseshoe magnet is to be passed with moderate pressure over the bars, taking care to let the marked end of this magnet precede, and its unmarked end follow it, and to move it constantly over the steel bars so as to enter or commence the process at a mark, and proceed to an unmarked end, and then enter the next bar at at its marked end, and so proceed.

193. After having so passed over the bars ten or a dozen times on each side, and in the same direction, as to the marks, they will be converted into tolerably strong and permanent magnets; but if, after having continued the process for some time, the exciting magnet is moved but once over the bars in a contrary direction, or if its S. pole should be permitted to precede after the N. pole has been first used, all the previously excited magnetism will disappear, and the bars will be found in their original state. This seems to show an effect of circulation rather than of any internal mechanical arrangement; and from the circumstance of a stronger power in proportion being produced in thin plates of steel than in thick ones, and the acquired magnetism being diminished by rust, filing, or grinding, it appears that the virtue communicated is more external than internal."*

140. That a suspended magnet will become fixed in such a direction as if its opposite poles were attracted by certain points of the earth, not very distant from the north and south poles respectively, was known at an early period, but it is somewhat uncertain

What kinds of magnets are best adapted to the purposes of navigation?
What is the method of producing bar magnets?
How are horseshoe magnets placed in order to be magnetized?
In what manner may a magnetized bar be neutralized, and its poles reversed?
What facts favour the supposition that magnetism is chiefly confined to the surface of a bar?

* Report of Mr. Millington's Lectures at the Royal Institution in 1818, published in Journal of Science, vol. vi. pp. 82, 83.

when navigators first availed themselves of this property of the magnet, in order to discover the points of the compass in cloudy weather, when neither the sun by day nor the stars by night can afford them any assistance. Some writers state that Marco Polo, the Venitian traveller, about 1260, introduced among the Italians the use of the mariner's compass, having learnt it from the Chinese; but it is more commonly regarded as the invention of Flavio di Gioja, a native of Amalfi, in the kingdom of Naples, who says that he used it in the Mediterranean Sea in the thirteenth century.

141. The compass which was first employed by European seamen, about the period just mentioned, appears to have been a very rude instrument, consisting of pieces of the natural loadstone, fixed on cork or light wood, so that it might float on the surface of water, in a dish on which were marked the cardinal points of the compass. At present the mariner's compass is more accurately constructed, under various forms adapted to peculiar purposes; but in all cases composed of a small flattened magnetic steel wire, or needle, carefully suspended on a pivot in a horizontal direction, so that it may vibrate and revolve with the least possible degree of friction; and when intended to be used on board a ship, it is made to hang in a frame which preserves its horizontal position independent of the motion of the vessel. A card is placed below the magnetic needle, on which are described two circles, one divided into 360 degrees, and the other marked with the thirty-two points of the compass; and thus the direction of the magnetic poles in any given situation may be ascertained and noted.

142. There are several circumstances which interfere with the regular action of the magnetic needle, and to which, therefore, the attention of the mariner must be directed in making observations, and performing calculations founded on them, so as to obtain exact information. These are chiefly the "dip" of the magnetic needle, its "secular" and "diurnal variation," and that anomalous variation that long puzzled navigators, but which is now supposed to depend on the attraction of the iron used in the construction of a ship, or any other portions of that metal which it may contain, acting on the compass and disturbing its regular operation. The dip of the needle is a tendency manifested by either pole to lose its balance except near the equator, the north pole sinking as if heaviest on the north side of the equator, and the south pole on the south side. As it is of importance to the

To whom has been ascribed the discovery of the directive influence of the earth upon suspended magnets?

How early was this principle applied by Gioja?

Of what did the compass then consist?

What is the form of the mariner's compass at present used?

In what manner is its *card* divided?

How many circumstances interfere with the regular action of the compass?

What is meant by the dip of the needle?

How is its amount to be ascertained?

sailor to be able to estimate the extent to which the compass may be thus affected in any situation, an instrument is provided for the purpose, called a "dipping needle," in which the magnetic wire is suspended in a vertical direction.

143. It has been already observed that the magnetic poles of the earth, or those points towards which the poles of a compass are directed, do not exactly coincide with the poles on which the earth performs its diurnal revolution; and this deviation of the magnetic from the true meridian, is termed the variation of the compass. It appears to have been first discovered, or rather accurately observed by Sebastian Cabot, in 1497; and in the seventeenth century, Henry Gellibrand ascertained that the variation itself is subject to a secular alteration. Thus when the variation was first noticed at London, the needle pointed to the east of the true meridian; in 1657 there was no variation, the needle pointing exactly north and south; it then progressively veered westward, having, as is supposed, attained its utmost western declination about 1818, when it had reached 24 deg. 36 min. W.; and it now appears to be annually verging towards the east.

144. Hence it seems not only that the earth's poles of revolution do not correspond with its magnetic poles, but also that the latter are not stationary, the line of no variation, which passed through London in 1657, now crossing the continent of North America; to account for which it has been conjectured by some, that the north magnetic pole revolves round the north pole of the earth in about 644 years, and consequently, in 1979, the line of no variation will again cross the island of Great Briain, as it did in 1657; for if the period of revolution of the magnetic pole be 644 years, half that period, $322 + 1657 = 1979$ will indicate nearly the next return of no variation, while others supposing that the earth's magnetism is due to the electric currents excited by the heat of the sun, and that these currents produce magnetizing effects, the resultants of which are in the points of greatest cold, have conceived that it is to these points that the north pole of the needle is directed, and that as such points may vary somewhat from age to age, the direction of the needle must vary with them.

154. The diurnal variation of the magnetic needle was first noticed by Mr. George Graham, who gave an account of his observations to the Royal Society in 1722. It amounts to several minutes of augmentation or diminution of the secular variation, at any given place, in a day; and it appears to be occasioned by the influence of the sun's light or heat, or perhaps by both. Its quan-

What is meant by the *variation* of the needle?

Is the variation constant, when we compare it through long periods of time?

Who discovered the *secular* alteration?

Give the history of this alteration as observed in Great Britain.

When was the *daily* variation discovered?

What is its amount?

On what does it appear to depend?

tity is likewise affected by the seasons, being more considerable during the summer than in the winter.

146. The intimate connexion between electricity and magnetism, evidenced by the very important discoveries recently made, affords abundant reasons for believing that the polarity of the magnetic needle must be liable to variations, from the influence of certain natural phenomena. Thus some observers, and especially Captain Franklin, have stated that the action of the needle is impeded by Aurora Borealis, the appearance of which seems to be dependent on electricity; and it has long since been remarked that atmospheric electricity often powerfully affects the magnet.*

147. Another curious fact is the induction of magnetism by the exposure of a steel wire or needle to the violet ray of the solar spectrum. These and other phenomena recently observed certainly indicate such a connexion between heat, light, electricity, and magnetism, as affords grounds for regarding them as probably depending on a common cause; and the very curious discoveries which have been already made, and the striking analogies observed between the operations of nature under different circumstances, furnish abundant inducement to contemporary philosophers, and indeed to all who feel an interest in the advancement of science, to pursue the track already opened, with the fair prospect that the assiduous inquirer will be amply rewarded for his time and attention to these most important topics of investigation.

What occasional occurrences influence the action of the magnetic needle?

What relation has been discovered between *light* and *magnetism*?

---

* "We have instances," says Professor Winkler, "that magnetic needles have acquired an inverted direction by the violence of a flash of lightning, the north pole coming to be the south."—*Elem. of Nat. Philos.* vol. i. p. 331.

Works in the department of Electricity.

A Popular Treatise on the subject of Electro-magnetism, by By Jacob Green. Philadelphia.

Cumming's Electrodynamics.

Cambridge Physics, treatise on Electricity, Magnetism, and Electro-magnetism.

Library of Useful Knowledge, treatises on the same subjects.

Singer on Electricity, 1 vol. 8vo.

Priestly on Electricity, 1 vol. 4to.

Franklin's Philosophical Papers, 1 vol. 8vo.

Faraday's recent Researches in the Transactions of the Royal Society.

Becquerel, in the Annales de Chimie

Thompson on Heat and Electricity.

Berzelius's Chemistry, (Fr.) vol. i. article Electricity. Paris edition

INDEX.

Aberration of the fixed stars, p. 343
  Chromatic, . . 393
Absolute space, ... 15
Action and reaction equal, . . 22
  irregular in machines, . 104
Accelerated motion, . . . 36
Achromatic telescopes, . . 392
Acoustics, general account of, . 231
  books on, . . . 276
Adjutages increase the flow of water, ... 170
Æolian harp, ... 260
Aeriform fluids, ... 15
  how confined, . 16
  dilate equally, . 301
Aerolites, ... 51
Aeronauts, regulate their elevation, ... 37
Aerostatics, ... 218
Aerial images in concave mirrors, 361
Air, properties of, ... 180
  currents of, produced by fall of water, ... 171
  columns of, in tubes, . . 246
  compressibility of, . . 181
  composition of, . . . 183
  compressed, ... 193
  combines with water, . . 194
  dry, a bad conductor of electricity, ... 426
  elasticity of, ... 185
  expansion of, by heat, . . 292
  gravity of, ... 182
  gun described, . . . 205
  thermometer, . . . 294
  vessel of a forcing pump, . 218
  weight of, . . . 182, 196
  pump, construction of, . . 186
    vacuum in, . . 195
    mode of action in, . 188
Albinos, ... 374
Ampère's electro-magnetic experiments, ... 453
Angles of incidence and reflection, 28
  of friction, ... 111
  of vision, ... 342
  different kinds of, . . 10
Angular velocity, ... 57
Animal power, ... 115
  structure, . . . 80
Anvil supported on the body, . 25
Aplanatic lenses, . . . 395
Aqueducts, Roman . . . p. 140
Arc of oscillation, ... 61
Archimedes' screw, ... 174
  mechanical feats, . 107
  experiments on Hiero's crown, . 150
Area of stability, ... 64
Aristotle, error of, . . . 43
Arnott's hydrostatic bed, . . 135
Artesian wells, ... 144
Astronomy, more perfect than other sciences, . 13
  how far known, . 12
Atmosphere, height of a uniform, 206
  extent of, . . . 207
  density of, by Laplace, . . . 208
  adhesion, produced by, . . . 209
Atmospheric refraction, . . 365
Ass, physical power of, . . 119
Attraction of gravitation, . . 36
  electric and magnetic, 12
  capillary, . . . 163
  cohesive, in liquids, . 123
  of metals for heat, . 396
  magnetic, . . . 451
Attwood's machine, ... 51
Audibility, ... 236
Aurora borealis, effects of, . . 462
Automaton, ... 265
Axis of a lens, ... 368
Axle and wheel, ... 84

Bacon, Roger's idea of flying, . 224
  formed speaking figures, . . 271
  knew the use of lenses, . . . 408
Baconio's vegetable electric pile, 444
Ball cannon, how brought to rest, 19
  ivory, compressed by collision, ... 24
  billiard, moved by springs, 33, 100
  of wax, proves force of gravity, 42
  weight of, at the centre of the earth, ... 45
Ballast, how stowed, ... 181
Balance for weighing, ... 81
  false, ... 82
  Danish, ... 82
  hydrostatic, ... 162

Balloon, why it ascends, . p. 37
inflated with hot air, . 221
with coal gas, . 223
calculations respecting, . 223
affords means of determining aerial temperatures, . . . 283
Bamberg bellows, . . . 192
Barker's mill, ... 176
Barlow on seasoning timber, . 290
Barometer invented, . . . 199
wheel, . . . 202
water, . . . 203
compound, . . 203
Barton's iris buttons, . . . 403
Battery, voltaic, . . . 440
Bed, hydrostatic, . . . 135
Beer, fermenting, effect of, . . 194
Bell, diving 227
Bellows, hydrostatic, . . . 133
smith's, ... 192
Bernouilli on human strength, . 116
Beudant's silk electrical machine, 431
Bevell'd wheels, ... 102
Bianchi's galvanic clock, . . 114
Billiard table, motions on, . . 29
Biot's experiments on sound, . 240
on vocal sound, 263
or repetitions in pipes, . . 270
Birds, wings of, ... 81
Black, Dr. on melting ice, . 305
Blind person restored to sight, 378
Bladders for swimming, . 158
air, in fishes, . 159
Boat moved by oblique force, . 35
rowing of a, . . . 79
flying, ... 224
Bodies, falling laws of, . 43
projected upwards, . 52
elastic and inelastic, . 24
Bones of the ear, ... 232
Books on acoustics, . . . 276
mechanics, . . . 121
heat, ... 332
optics, . . . 417
electricity, . . . 462
hydrostatics, . . 165
hydraulics, . . . 179
pneumatics, . . 230
Boiler, Perkins'. 312
Bolognian phosphorus, . . 337
Bossut on flowing liquids and jets, 169
Bottle imps, ... 191
Bramah's hydrostatic press, . 134
Breast wheel, ... 175
Brewster on double refraction, . 405
Bridge, iron arched, raised by heat, ... 289
Briot's coining press, . . . 105
Bouyancy, centre of, . . . 161
Buchanan on human labour, p. 116
Bucket supported on the edge of a table, ... 69

Cæsar, Julius, employed specula, 408
Cadet de Vaux on preserving lamp glasses, ... 290
Caloric, ... 278
engine, ... 323
Calorimeter, Lavoisier's, . . 304
Calorimotor, Hare's, . . 441, 443
Camel, power of the, . . . 119
water, ... 162
Camera lucida, ... 414
obscura, . . 373, 414
Canal locks, ... 146
Candle may be shot through a plank, ... 23
Canton on compression of water, 125
Capacity for heat, . . . 304
Capillary attraction, . . 163
Capstan, ... 85
double, ... 87
Cargueros, ... 117
Catoptrics, ... 347
Cataracts, ... 145
Cavendish on the density of the globe, ... 41
Celsius' Thermometer, . . 295
Central forces, ... 56
Centrifugal forces, . . 56, 57, 58
Centripetal forces, . . 56, 57
Centre of action, . . . 72
gravity, . . 65, 67
pressure, . . . 137
curvature of mirrors, . 355
Chantry's observations on hot air, 326
Change of motion proportionate to force, ... 28
Chantepleur apparatus, . . 212
Charles first inflated balloons with hydrogen, . . . 221
Chimborazo, gravitative attraction of, ... 40
Chladni's experiments on sound, 240
do. do. 251
Chromatics defined, . . . 384
Chain pump, ... 172
Circle, divisions of, . . . 9
Circus, motions in, . . . 34
Cistern, flowing of water from, . 136
regulated by a ball-cock, 160
Circuit, galvanic, . . . 439
Clock, electrical, . . . 114
Coaches, when liable to be overturned, ... 68
Cochlion, ... 174
Cog, hunting, ... 101
Cogs, ... 87
Cohesion of liquids, . . 123
Coining press, ... 104

Colour, cause of, ... p. 402
Colours, ... 384
number of, ... 385
breadth of, in the spectrum, ... 390
of thin plates and rings, . 399
Columns, electrical, ... 445
Combustibles, ... 287
Combustion, a source of moving power, ... 114
Components of oblique forces, 31, 32
Compass needles, ... 460
variations of the, . . 461
Composition of forces, frequent, . 33
Compensation pendulums, . . 103
Compressibility of air, . . . 181
Cone, double, to show centres of gravity, ... 67
Concords in music, ... 246
Contracted vein, ... 167
Concert pitch, ... 253
Conductors of heat, . . . 320
Convex mirror, ... 356
spectacles, . . . 410
Conductors of electricity, . . 426
Convulsive motions by galvanism, 438
Cornea, ... 375
flattened in aged persons, 409
Cords, tension of, ... 88
Corks, used in swimming, . . 158
Cordage, stiffness of, . . . 108
Couronne de tasses, . . . 440
Coulomb on human labour, . 116
Crickets, notes of, . . . 237
Cruickshank's battery, . . 440
Curved surfaces, motions on, . 54
Curvilinear motions, . . . 55
Cuvier's experiments on the voice of animals, ... 265
Cycloid, the curve of isochronism, 61
Cylinder electrical machine, . 430

Dalton on liquid expansion, . 301
Daniel on the pyrometer, . . 298
on quantity of rain falling, ... 142
Danish balance, ... 82
Davy's discoveries by galvanism, 446
on heating by friction, . 286
Deflagrator, Hare's, . . 441, 442
Delue on the maximum density of water, ... 302
Delisle's thermometer, . . . 296
Density defined, ... 147
related to temperature, . 302
Desaguliers on human labour, . 116
Descent of bodies from the moon, 46
Dexterity, feats of, ... 71
Diameter, polar, of the earth, . 45
Dickenson, Captain, use of diving bells, ... 229
Differential thermometer, . . p. 299
Diminution of objects by distance, 380
Dioptrics, ... 362
Dipping needle, ... 461
Direction of gravitation, . . 41
line of, ... 70
Dispersion of light by lenses, . 390
Discharge of liquids through orifices, ... 169
Distances measured by sound, . 238
Diving bell, ... 227, 228
Diving, deep, effect on the ear, 138, 232
jackets, ... 229
Distillation, ... 310
Dogs employed to labour, . 119
Dollond's achromatic lenses, . 394
Double refraction, . . . 403
vision, ... 377
Dragging friction, ... 110
Drebbel, inventor of the thermometer, ... 293
supposed inventor of microscopes, . . 411
Driving wheel, ... 100
Drum of the ear ruptured by diving, . . 232
capable of tension, . . 237
Dromedary, power of, . . . 119
Drowning, how to prevent, . 157
Druids, ... 92
Duhamel on musical glasses, . 251
Dynamics defined, ... 17

Ear, musical, ... 242
Earth's attraction, ... 39
Earth supposed to be perforated, 46
Ebullition, ... 309
in vacuo, ... 310
Echo, ... 267, 268
Eckeberg's extraordinary feats, . 25
Eclipse of the sun, ... 346
Ecliptic, obliquity of, causes the seasons, ... 281
Efficiency of wheel work, . . 87
the inclined plane, 92
the screw and lever, 96
compound machines, 106
the hydraulic ram, . 178
Efficacious rays, ... 396
Elater noctilucus, ... 336
Elasticity common to all matter, . 23
a measure of gravity, . 42
of the human body, . 25
of steam, ... 316
as a moving power, . 113
of air. 185
experiments on, . . 191
Electricity, ... 418
excited by friction, . 424
kinds of, ... 425

Electricity, kinds of, all identical, p. 449
Electrical animals, . . 447
balance, . . . 428
chime of bells, . . 435
dance, . . . 435
jar, ... 434
machine, . . 429, 431
Electric fluid, ... 421
positive and negative, . . . 423
Electrics, ... 427
Electroluminous ether, . . 16
Electromagnetism explained, . 421
Electromagnetic cylinder, . . 453
induction, . 452
Electrometer, ... 428
Electroscope, ... 428
Elements, four, apparatus of, . 149
Elephants, strength of, . . 119
walk on tight rope, . 71
Engine, steam, ... 313
fire, ... 218
caloric, ... 323
Equator, centrifugal force at, . 58
Equilibrium in a balance, . . 29
by cords and pullies, 29
of lamps suspended, 30
stable and unstable, 71
of floating bodies, . 161
Ericsson's caloric engine, . . 323
Esquimaux use *snow eyes*, . . 411
ventriloquists, . . 275
Ether, boiling, freezes water, . 309
luminiferous, . . . 339
electroluminous, . . 16
Eulenstein, improved the Jews'-harp, ... 258
Euler on Barker's mill, . . 176
Eustachian tube, ... 231
Evans', Oliver, steam-engine, . 318
Evaporation, rate of, . . . 308
of ice, . . . 308
Expansion of bodies, . . 279, 288
liquids, . . . 300
in freezing, . . 303
Experiment, its value to physical science, . . 13
on composition of forces, . . . 33
on bodies falling in vacuo, . . . 38
with the air-pump, . 190
Extraordinary rainbows, . . 398
Eye, structure of, . . . 374

Fahrenheit's thermometer, . . 294
Faraday, gasses condensed by, . 179
magneto-electric sparks, 454
on vibrating plates, . 252
Fata Morgana, ... 353
Fat persons float easily, . . 156
Feather and guinea apparatus p. 38
Fecundating powders in the air, 220
Firmus, feats of strength by, . 25
Figures, geometrical, . . . 10
Fire engine, ... 218
Fishes, air bladders in, . . 159
electric, ... 448
Flea, comparative strength of, . 113
Float boards, direction of, . . 175
Floating of bodies on water, . 155
Floatation employed to raise weights, ... 160
Florence academy, . . . 125
Flow of water through apertures, 167
Fluid, electric, ... 421
aeriform, ... 15
imponderable, . . . 16
magnetic, how used, . 16
viscous, ... 122
Fly wheel, ... 104
Flying, art of, . . . 220, 224
Foci conjugate, ... 370
Focus of a mirror, . . . 355
lens, ... 370
Forcing pump, ... 217
Forks, tuning, differ in different nations, ... 254
Force of traction, . . . 118
or impetus, how estimated, 22
of gravitation, . . . 50
Forces, parallelogram of, . . 31
central, ... 56
composition of, . . 31
union of, in one line, . 32
resolution of, . . . 35
Fordyce on ponderability of heat, 277
Fountain, Hero's, . . . 193
Fountains, submarine, . . 144
intermitting, . . 214
Four elements, ... 149
Franklin on learning to swim, . 157
pouring oil on the sea, 171
electrical kite of, . . 226
theory of electricity by, 422
Freezing, artificial mode of, . 306
French horn, ... 259
Friction, ... 20
action of, . 108, 109, 110
angle of, . . . 111
wheel, ... 111
Frogs electrified after death, . 437
Fruits, shrivelled, expand in vacuo, ... 190
Fulcrum, ... 75
Fusee, ... 86

Gamut, musical, ... 246
Galileo on falling bodies, . . 43
discovered the law of oscillation, . . . 61
Gasses, specific gravity of, . . 154

Gauges, rain, their construction, *p.* 142
Garipuy, application of siphons, . 214
Gay, Lussac, balloon ascension, . 222
Gasses, different kinds of, . . 183
their power of conducting sound, ... 239
Gattoni abbate, ... 260
Galvani's discovery in electricity, 419
Galvanism, ... 436
Geometrical lines, ... 9
Gilbert, Dr. 418
Giant's harp, ... 260
Glasses broken by sound, . . 251
Globular form of liquid masses, . 165
Glottis, ... 262
Glow worm, ... 336
Goat employed in mechanical labour, ... 120
Gold, globe of, compared to the earth, ... 39
Gongs used in China, . . . 256
Governor for machinery, . . 105
Gray's electrical discoveries, . 419
Gravity, cause of, unknown, . 11
affects all bodies, . 20, 38
centre of, ... 66
prevents perpetual motion, ... 20
a general moving force, . 36
is in proportion to masses, 39
gives velocities inversely as masses, . . . 39
influence of, by Cavendish, 41
its direction, . . 41, 42
force of, increases with the height, . . . 42
is inversely as squares of distances, . . . 44
counteracted by centrifugal force, . . 59
determined by pendulums, 63
of mountains, . . . 40
experiments on, . . 40
intensity of, at London, . 50
centres of, how determined, ... 67
acts as a moving power, 113
specific, . . . 147, 162
centre of, in liquid masses, ... 166
causes the flow of liquids, 168
of air, ... 182
Grindstones split by centrifugal force, ... 59
Guinea and feather experiment, . 38
Guitar, structure and use of, . 255

Hammer, a mechanical power, . 78
how driven upon its handle, . . . 26
Hammer, water, . *p.* 130
Hammering produces heat, . 287
Handmill, ... 104
Hare's litrameter, ... 150
deflagrator and calorimotor, 441
Harmonica, ... 256
Hawksbee's electrical discoveries, 418
Hearing trumpet, . . . 275
Heat, a moving power, . . 114
cause of, ... 277
sources of, ... 280
sources of, within the earth, 284
produced by friction, . . 285
evolved by compression, . 287
latent, ... 303
specific, ... 304
propagation of, . . . 320
reflection of, . . . 329
Hebstock to raise carriages, . 83
Heights measured by falling bodies, . 51
barometer, 201
Heliostat, ... 417
Helix defined, ... 95
Hemispheres, Magdeburg, . . 197
Henry's mode of magnetizing soft iron, . . . 454
vascillating magnet, . 457
induction of electricity, . 458
Hero's fountain, ... 193
Herbert on expansion, . . . 300
Herschel on solar heat, . . 280
on thin plates, . . 400
Hiero's crown, fraud in, detected, ... 150
High pressure steam-engine, . 317
Hildreth on the cicadae, . . 261
Hogshead burst by a small tube, 133
Home, Sir E. on the fly's foot, . 209
Hollow cylinders, strength of, . 113
Horn, French, ... 257
Horse power, standard of, . . 118
Horses, strength of, . . . 118
Humours of the eye, . . . 375
Human body, stability of, . . 70
Humboldt's description of cargueros, ... 117
Humboldt on equatorial climates, 282
Hunter's screw, ... 97
Hunting cog, ... 101
Huygens' arc of isochronism, . 61
Hydraulic machines, . . . 172
ram, ... 177
Hydraulics, science of, . . 166
books on, . . . 179
Hydrogen applied to aerostation, 221
Hydrometer, ... 163
Hydrostatic balance, . . . 162
paradox, . . . 132
press, . . . 134
Hydrostatics, science of, . . 122

Ice, effect of, in preventing friction, ... p. 109
evaporated at low temperature, ... 308
Iceland spar, ... 404
Images, double by refraction, . 404
formed by lenses, . . 372
in a dark room, . . 340
in plane mirrors, . . 350
in a concave mirror, . 360
Impenetrability of air, . . . 180
Imponderable fluids, . . . 16
Impressions, durability of, . . 381
Imps, bottle, ... 191
Incandescence, ... 279
Incidence, angle of, . . 364
Inclined planes, ... 91
motions on, . 53
Induction of electricity, . . 427
Index of refraction, . . . 365
Inertia, nature of, ... 20
Incoercible fluids, . . 16
Inflaming point of vapours, . 327
Ingenhouz, Dr. on conduction of heat, ... 321
Insects, sounds produced by, . 261
eyes of, ... 373
Insensible spots on the retina, . 383
Interference of liquid particles, . 167
Insulation, electrical, . . 427
Invariable stratum, . . 284
Invisible lady, ... 271
Iris buttons, ... 403
Isochronism of pendulums, . . 61
Italian musical scale, ... 248
Ivory compressed by collision, . 24

Jacobi, Barbara, ventriloquist, . 274
Jar, Leyden, ... 433
Jew's-harp, ... 257

Kaleidoscope, structure of, . . 350
Kempelen's automaton, . . 265
Killarney, echo at, ... 269
Kite, paper, its mode of action, . 226
Knife used by druggists, . . 79
Kratzenstein's vocal tubes, . . 264

Labyrinth of the ear, . . . 231
Labour, human, ... 116
Lacerta gecko, ... 209
Ladder, how raised, . . . 80
Lama, power of, ... 120
Lamp glasses, sinumbral, . . 367
Lapwing, ... 261
Laplace on density of air, . . 208
Latent heat, ... 306
Larynx, ... 262
Lathe, turning, ... 80
Laws of curvilinear motion, . 28
Laws of falling bodies, . p. 49
motion, by Attwood, . 63
Leaden ball equal to the atmosphere, ... 206
Leaning towers, ... 69
Lemon squeezers, . . . 79
Lengths of pendulums, . 163—164
Lenses, burning, ... 388
optical, ... 368
convex, ... 369
concave, ... 371
achromatic, . . . 394
Levelling instrument, . . . 139
Lever, properties of, . . . 74
mode of its action, . . 75
theory of, ... 76
orders of, ... 78
progressive, . . . 78
compound, . . . 81
Leyden phial, ... 432
Lifting pump, ... 217
Light and heat, cause of, unknown, 12
interrupted by the air. . 334
transmission of, . . 335
velocity of, . 338, 342, 344
moves in right lines, . . 339
intensity of, how diminishes, 340
theory of, ... 386
Lightning identical with electricity, ... 419
rods, ... 436
Liquid substances defined, . . 15
pressure on container, . 137
Liquids, properties of, . . . 122
and solids, how different, 123
form of, in large masses, 124
weight and pressure of, . 129
equal pressure of, . . 136
different in density, . 148
impact of, ... 172
conduct heat imperfectly, 322
produce electricity by friction, ... 425
Liquors bottled in condensed air, 227
Litrameter of Dr. Hare, . . 150
Loadstone, natural, . . . 450
Locks on canals, . . . 146, 147
Locusts, ... 261
Ludolf's electrical discoveries, . 419
Lukens' magneto-electric machine, ... 455
Luminous bodies, . . . 333
Lunar bow, ... 398
Lyon's account of arctic dogs, . 119
Lyre, account of the, . . . 254

Machine, Attwood's 51
effects of, how investigated, ... 72
complex, ... 98

Machine, compound, how estimated, . . p. 105
usefulness of, . . 112
Mainspring of a watch, . . 86
Magic lantern, ... 415
Magdeburg hemispheres, . . 197
Magnetism, ... 450
terrestrial, . . 459
Magnetizing, ... 459
Malus discovered polarization, . 406
Maskeleyne, experiments of, . 41
Masses and velocities produce momentum, ... 21
Mast-head, ball dropped from, . 34
Materials used in the arts, . . 112
Maximum density of water, . 302
Mechanics, nature of, . . . 17
necessity of, . . 17
Mechanic powers, ... 72
Media, refracting, ... 364
Medium, resistance of, to motion, 19
Mechanical use of the gases, . 184
Melville Island, ... 282
Meniscus lens, ... 372
Mercurial gauge, ... 187
Metals, polished, bad radiators, . 331
Metronome, Maelzell's, . . . 65
Micrometer screw, ... 98
Microscope, simple, ... 411
compound, . . . 412
solar, ... 416
lucernal, . . . 417
Middle C of the piano forte, . 249
Mill, Barker's, ... 176
Minerals luminous after heating, 338
Mirage, ... 351
artificial, ... 352
Mirror, plane, ... 349
concave, effects of, . . 359
Chinese, ... 357
burning, ... 328
Mixtures, calorific, ... 288
frigorific, ... 307
Mobility defined, ... 18
how estimated, . . . 18
Moccia's power of floating, . 156
Molard restoring the position of walls, ... 289
Momentum, how estimated, . 72
of power and resistance, 78
Montgolfier's hydraulic ram, . 177
balloon, ... 221
Moon seen through clouds, . . 18
phases of the, ... 346
Morveau on Wedgewood's pyrometer, ... 298
Motion requires an active cause, . 19
affected by inertia, . . 21
different kinds of, . . 27
direction of, . . . 27
Motion accelerated, . . p. 36, 47
on inclined planes, . . 52
rotatory, ... 99
conversion of, . . . 101
of liquids, how caused, . 166
in distant bodies, . . 380
Moving bodies, ... 25
force, oblique, . . . 35
powers, ... 113
Muschenbroek's jar, ... 432

Nairne's electrical machine, . 429
Natural philosophy, object of, . 14
forces producing motion, 72
Nature supposed to abhor a vacuum, ... 199
Navigation of rivers, ... 146
Newcomen's engine, ... 314
Newton's laws of curvilinear motion, ... 28
cause of planetary motions, ... 38
theory of light, . . 386
error respecting dispersion, ... 393
experiments on coloured rings, ... 400
Niagara, cataract of, ... 145
Nighthawk, noise of, . . . 261
North pole, weight of a body at the, ... 45
Notes, musical, ... 247
Nut crackers, ... 79

Oblique action, ... 88
Octave organ pipes, ... 244
Oersted, water compressed by, . 126
discovers electromagnetism, ... 425
Oil, effect of, in calming ripples, . 171
Opaque bodies, ... 407
Optical axis, ... 404
instruments, ... 407
Optics, science of, ... 333
works on, ... 417
Orbits of the eyes, ... 375
Ore, a mode of raising, . . . 86
Organ pipes, length of, . . . 244
Oscillation of pendulums, . . 59
centre of, ... 64
Otto Guericke's air-pump, . . 190
hemispheres, . 198
Overshot wheel, ... 175
Oxen, power of, ... 120
Oxyhydrogen microscope, . . 417

Pacos, power of, ... 120
Paganini, ... 255
Papin's digester, ... 311
Parachute, ... 223

Paradox, hydrostatic, . . p. 132
Paraselene and Parhelia, . . 353
Parallelogram of forces, . . 30
Parallelopiped, sides of, . . 33
Parallel motion of Watt, . . 102
Pascal, discovery of in hydrostatics, ... 134
on barometric measurements, ... 201
experiments on liquid columns, ... 204
Pendulums, oscillation of, . . 60
weight of, . . 61
length of, . . 62
compensating, . . 103
Penumbra, ... 345
Percussion and pressure compared, ... 93
Perkins, steam boiler of, . . 312
on compressibility, . 126
on condensation of air, . 180
Peron on human labour, . . 118
Persian wheel, ... 173
Phases of the moon, ... 346
Phantasmagoria, ... 416
Phantasmascope, ... 382
Philosophical inquiry, limits of, . 13
Philosophy, natural, arrangement of, . . 14
defined, . 11
Phosphorescence of matter, . 335
of the sea, . 337
Physical sciences, province of, . 14
Piezometer of Perkins, . . 127
Pincushion and cannon ball compared, ... 23
Pile, electric, ... 444
voltaic, ... 439
Pinion and wheel, ... 99
Plane, inclined, . . 53, 91, 92
Plaster of Paris, mirrors made of, 328
Plates, colours of thin, . 399
Pliny on speaking nightingales, . 266
Pluviameter or rain-gauge, . . 142
Pneumatics, science of, . . 179
Polarization of light, . . . 406
Polarity, magnetic, by light, . 462
Polyedrons, ... 10
Pompeii, lead pipes used in, . 140
Porters, strength of, . . . 117
Potter's wheel, ... 59
Power or impulse defined, . . 21
when counterbalances resistance, ... 105
Powers, mechanic, division of, 72, 73
moving, ... 113
Press, hydrostatic, . . . 134
Pressure on curved surfaces, . 55
and percussion, . . 93
centre of, . . . 137
Pressure, hydrostatic, . . . p. 131
of air on the body, . 206
Prince, Dr. improved the air-pump, 196
Printing press, Russel, . . . 88
Prisms, defined, ... 11
refracting, ... 385
Proteus, supposed meaning of, . 14
Pumps, ... 214
with holes in the suction pipes, ... 216
lifting, ... 216
Pulley described, . . . 89, 90
compound, ... 91
Pupil of the eye dilated, . . 376
Puy de dome, experiments on, . 201
Pyronomics, ... 277
Rack and pinion, ... 102
Radiation, ... 327, 330
Radius of curvature, ... 57
Railway planes, ... 92
Rain, how retarded, ... 141
quantity of estimated, . 141
gauge, ... 142
quantity of in different countries, ... 143
Rainbow explained, ... 396
Rarefaction, degree of, . 188—195
Rays, efficacious, ... 396
refracted by drops, . . 396
Reaumur's thermometer, . . 294
Receiver fixed to air-pump, . 197
Reciprocating motion, . . . 101
Regulation of machinery, . 102, 103
Reindeer, labour performed by, . 120
Remora, ... 210
Rennie on strength of granite, . 112
Reed suspended by hair and broken, ... 26
Reflected motion, ... 28
Reflection of sound, . . . 266
of light, . . . 348
by thin plates, . . 401
atmospheric, . . 351
from concave surfaces, 358
from convex surfaces, 354
Refraction of light, . . . 363
angle of, . . . 364
index of, . . . 365
double, . . . 403
negative and positive, 405
Refractive power, ... 391
Refrangibility of colours, . . 388
Resiliency, ... 24
Resistance defined, . . . 21, 72
as related to power, . 21
Resinous electricity, . . . 423
Resonances, ... 253
Resolution of forces, . . . 35
Resultant of oblique forces, 31

Resultant of three or more forces, p. 32
Retina of the eye, ... 341
Ricochet motion on water, . . 128
Rider in a circus, ... 34
Rings, coloured of Newton, . 400
Rigidity of cordage, ... 111
Ritchie's magneto-electric apparatus, ... 455
Rockets, sky, ... 225
Rolling friction, ... 110
Roman aqueducts, ... 140
Romans understood hydrostatic pressure, ... 140
Rope pump, ... 173
  ferry boat, ... 35
Rowing, labour in, ... 117
Rozier and Romain, . . . 222
Rumford, ... 278
  on heating by friction, . 286
  calorimeter of, . . . 305
Russel press, ... 88

Sadler the aeronaut, ... 222
Sails set to receive a side wind, . 35
  of a windmill, ... 35
Saint Bernard, mount, ... 283
Sand on vibrating plates, . . 252
Santorio's thermometer, . . 293
Sappharina indicator, . . . 337
Saxton's electro-magnet, . . 55
Scale of musical composition, . 245
  diatonic, ... 246
Scales for weighing, . . . 81
Scoriae float on melted metals, . 158
Scott, (Sir W.), insensible to music, ... 242
Screw, properties of, . . . 94
  Hunter's, ... 97
  efficiency of, ... 95
Sealing-wax, electrical state of, . 424
Seconds' pendulum, ... 64
Seeds conveyed through the air, 218
Seesaw used as a machine, . . 75
Shadows, ... 345
Sharp castings of iron, . . . 302
Shuckburgh on specific gravity, . 152
Sight, how assisted, ... 15
Siphon, invested with mercury and water, . . . 149
  principle of the, . . 212
  Wirtemberg, . . . 213
Sling, principle of, . . . 56, 58
Smoking through the ears, . . 232
Smoke ascending in air, . . 37
  descend when cooled, . 37
  and balloon near each other, 38
Smoothness, only apparent, . . 109
Snow eyes, used by the Esquimaux, ... 411
Snow melted by black earth, . 331
Soda water, . . . p. 194
Solid bodies, ... 15
  figures, ... 10
Solids immersed in fluids, . . 138
  pressed by liquids, . . 171
Soniferous undulations, . . 235
Sonorous bodies, ... 243
Sound, medium of, ... 233
  inaudible in vacuo, . . 233
  propagated through solids, 234
  vibrations caused by, . . 234
  diminished by distance, . 237
  inversely as square of distance, ... 238
  velocity of, ... 238
  conducted by water, . 239
  transmitted by solids, . 240
  interference of, . . . 231
  reflection of, ... 266
  concentrated by a sail, . 270
Space, relative, defined, . . 15
Spaces described in falling, . 48
  as square of velocities, . 50
  relative to power and resistance, ... 106
Sparks from voltaic apparatus, . 445
Speaking trumpet, . . . 272
Specific gravity, by the siphon, . 150
  table of, . . 153
  of persons, . 155
Specific heat, ... 304
Spectacles, ... 407
Spectre of the Brocken, . . 361
Spectrum, solar, ... 385
Spina, inventor of spectacles, . 407
Spiral, ... 95
Spirit, level, ... 139
Sponge, principle of its action, . 164
Stable equilibrium, ... 71
Stability, area of, ... 70
Statics defined, ... 17
Statera, Roman, ... 82
Steel-yard, ... 82
Steamboat, iron, ... 160
Steam, temperature of, . . 311
  engine of Watt, . . 312
  engine of Evans, . . 319
  boilers projected upwards, 225
Stewart on ventriloquism, . . 273
Stockenschneider on heating, . 286
Stonehenge, ... 92
Strength of materials, . . . 112
Strings, musical, ... 243
Sun blind, ... 85
  the fountain of heat, . . 280
  influence of, on climate, . 282
Surfaces, convex motions on, . 55
Sultzer's discovery on metallic effects, ... 427
Suspension, points of, . . . 81

Swimming, how learned, . p. 156
importance of, . . 157
Syringe, exhausting, . . . 187

Table of falling bodies, . 48, 51
specific gravities, . . 153
Tackle of pullies, . . 91
Tantalus' cup, ... 213
Tate liqueur, ... 212
Telescopes, achromatic, . . 392
refracting, . . 413
reflecting, . . 414
Temperature, ... 282
remarkable, . . 285
Temperatures obtained by Daniel, 299
scales of, . . 298
Teneriffe, peak of, . . . 379
Tension, ... 112
of cords, ... 88
Thaumatrope of Dr. Paris, . . 381
Thermometer, ... 292
scales, . . . 298
mercurial, . . 297
differential, . . 299
Time of falling bodies, . . 48
related to mechanical action, ... 107
Tobacco pipe, experiment with, . 69
Toggle joint, ... 88
Torricelli invented the barometer, ... 199
Torricellian tubes, . . . 201
Tournaments, collision in, . . 23
Torpedo, explosive, . . . 230
electric, . . . 448
Towers, leaning, ... 69
Traction, force of, . . . 118
Transmitting motion, . . . 87
Transparent bodies, . . . 333
Transparency of media, . . 334
Tread wheel, ... 86
Tuba stentoriphonica, . . . 273
Tubes, safety, Watson's, . . 159
capillary, ... 164
long, retard flowing water, 170
of adjutage, . . . 170
Tunics of the eye, . . . 374
Tuning forks, ... 254
Twilight, ... 366

Undulations, theory of, . . 338
Uniformly moving bodies, . . 27
Unstable equilibrium, . . 71

Vacuum, perfect, unattainable in the air-pump, . . 195
nature's abhorrence of, 199
Vaporization, ... 307
Variation of gravity, measured, . 59
the compass, . . 461
Velocity before and after impact, p. 21
of moving bodies, . . 25
measured by time and space, ... 26
degrees of, produced by falling, ... 42
required to project bodies to the moon, . 46
acquired, . . . 47, 49
on inclined planes, . 54
angular, . . . 57
maximum in a jet of water, . . . 168
of light, ... 342
of sound, ... 238
Vein contracted in flowing liquids, 167
Venturi, marsh drained by, . 171
Vent hole in casks, . . . 211
Vessels, two, encountering, ruinous to the smaller, . . . 23
Vibrating figures, . . . 68
Vibrations of musical strings, . 235
of sonorous bodies, . 243
numbers of, . . 248
visibly demonstrated, 250
of luminiferous ether, 387
Vision, organs of, . . . 373
at different distances, . 376
distant, ... 379
Voice, human, ... 262
Volta modified Galvani's theory, 420
Von Mengen, Baron, a ventriloquist, ... 275
Vowel sounds formed by pipes, . 265

Walcot, Dr. mimicry by, . . 273
Walrus, foot of, ... 210
Water barometer, . . . 203
compressibility of, . . 124
compressed by Perkins, . 128
daily supply of, in London, 140
collected in basins under ground, ... 145
resistance of, to pressure, . 152
distilled, weights of, . . 153
camel, ... 160
discharged from a basin, . 170
wheels, ... 174
works, air-vessel of, burst, 177
rising in a pump, . . 200
held in an inverted tumbler, 211
Watt's jointed bars, . . 102, 316
estimate of horse power, . 118
steam-engine, , . . 314
sun and planet wheels, . 101
Wedge explained, ... 93
Weighing machine, ... 83
Weight of body carried to the moon, ... 44
as a moving force, . 72

Weight, of liquids, . . p. 129
diminution of, by immersion, . 130
only apparent, . 132
of air, ... 182, 184
Wedgewood's pyrometer, . . 297
Wells, Artesian, ... 144
Wheatstone on sound, . . 258
Wheel removed from a carriage, 77
and axle, ... 83
work, efficiency of, . . 87
and pinion, . . . 99
driving, ... 100
toothed, ... 100
sun and planet, . . 101
Persian, ... 173
overshot and breast, . 175
barometer, . . . 202
Wheels, friction, ... 111
Whirling table, ... 57
Whispering gallery, . . . 270
White's pulley, ... 91
Wick raises oil by capillarity, . 164
Wind instruments, . . . 256
pipe of animals, . . 262
Wirtemberg siphon, . . . 213
Wollaston on sounds inaudible, . 237
Wollaston's concavo-convex lenses, 410
Works of reference on mechanics, 121
hydraulics, 179
acoustics, . 276
pyronomics, 332
optics, . 417
electricity, 463
hydrostatics, . 165
pneumatics, 230

THE END.

From C. H. Alden, A. M., Chairman of the Examining Committee of the American Association for the Supply of Teachers, and Principal of the Philadelphia Female High School.

Sir,—I have with care looked over a very valuable work, lately from your press, "Eschenburg's Manual of Classical Literature," and I close the volume with feelings which prompt me to state to you, in a few words, my opinion of its merits. Its title is sufficiently indicative of its contents, but without examination, no scholar would suppose that in about 650 pages are comprised full, but concise and able, treatises on the following subjects:—Archæology of Greek and Roman Literature and Arts, History of Greek and Roman Literature, Mythology of the Greeks and Romans, Greek and Roman Antiquities, and Classical Geography and Chronology. A glance at these subjects will show, that if sufficiently exact, this Manual will supply the place of some four or five volumes, which the diligent student finds it useful often to consult. The portion devoted to the view of the Classical Authors may seem too limited, and yet all that can be easily retained in memory, i. e. the most important facts, are given. In other respects I am not disposed to wish it enlarged by the addition of a single paragraph. The fact that this Manual has gone through seven or eight editions in Germany, a country, most of all, celebrated for classical attainments, is of itself no mean commendation of its excellence; and it is somewhat singular that three or four eminent classical scholars, in distant parts of our country, were engaged in the translation of it at the same time, unknown to each other: so general is the conviction of its utility among us. Though Professor Fiske very modestly comes before the public as a translator of the work only, it will be found that many and very important additions and useful alterations are made. Besides what is necessary on the subject of the value of Greek and Roman coins, there are interesting additions to the text of Eschenburg respecting the remains of Athens and Rome, and a condensed view of the sacred writings, and the writings of the early Christians, as found in the Greek language. The whole of part five is also added. Professor Fiske deserves much from our scholars for this excellent epitome, and I have little doubt that he will be gratified by its extensive circulation and use. It is well adapted to our high schools and academies, as well as indispensable to the college student, unless, indeed, he would have the trouble to refer often to Adams, Lempriere, Urquhart, and others. In every public and private library it deserves a place, and will no doubt find one, when the work becomes generally known.

Very respectfully, CHARLES HENRY ALDEN.

July 7, 1836.

The following extracts are from a critical notice of the "Manual," published in the Biblical Repository, Andover, Mass.

"Eschenburg's Manual of Classical Literature" has long had a high reputation in Europe, having gone through seven or eight editions in German, and one in a French translation. The author zealously extended a taste for English literature in Germany, having translated the works of Burney, Shakspeare, &c. Among his publications, the one now first presented to the American public, and which has been adopted as the basis of public and private instruction in the major part of the colleges and universities in Germany, is designed to form a complete manual of the most essential aids in reading the classical authors. The matter, in the American dress, is arranged under five parts, or heads:—Part I. Archæology of Literature and Art. Part II. History of Ancient Literature, Greek and Roman. Part III. Mythology of the Greeks and Romans. Part IV. Greek and Roman Antiquities. Part V. Classical Geography and Chronology. The volume is divided into about 600 paragraphs, for the sake of convenient reference. These are printed in a larger type, and are for the most part a translation from Eschenburg. Inserted between many of these paragraphs are a large number of references, explanatory remarks, illustrations, &c., nearly all from the pen of the translator. In these additions, Professor Fiske has rendered more complete the great design of the work, in that which constitutes its peculiarity, and distinguishes it from other works in the language.

As to the need of such a work as this of Eschenburg, there can be but one opinion. Some valuable detached sources of information may be found, like Potter's Antiquities; but no comprehensive, copious, and at the same time select and discriminating manual on the subject has been within the reach of the mass of students. The statement of the contents of the work of Eschenburg just given, will furnish some idea of the comprehensive nature, as well as the scientific arrangement of the topics; both of which are characteristic of the volume. The number of works referred to, the various sources and materials for further illustration and investigation, are very great. While these will not impede the progress of the young student, being for the most part thrown into a small and separate type, they will furnish the advanced scholar clues and hints for more extended and profound research. The references are not merely to German works, but to English publications, and frequently to important articles in our periodical Reviews. The manner in which the translator has executed his work needs no commendation from us.

5

success of "Part II.," which you have just published, is therefore not to be doubted. Given to the public under the supervision of the same accredited scholar as the former volume; enriched by additional illustrations; in many places emended, and containing a valuable list of bibliographical notices, it can, with propriety, be commended to the use of schools and academies, as well as to private families, as a most valuable manual. The treatise on Chemistry, though necessarily very short, embraces a perfect outline of the science, and contains the most recent discoveries. The tracts on Metallurgy, Mineralogy, Chrystallography, Geology, Oryctology, and Meteorology, are nowhere more lucidly and attractively explained. This volume ought to accompany Part I., wherever that is adopted; indeed, in my opinion, it is more deserving of public favour.

The style and execution of the "Scientific Class-Book, Part II.," as a production of your press, is highly creditable.

February 16, 1836.

From John M. Keagy, M. D., Professor elect of Dickinson College.

After an examination of the second volume of the "Scientific Class-Book," I feel a pleasure in stating that it fully sustains the character given of the previous part, as an excellent compend on the subjects of which it treats. The Chemistry and Metallurgy, the Geology, and History of Fossils, and the sketch of Meteorology, are particularly clear and comprehensive, to be comprised within the limits of a single duodecimo. JNO. M. KEAGY.

Philadelphia, February 15, 1836.

From Professor Beck, Rutgers College, New Brunswick, N. J.

"The Book of Science," by Mr. J. M. Moffat, which forms the basis of the present volume, (Scientific Class-Book,) has already become extensively and deservedly popular in England. Professor Johnson, the American editor of these volumes, has greatly improved them by correcting many of the errors contained in the original works, and by the addition of many interesting notes, of a set of questions for examination, lists of works for reference, &c. They are very properly styled "A Popular Introduction to the Principles of Physical Science." On each of the subjects treated of, there is an amount of information in these volumes which is seldom found in elementary treatises of this description; while this information is set forth in such a manner as peculiarly to engage the attention of the pupil. In their composition, the best authorities have been consulted, and "due acknowledgments have been made wherever they seemed to be required." These works are indeed what they purport to be—*Scientific* Class-Books; and Professor Johnson deserves well of the friends of science for the labour which he has devoted to the preparing of them for the American public. If the friends of education are really in earnest in the business of improvement, these books will soon take the place of those incorrect and defective treatises on the various branches of physical science which most unfortunately are now so generally adopted.

Refuge, near Mechanicsburg, Pa., June 15, 1836.

Sir,—I have examined your "Scientific Class-Book," Parts I. and II. As the result of my examination, I am happy to state that in these books I found a work well adapted to, and much wanted in our schools. The editor, Professor Johnson, has evinced a sound judgment in the additions made; and you, as publishers, have conferred a lasting favour upon the public in giving this judicious work circulation, and I trust it will be generally introduced in all our schools and families. I can recommend it as one of the best works extant, on the physical sciences. I shall cordially use my influence to give the work an extended introduction into schools, lyceums, and families. J. D. RUPP,

Agent for the Pa. Lyceum.

From C. H. Anthony, Esq., City Surveyor, (Troy, N. Y.,) and Lecturer on the Natural and Experimental Sciences.

As a teacher of the Natural and Experimental Sciences, I have often felt the need of some works in all respects adapted to the present state of science in this country. My *beau ideal* of such a work is fully realized in the "Scientific Class-Book," parts First and Second; and I have lost no time in introducing them into my school.. Part First is *excellent*; but Part Second I consider as the best text-book in general science ever published in the English language.

From Samuel Jones, A. M., of Philadelphia.

I have already given the First Part of the "Scientific Class-Book" my approval; and now, after having tested the utility of the Second Part, I am fully prepared to endorse the favourable opinion expressed by others of its value.

curate knowledge of etymology is deemed important. Dr. Keagy's preliminary essay on the forms of thought as giving origin to those of expression, will greatly enhance the value of the work to all teachers who place any reliance on the philosophy of instruction. WM. RUSSELL,

No. 92, South 8th street, Philadelphia.

From Mr. J. H. Brown, Teacher, Philadelphia.

The "Etymological Dictionary" of Oswald, needs no commendation when it is known that its merits have been such as to induce Dr. J. M. Keagy to revise and improve it for the use of schools and academies.

The merits of the work will bear testimony in favour of the ability of Mr. Oswald for the present undertaking; while the extensive philological researches of Dr. Keagy, his devotion to the cause of education, particularly to the study of language, and his success as a teacher, leave no room to doubt the merit and utility of the present work.

No one aiming to make himself master of the English language, should be without a copy of the present work, for daily examination and reference.

J. H. BROWN,

May 16, 1836. No. 52 Cherry street.

"The Etymological Dictionary by Dr. Keagy on the basis of Oswald," appears to me highly adapted to remove many of the difficulties with which youth have to contend in their earlier attempts at composition. Those who have had the slightest experience in teaching, must be aware how utterly inadequate our ordinary dictionaries are to the wants of the pupil; and even were his judgment sufficiently matured to make the necessary discrimination, the time requisite for searching the larger dictionary, could not well be spared from other studies. While the work, however, presents many important advantages to the learner, it proposes neither to supersede the exercise of his judgment, nor to secure in every instance a just application of the language without labour and care. From the ease with which reference is made to principles, in the arranging of the words according to their genera, thereby enabling the pupil to acquire the signification of a whole class of words with comparative ease; and in the facilities afforded to the mere English scholar for obtaining a radical acquaintance with his own language, the Etymological Dictionary offers decided advantages to the pupil, and must prove a valuable auxiliary to the teacher. JAMES GOODFELLOW,

Teacher, Sansom street.

From Charles Henry Alden, A. M., Chairman of Examining Committee of the American Association for the Supply of Teachers.

Mr. Edward C. Biddle,—

I have examined with great interest your "Etymological Dictionary," and I am convinced that its use will prove of immense benefit to pupils and students of every age. While its prominent design is to furnish a correct knowledge of our language, it will serve also as a most admirable apparatus for mental discipline. To the teacher who is not acquainted with the Latin and Greek languages, this work is invaluable; and even to the classical scholar, the number of derivatives placed after the several roots, will suggest shades of signification invaluable to him who is desirous of expressing his thoughts in definitive terms.

Dr. Keagy's Introduction is such as a mind like his might be supposed to produce. Successfully devoted to elementary instruction for several years, and having given his attention very much to what may be called the philosophy of education, he has here put together a series of facts, and from them deduced principles of primary interest to all, especially to parents and teachers. The work ought to be adopted as a text-book in our high schools, and be possessed and daily used by our students in college.

From J. B. Walker, A. B., Teacher, of Philadelphia.

Such a book as "Oswald's Etymological Dictionary of the English Language" has long been a desideratum. I am gratified to find that this excellent work, improved and rendered more practically useful by the labours of Dr. Keagy, has at length been given to the public. It is well fitted to exercise the pupil's powers of discrimination and judgment, and to aid him in acquiring a *thorough* knowledge of the English language. It commends itself to the consideration and adoption of teachers.

IN PRESS.

A BIBLIOGRAPHY OF ZOOLOGY, with Bibliographical Sketches of the principal Authors. By William Swainson, F. R. S. L. S. First American Edition, with numerous Illustrations and Corrections by S. S. Haldeman, Member of the Academy of Natural Sciences of Philadelphia, Author of "A Monograph of the Limniades, or Freshwater Univalve Shells of North America," &c. Embellished with a Portrait of Thomas Say.

This important work, by an English naturalist of high standing, contains the names of about five hundred writers on Natural History, with a complete list of their works, and numerous biographical sketches.

Such a work has long been a desideratum, both among professed naturalists and students of natural history, especially in this country; where it has hitherto been almost impossible to ascertain what works have been written upon particular branches of the subject.

To the present edition, the American editor has added about one hundred names, including an extended list of American authors; and many important German, French and Italian names.

IN PREPARATION FOR THE PRESS.

A GEOGRAPHY OF PENNSYLVANIA, designed for the use of Schools and for the general reader.

Such means have been taken for the collection of information as the publisher believes will enable him to issue a work embracing, in a condensed form, a view of the physical character, climate, population, productions, wealth, internal improvements, state of education, &c. &c., throughout the State, and in each county.

The services of a gentleman, eminently qualified for the office, have been secured, to edit the work, which the publisher hopes may prove worthy the patronage of the public.