Gerolz

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A

SCHOOL COMPENDIUM

OF

NATURAL AND EXPERIMENTAL

PHILOSOPHY,

EMBRACING THE ELEMENTARY PRINCIPLES OF

MECHANICS, HYDROSTATICS, HYDRAULICS, PNEUMATICS, ACOUSTICS, PYRONOMICS, OPTICS, ELECTRICITY, GALVANISM, MAGNETISM, ELECTRO-MAGNETISM, MAGNETO-ELECTRICITY, AND ASTRONOMY.

WITH A DESCRIPTION OF THE

STEAM AND LOCOMOTIVE ENGINES.

BY

RICHARD GREEN PARKER, A.M.

PRINCIPAL OF THE JOHNSON GRAMMAR SCHOOL, BOSTON; AUTHOR OF AIDS TO ENGLISH COMPOSITION, OUTLINES OF GENERAL HISTORY, ETC., ETC., ETC.

"Delectando pariterque monendo,
Prodesse quam conspici"

NEW YORK:

PUBLISHED BY A. S. BARNES & CO.,

NO. 51 JOHN-STREET.

CINCINNATI:—H. W. DERBY & CO.

1853.

TO THE

Hon. SAMUEL ATKINS ELIOT,

MAYOR OF THE CITY OF BOSTON, AND CHAIRMAN OF THE SCHOOL COMMITTEE.

Sir,

The Public Schools of this city are under many obligations to you, for the interest you have taken in them, and for your disinterested exertions for their improvement. This volume, designed to supply a want which they have long felt, affords an opportunity of acknowledging the obligation, which I gladly embrace. The gratification which I feel in seeing you at the head of our municipal institutions, I beg leave to express in borrowed language:—

Tibi ut gratuler non est in animo; sed contra, hanc occasionem, mihi sic oblatam, nostram civitatem gratulandi, reniti non possum. Quæ omnia solita tua benevolentia ut accipias quæso.

I am, Sir, very respectfully,

Your obedient Servant,

RICHARD GREEN PARKER

PREFACE.

The School Committee of the city of Boston having recently furnished the Grammar Schools with apparatus for exemplifying the principles of Natural Philosophy, the author of this work, who, for twenty years, has been at the head of one of these large establishments, and has felt the want of an elementary treatise *unencumbered with extraneous matter*, has been induced to attempt to supply the deficiency. If he is not deceived in the result of his labors, the work will commend itself to notice by the following features:

1. It is adapted to the *present state* of natural science; embraces a wider field, and contains a greater amount of information on the respective subjects of which it treats, than any other elementary treatise of its size.

2. It contains engravings of *the Boston School set of philosophical apparatus;* a description of the instruments, and an account of many experiments which can be performed by means of the apparatus.

3. It is enriched by a representation and a description of the *Locomotive* and the *Stationary Steam Engines*, in their latest and most approved forms.

4. Besides embracing a copious account of the principles of Electricity and Magnetism, its value is enhanced by the introduction of the science of Pyronomics, together with the new sciences Electro-Magnetism and Magneto-Electricity.

5. It is peculiarly adapted to the convenience of study and of recitation, by the figures and diagrams being first placed side by side with the Illustrations, and then repeated on separate leaves at the end of the volume. The number is also given, where each principle may be found, to which allusion is made throughout the volume.

6. It presents the most important principles of science in a larger type; while the deductions from these principles, and the illustrations, are contained in a smaller letter Much useful and interesting matter is also

crowded into notes at the bottom of the page. By this arrangement, the pupil can never be at a loss to distinguish the parts of a lesson which are of primary importance; nor will he be in danger of mistaking theory and conjecture for fact.

7. It contains a number of original illustrations, which the author has found more intelligible to young students, than those with which he has met elsewhere.

8. Nothing has been omitted which is usually contained in an elementary treatise.

A work of this kind, from its very nature, admits but little originality. The whole circle of the sciences consists of principles deduced from the discoveries of different individuals, in different ages, thrown into common stock. The whole, then, is common property, and belongs exclusively to no one. The merit, therefore, of an elementary treatise on natural science must rest solely on the judiciousness of its selections. In many of the works from which extracts have been taken for this volume, the author has found the *same language* and expressions without the usual marks of quotation. Being at a loss, therefore, whom to credit for some of the expressions which he has borrowed, he subjoins a list of the works to which he is indebted, with this general acknowledgment; in the hope that it may be said of him as it was once said of the Mantuan Bard, that "he has *adorned* his thefts, and polished the diamonds which he has stolen."

It remains to be stated, that the Questions at the bottom of the page, throughout the volume, were not written by the author, but were prepared by another hand.

R. G. P.

BOSTON, *March*, 1848.

ADVERTISEMENT

TO THE SEVENTEENTH EDITION

Ten years have elapsed since this work first appeared in permanent form from the hands of the stereotyper. During this time, the author has been gratified to learn that sixteen editions have been called for by the public; but this gratification has been mingled with regret that he has been unable from time to time to make such improvements as he knew were needed, and which the progress of science, as well as a more extended experience, seemed imperiously to demand. He gladly avails himself of the present opportunity, afforded by the new publishers into whose hands it has fallen, to make such improvements as in his opinion will render it more worthy of the liberal patronage it has received; for although it is a long time since the author has had any pecuniary interest in the work, he hopes that it is not true that he has had "no further solicitude."

The necessity of a revision of the work at this time will appear from the following statement. By a vote of the School Committee of Boston in 1836, a certain portion of philosophical apparatus was introduced into the Grammar Schools, as an experiment. The apparatus was designed to unite economy with simplicity, and was confined to the departments of Pneumatics and Electricity. To this apparatus the book was specially adapted, though not wholly confined. By a recent vote of the Committee, (August, 1847,) apparatus of superior construction, and embracing a much wider field, was substituted for the cheap and defective sets that were at first introduced. It becomes necessary, therefore, in a volume prepared with special reference to the wants of the Boston schools, to have regard to the construction and the character of the instruments by which the principles of physical science are illustrated in these large establishments; the author has therefore deemed it expedient to make such a revision of the whole work, as will not only render it a convenient manual to accompany the new apparatus, but also embrace the recent improvements and discoveries by which the branches of science of which it treats have been enriched. A schedule of the new apparatus is subjoined; and the author indulges the expectation that the present edition of this work will be found more worthy than its predecessors of the favor which the public have bestowed upon it.

LILAC LODGE,
DEDHAM, *October*, 1847.

LIST OF WORKS

WHICH HAVE BEEN CONSULTED, OR FROM WHICH EXTRACTS HAVE BEEN TAKEN, IN THE PREPARATION OF THIS VOLUME.

Annals of Philosophy; Arnott's Elements of Physics; Bigelow's Technology; Cambridge Physics; Chambers' Dictionary; Enfield's, Olmsted's, Blair's, Bakewell's, Draper's, Grund's, Jones', Comstock's, and Conversations on Natural Philosophy; Davis' Manual of Magnetism; Encyclopædia Americana; Franklin's Philosophical Papers; Henry's Chemistry; King's Manual of Electricity; Lardner on the Steam Engine; Library of Useful Knowledge; Paxton's Introduction to the Study of Anatomy; Pambour on Locomotive Engines on Railways; Peschel's Elements of Physics; Philips' Astronomy; Sir John Herschel's Astronomy; Silliman's Journal of Science; Singer's Electricity; Scientific Class Book; Scientific Dialogues; Smith's Explanatory Key; The Year Book; Turner's Chemistry; Wilkins' Astronomy; Worcester's and the American School Geography; Lathrop, McIntire, and Keith on the Globes

SCHEDULE OF PHILOSOPHICAL APPARATUS FOR THE BOSTON GRAMMAR SCHOOLS.*

Adopted by the School Committee, August, 1847

LAWS OF MATTER.

Apparatus for illustrating Inertia.
Pair of Lead Hemispheres, for Cohesion.
Pair of Glass Plates, for Capillary Attraction.

LAWS OF MOTION.

Ivory Balls on Stand for Collision.
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Complete set of Mechanicals, consisting of Pulleys; Wheel and Axle Capstan; Screw; Inclined Plane; Wedge.

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Brass Magdeburg Hemispheres.

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* The cost of this apparatus is about two hundred and sixty dollars. It was made by Mr. Joseph M. Wightman, No. 33 Cornhill, Boston, and in an eminent degree unites beauty with durability.

Improved Weight-lifter, for upward pressure.
Iron Weight of fifty-six pounds and strap, } for Weight-lifter.
Flexible Tube and Connectors, }
Brass Plate and Sliding Rod.
Bolt Head and Jar.
Tall Jar and Balloon.
Hand and Bladder Glasses.
Wood Cylinder and Plate.
India-rubber Bag, for expansion of air
Guinea and Feather Apparatus.
Glass Flask and Stop-cock, for weighing air.

ELECTRICITY.

Plate Electrical Machine.
Pith-ball Electrometer.
Electrical Battery of four Jars.
Electrical Discharger.
Image Plates and Figure.
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Miser's Plate, for shocks.
Tissue Figure, Ball and Point.
Electrical Flyer and Tellurian.
Electrical Sportsman, Jar and Birds.
Mahogany Thunder-house and Pistol.
Hydrogen Gas Generator.
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OPTICS.

Glass Prism, and pair of Lenses.
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MAGNETISM.

Magnetic Needle on Stand.
Pair of Magnetic Swans.
Glass Vase for Magnetic Swans.
Horseshoe Magnet.

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Set of thirteen Geometrical Figures of Solids.
Box of sixty-four one-inch Cubes, for Cube Root, &c.

AUXILIARIES.

Tin Oiler; Glass Funnel; Sulphuric Acid
Set of Iron Weights for Hydrostatic Paradox.

CONTENTS.

INTRODUCTION.

The term Philosophy literally signifies, the love of wisdom; but, as a general term it is used to denote an explanation of the reason of things, or an investigation of the causes of all phenomena, both of mind and of matter.

When applied to any particular department of knowledge, the word Philosophy implies the collection of general laws or principles, under which the subordinate facts or phenomena relating to that subject are comprehended. Thus, that branch of Philosophy which treats of God, his attributes and perfections, is called Theology;* that which treats of the material world is called Physics, or Natural Philosophy; that which treats of man as a rational being, is called Ethics, or Moral Philosophy; and that which treats of the mind is called Intellectual Philosophy, or Metaphysics.†

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* The word Theology is derived from two Greek words, the former of which (θεος) signifies God, and the latter (λογος) means a discourse; and these two words combined in the term *Theology*, literally imply a discourse about God. The latter of these two Greek words (λογος or logos) is changed into *logy* to form English compounds, and it enters into the composition of many scientific terms. Thus, we have the words mineral*ogy*, the science of minerals; meteoro*logy*, the science which treats of meteors; ichthyo*logy*, the science of fishes; entomo*logy*, the science of insects; litho*logy*, of stones; concho*logy*, of shells, &c.

† The word Metaphysics is composed of two Greek words, Meta, (or μετα,) which signifies *beyond*, and phusis, (or φυσις,) which signifies *nature*, and in composition these words imply something *beyond nature*. From

All material things are divided into two great classes, called organized and unorganized matter. Organized matter is that which is endowed with organs adapted to the discharge of appropriate functions, such as the mouth and stomach of animals, or the leaves of vegetables. By means of such organs they enjoy life. Unorganized matter, on the contrary, possesses no such organs, and is consequently incapable of life and voluntary action.

Physical Science, or Physics, with its subdivisions of Natural History, (including Zoology, Botany, Mineralogy, Conchology, Entomology, Ichthyology, &c.,) and Natural Philosophy, including its own appropriate subdivisions, embraces the whole field of organized and unorganized matter.

The term Natural Philosophy is considered by some authors as embracing the whole extent of physical science, while others use it in a more restricted sense, including only the general properties of unorganized matter, the forces which act upon it, the laws which it obeys, the results of those laws, and all those external changes which leave the substance unaffected It is in this sense that the term is employed in this work.

Chemistry, on the contrary, is the science which investigates the composition of material substances, the internal changes which they undergo, and the new properties which they ac-

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the latter of these words, phusis, (φυσις,) we obtain the term *physics*, which in its most extended sense implies the science of nature and natural objects, comprehending the study or knowledge of whatever exists. The natural division of all things that exist is into body and mind—things material and immaterial, spiritual and corporeal. Physics relates to material things—Metaphysics to immaterial. Man, as a mere animal, is included in the science of Physics; but, as a being possessed of a soul, of intellect, of powers of perception, consciousness, volition, reason, and judgment, he becomes a subject of consideration in the science of Metaphysics.

quire by such changes. The operations of Chemistry may be described under the heads of, Analysis or decomposition, and Synthesis or combination.

Natural Philosophy may be said, pre-eminently, to treat of motion, while Chemistry particularly relates to change or alteration. By the former we become acquainted with the condition and relations of bodies as they spontaneously arise without any agency of our own. The latter teaches us how to alter the natural arrangement of elements to bring about some particular condition that we desire. To accomplish these objects in both of the departments of science to which we refer, we make use of appliances called philosophical and chemical apparatus, the proper use of which it is the office of Natural Philosophy and Chemistry respectively to explain. All philosophical knowledge proceeds either from observation or experiment, or from both. It is a matter of observation that water, by cold, is converted into ice; but if, by means of freezing mixtures, or evaporation, we actually cause water to freeze, we arrive at the same knowledge by experiment.

By repeated observations, and by calculations based on sucl observations, we discover certain uniform modes in which the powers of nature act. These uniform modes of operation are called *laws*;—and these laws are general or particular according to the extent of the subjects which they respectively embrace. Thus, it is a general law that all bodies attract each other in proportion to the quantity of matter which they contain. It is a particular law of electricity that similar kinds repel, and dissimilar kinds attract each other.

The collection, combination, and proper arrangement of such general and particular laws, constitute what is called Science. Thus, we have the science of Chemistry, the science of Geometry, the science of Natural Philosophy, &c.

The terms, art and science, have not always been employed with proper discrimination. In general, an art is that which depends on practice or performance, while science is the examination of general laws, or of abstract and speculative principles. The theory of music is a science; the practice of it is an art.

Science differs from art in the same manner that knowledge differs from skill. An artist may enchant us with his skill, although he is ignorant of all scientific principles. A man of science may excite our admiration by the extent of his knowledge, though he have not the least skill to perform any operation of art. When we speak of the mechanic arts, we mean the practice of those vocations in which tools, instruments, and machinery are employed. But the science of mechanics explains the principles on which tools and machines are constructed, and the effects which they produce. Science, therefore, may be defined, a collection and proper arrangement of the general principles or leading truths relating to any subject; and there is this connection between art and science, namely—"A principle in science is a rule of art."

NATURAL PHILOSOPHY

CHAPTER I.

DIVISIONS OF THE SUBJECT.

1. Natural Philosophy is the science which treats of the powers and properties of natural bodies, their mutual action on one another, and the laws and operations of the material world.

2. Some of the principal branches of Natural Philosophy are, Mechanics, Pneumatics, Hydrostatics, Hydraulics, Acoustics, Pyronomics, Optics, Astronomy, Electricity, Galvanism,* Magnetism, Electro-Magnetism, and Magneto-Electricity.

1. Mechanics is that branch of Natural Philosophy which relates to motion and the moving powers, their nature and laws, with their effects in machines, &c.

2. Pneumatics treats of the nature, properties, and effects of air.

* It may perhaps be questioned whether the subjects of Galvanism, Electro-Magnetism, and Magneto-Electricity, do not more properly fall within the province of Chemistry, as they describe effects dependent on chemical action. As this volume is designed for the diffusion of useful information, a strict adherence to rigid classification has not been deemed so important, as to exclude the notice of subjects so intimately connected with one of the most interesting branches of Natural Philosophy.

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1. What is Natural Philosophy?

2. What are the principal branches of Natural Philosophy? What is Mechanics? Of what does Pneumatics treat?

3. Hydrostatics treats of the nature, gravity, and pressure of fluids.

4. Hydraulics treats of the motion of fluids, particularly of water; and the construction of all kinds of instruments and machines for moving them.

5. Acoustics treats of the nature and laws of sound.

6. Pyronomics treats of heat, the laws by which it is governed, and the effects which it produces.

7. Optics treats of light, of color, and of vision, or sight.

8. Astronomy treats of the heavenly bodies, such as the sun, moon, stars, comets, planets, &c.

9. Electricity treats of thunder and lightning, and the causes by which they are produced, both naturally and artificially.

10. Galvanism is a branch of Electricity.

11. Magnetism treats of the properties and effects of the magnet, or loadstone.

12. Electro-Magnetism treats of Magnetism induced by Electricity.

13. Magneto-Electricity treats of Electricity induced by Magnetism.

CHAPTER II.

OF MATTER* AND ITS PROPERTIES.

3. Matter is the general name of every thing that occupies space, or has figure, form, or extension.

* The ancient philosophers supposed that all material substances were composed of Fire, Air, Earth, and Water, and these four substances were called the four elements, because they were supposed to be the simple substances of which all things were composed. Modern science has proved that not one of these is a simple substance, but that there are at least fifty-five simple substances, thirty-two of which are metallic and twenty-four non-metallic. The consideration of those substances which enter into the composition of all matter, in whatever form, belongs to

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Of what does Hydrostatics treat? Hydraulics? Acoustics? Pyronomics? Optics? Astronomy? Electricity? Of what is Galvanism a branch? Of what do Magnetism treat? Electro-Magnetism? Magneto-Electricity?

3. What is Matter?

4. There are seven essential properties belonging to all matter, namely: 1. Impenetrability, 2. Extension, 3. Figure, 4. Divisibility, 5. Indestructibility, 6. Inertia, and 7. Attraction.

1. These are called essential properties, because no particle of matter can be deprived of them, or exist without them.

2. There are certain other properties existing in different bodies, called accidental properties, because they do not necessarily exist in the bodies themselves, but depend upon their connection with other bodies. Thus, color and weight are accidental properties, because they do not necessarily exist in the bodies that possess them, but depend upon their connection with other things.

3. There are also certain terms used to express the state in which matter exists, such as Porosity, Density, Rarity, Compressibility, Expansibility, Mobility, Elasticity, Brittleness, Malleability, Ductility, and Tenacity.

5. Impenetrability is the power of occupying a certain space, so that where one body is, another cannot be, without displacing it.

1. Impenetrability belongs to fluids as well as solid bodies. The reason why fluids appear less impenetrable than solid bodies, is, that the particles of which they are composed move

the science of Chemistry. Bodies which consist of one simple substance are called *homogeneous*, while those which consist of two or more simple substances are called *heterogeneous*. Thus, water is a heterogeneous substance, being composed of two simple or homogeneous aeriform fluids, called Hydrogen and Oxygen. An aeriform fluid is a fluid in the form of air. When the particles of which matter is composed is mentioned, it is to be understood that the smallest imaginable portion is meant, not of the homogeneous substances of which it may be composed, but of the matter itself, whether homogeneous or heterogeneous.

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4. How many essential properties of matter are there? What are they? Why are they called essential properties? What other properties exist in different bodies? Why are they called accidental properties? Are color and weight essential or accidental properties? Why? What terms are used in Philosophy to express the state in which matter exists?

5. What is meant by Impenetrability? Does impenetrability belong to fluids? Why do fluids appear less impenetrable than solid bodies? What is supposed to be the form of the particles of fluids?

easily among themselves, on account of their slight degree of cohesion.*

2. Put some water into a tube closed at one end; and then insert a piece of wood that fits closely the inside of the tube. It will be impossible to force the wood to the bottom of the tube, unless the water be first removed. The same experiment may be made with air instead of water; and proves that water, air, and all other fluids are equally solid, or impenetrable, with the hardest bodies.

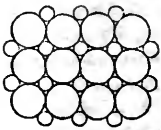
3. The impenetrability of water was shown by an experiment made at Florence many years ago. A hollow globe of gold was filled with water, and submitted to great pressure. The water was seen to exude through the pores of the gold, and covered it with a fine dew.

4. When an open vial, not inverted, is plunged into a basin of water, the air will rush out in bubbles, to make room for the water; and if an inverted tumbler or goblet be immersed in water, the water will not rise far in the tumbler unless it be inclined so that the air can escape. These are further proofs of the impenetrability of air.

5. When a nail is driven into wood, or any other substance, it forces the particles asunder, and makes its way between them; and the wood is not increased in size by the addition of the nail, because wood is a porous substance, the particles of which may be compressed, and thus make way for the nail.

* It is a well-known fact, that a certain quantity of salt, the particles of which are supposed to be smaller than those of water, can be put into a vessel full of water, without causing it to overflow; and as the particles of which sugar is composed are smaller than those of salt, a portion of sugar may be added after the fluid is saturated with salt. This may be accounted for by supposing that the particles of fluids are round, and therefore touch one another only in a few points. There will be spaces between the particles in the same manner that there are between large balls which are piled on one another. Between these spaces other smaller balls may be placed; and these smaller balls, having spaces between them, will admit others still smaller, as may be seen in Fig. 1.

Fig. 1.



What follows from this? What figure illustrates this? What example can you give to prove the impenetrability of water? What of the air? What of solids?

6. Extension is but another name for bulk, or size and it is expressed by the terms length, breadth, width, height, depth, and thickness.*

7. Figure is the form or shape of a body. Two circles or two balls may be of the same shape or figure, while they differ in extension. The limits of extension constitute figure.

8. Divisibility is susceptibility of being divided. To the divisibility of matter there is no known limit.

1. A single grain of gold may be hammered by a gold-beater until it will cover fifty square inches; each square inch may be divided into two hundred strips; and each strip into two hundred parts. One of these parts is only *one two-millionth* part of a grain of gold, and yet it may be seen with the naked eye.

2. The particles which escape from odoriferous objects also afford instances of extreme divisibility.

9. By the Indestructibility of matter is meant that it cannot be destroyed. It may be indefinitely divided, or altered in its form, color, and accidental properties, but it must still continue to exist in some form through all its changes of external appearance.

1. When water disappears, either by boiling over a fire, or

* Length is the extent from end to end. Breadth or width is the extent from side to side. Height, depth, or thickness, is the extent from the top to the bottom. The measure of a body from the bottom to the top is called height; from the top to the bottom is called depth. Thus we speak of the depth of a well, the height of a house, &c.

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6. What is meant by Extension? What terms are used to express the size of a body? What is length? Breadth? Height, depth, or thickness? What is the difference between height and depth?

7. What is meant by Figure? May bodies be of the same shape or figure and of different dimensions? Give an example. What constitutes figure?

8. What is meant by Divisibility? Is there any known limit to the divisibility of matter? Mention some examples of the extreme divisibility of matter.

9. What is meant by the Indestructibility of matter? May it be changed in form and in external appearance? Give examples of such changes.

evaporating by the heat of the sun, or, in other words, when "*it dries up,*" it rises slowly in the form of steam or vapor. This vapor ascends in the air and constitutes clouds; these clouds again fall to the earth in the shape of rain, snow, or hail, and form springs, fountains, rivers, &c. The water on or in the earth, therefore, is constantly changing its shape or situation, but no particle of it is ever actually destroyed.

2. The simple substances of which fuel is composed are not destroyed when the fuel is burnt. Parts of them arise in smoke or vapor, and the remainder is reduced to ashes. A body in burning undergoes remarkable changes; but the various parts into which it has been separated by combustion, continue in existence, and retain all the essential properties of bodies.

10. Inertia is the resistance which inactive matter makes to a change of state, whether of motion or rest.

A body at rest cannot put itself in motion, nor can a body in motion stop itself.

A body, when put in motion, will continue to move forever, unless it be stopped. When a stone or ball is thrown from the hand, there are two forces which continually operate to stop it, namely, the resistance of the air, and gravitation: all motion which is caused by animal or mechanical power, will be destroyed by the combined action of these forces. But could these forces be suspended, the body in motion would continue to move forever.

Fig. 2.

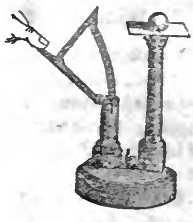

Fig. 2 represents the simple apparatus of Mr. Wightman, for illustrating inertia. A ball and a card being placed upon the pillar, motion is given to the card by means of a spring, but the ball remains on the pillar.

11. Attraction is the tendency which different bodies or portions of matter have, to approach or to adhere to each other.

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10. What is meant by Inertia? Can a body at rest put itself in motion? Can a body in motion stop itself? When a stone or ball is thrown from the hand, how many forces continually operate to stop it? What are they? How could a body in motion be made to move forever? Explain the apparatus for illustrating inertia.

Every portion of matter is attracted by every other portion of matter, and this attraction increases as the quantity of matter is increased, and diminishes as the quantity of matter is diminished.

12. There are two kinds of attraction belonging to all matter, namely, the attraction of gravitation and the attraction of cohesion.

The attraction of gravitation is the tendency of different bodies to approach each other.

The attraction of cohesion is that which causes the particles of a body to cohere to each other.

By the attraction of gravity, a stone falls to the ground. By the attraction of cohesion, the particles which compose the stone are held together.

1. All matter is composed of very minute particles, which are connected together in different bodies by different degrees of cohesion.*

2. The particles of which bodies are composed absolutely touch one another in few points only. There are small spaces called *pores*† between the particles; and the proportion of these pores gives rise to the terms density and rarity. A body in which the pores are small and few in number, is called a *dense* body. When the pores are large and numerous, the body is said to be *rare.*

Density, therefore, implies the closeness and compactness of the

* Cohesive attraction is illustrated by means of a pair of *leaden hemispheres*, which being pressed together, will be found to cohere. The experiment may be made with equal success with two bullets scraped smooth at the points of contact.

† The pores of bodies are generally filled with air.

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11. What is attraction? Is every portion of matter attracted by every other portion of matter? How does this attraction increase and diminish?

12. How many kinds of attraction are there belonging to all matter? What is the attraction of gravitation, or gravity? What is the attraction of cohesion, or cohesive attraction? What causes a stone to fall to the ground? By what are the particles which compose the stone held together? Of what is matter composed? Is the cohesive power which unites them the same in all bodies? How may cohesive attraction be illustrated? Do the particles of matter in bodies absolutely touch each other? What are the spaces between them called?

particles of a body, and indicates the quantity of matter contained in it under a given bulk.

Rarity is the reverse of density, and implies extension of bulk, without increase of quantity of matter.

13. Compressibility implies the reduction of the limits of extension. Of this all substances are susceptible if a sufficient force be applied.*

14. Expansibility is the reverse of compressibility, and implies the increase of the limits of extension.

15. Mobility implies susceptibility of motion.

16. Elasticity is the property which causes a body to resume its shape after being compressed or expanded.

Thus, when a bow is bent, its elasticity causes it to resume its shape. India-rubber possesses this property in a remarkable degree, but the gases in a still greater. The elasticity of ivory is very perfect, that is to say, it restores itself after compression with a force very nearly equal to that exerted in compressing it. Liquids, on the contrary, have scarcely any elasticity.

17. Malleability implies susceptibility of extension under the hammer or the rolling-press. This property belongs to some of the metals, as gold, silver, iron, copper, &c., but not to all; and it is of vast importance to the arts and conveniences of life. Gold is the most malleable of all metals.

18. Brittleness is the reverse of malleability, and implies aptness to break into irregular fragments. This property belongs chiefly to hard bodies.

* Sir Isaac Newton conjectured, that if the earth were so compressed as to be absolutely without pores, its dimensions might not be more than a cubic inch.

What do you understand by density? What by rarity?

13. What is compressibility? Are all substances susceptible of it?

14. What is expansibility?

15. What is mobility?

16. What is elasticity? What substance possesses this property in a remarkable degree?

17. What is malleability? Does this property belong to all the metals? What metal possesses it in the highest degree?

18. What is brittleness? What bodies are most brittle?

19. Ductility is that property which renders a substance susceptible of being drawn into wire.

Platina is the most ductile of all metals. It can be drawn into wire scarcely larger than a spider's web.

20 Tenacity implies a great degree of adhesion among the particles of bodies. The tenacity of bodies constitutes their strength, or their capability of sustaining weight. Iron, on account of its fibrous structure,is very tenacious.

CHAPTER III.

OF GRAVITY.

21. The term Gravity, in Philosophy, expresses the reciprocal attraction of separate portions of matter.

All matter possesses this attraction, and all bodies attract each other with a force proportionate to their size and density, when at a given distance from each other.

A body unsupported falls to the earth. This is caused by the superior attraction of the earth, arising from its density and size.

22. The attraction of gravitation causes weight.

1. When we say that a body weighs an ounce, a pound, or a hundred pounds, we express, by these terms, the degree of attraction by which it is drawn towards the earth.

2. *Weight, therefore, is the measure of the earth's attraction.* As this attraction depends upon the quantity of matter there is in a body, it follows that those bodies which contain the most matter will be most strongly attracted, and will consequently be the heaviest.

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19. What is ductility? Which is the most ductile of the metals?

20. What is tenacity? Which is the most tenacious of the metals?

21. What do you understand by the term gravity? Do all bodies possess this attraction? To what is its force proportional? If a body be unsupported, will it remain stationary? Why will it fall?

22. What causes weight? When you say that a body weighs an ounce what do you mean by it? What, therefore, is weight?

23. The force of gravity is greatest at the surface of the earth, and decreases both upwards and downwards, but in different degrees.*

It decreases above the surface as the square of the distance from the centre increases. From the surface to the centre it decreases, simply as the distance increases. That is, gravity at the surface of the earth (which is about 4000 miles from the centre) is four times more powerful than it would be at double that distance, or 8000 miles from the centre.

According to the principles just stated, a body which at the surface of the earth weighs a pound, at the centre of the earth will weigh nothing.

1000	miles	from	the	centre	it will	weigh	$\frac{1}{4}$ of a pound,
2000	"	"	"	"	"	"	$\frac{1}{2}$ of a pound,
3000	"	"	"	"	"	"	$\frac{3}{4}$ of a pound,
4000	"	"	"	"	"	"	1 pound,
8000	"	"	"	"	"	"	$\frac{1}{4}$,
12000	"	"	"	"	"	"	$\frac{1}{9}$, &c.†

* The force of gravity is absolutely greatest at the centre of the earth; but at that point it is exerted in all directions, and consequently a body at that point would remain stationary, because there is no superior attraction for it to obey.

† It follows from what has been stated, with regard to weight as a consequence of attraction, that if there were but one body in the universe, it would have no weight, because there would be nothing to attract it. But cohesive attraction would still exist, and keep the particles which compose the body united. As the attraction between all bodies is mutual, it follows that when a stone or any heavy body falls to the earth, the earth will rise to meet it. But as the attraction is in proportion to the quantity of matter each contains, the stone will fall as much farther than the earth rises, as the earth exceeds the stone in mass. Now the earth is one quatrillion, that is, one thousand million millions times larger than the largest body which has ever been known to fall through our atmosphere. Supposing, then, that such a body should fall through a distance of 1000 feet—the earth would rise no more than the hundred billionth part of an inch, a distance altogether imperceptible to our senses. The principle of mutual attraction is not confined to the earth. It extends to the sun, the planets, comets, and stars. The earth attracts each of them, and each of them

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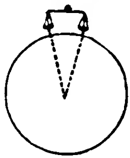
23. Where is the force of gravity greatest? How does it change? How does it decrease above the surface of the earth? How below?

24. The direction in which falling bodies approach the surface of the earth, is called a vertical line.* Such lines are everywhere perpendicular to the surface, and when prolonged will meet nearly at the centre of the earth.

For this reason no two lines suspended by weights, will be parallel to each other. Even a pair of scales, hanging perpendicular to the earth, are not exactly parallel, because they point to the same spot, namely, the centre of the earth; but the convergency is so small, that their inclination is not perceptible to our senses. [See Fig. 3.] For the same reason no two bodies can fall to the earth in parallel lines.

Fig. 3.



25. According to the laws of attraction, all bodies at an equal distance from the earth will fall to it in the same space of time, if nothing impede them. But bodies of different density fall with different degrees of velocity, on account of the resistance of the air; and as heavy bodies overcome this resistance more easily than light ones, the former will fall with the greater velocity.

The resistance which the air opposes to the fall of bodies, is proportioned to their surface, not to their weight.

attracts the earth, and these mutual attractions are so nicely balanced by the power of God, as to cause the regular motions of all the heavenly bodies, the diversity of the seasons, the succession of day and night, summer and winter, and all the grand operations which are described in astronomy.

* A vertical line is sometimes called a *plumb-line*, because it is formed by a weight suspended at rest from a string. As the weight thus employed is usually of *lead*, the term *plumb*, from the Latin *plumbum*, lead, is applied to the line.

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24. In what direction will a falling body approach the surface of the earth? Will the lines of suspension of different bodies ever be parallel? Where will they meet, if sufficiently produced?

25. Will all bodies at equal distances from the earth, fall to it in the same time? Why not? What bodies falls fastest? To what is the resistance of the air proportional?

Heavy bodies can be made to *float* in the air, instead of falling immediately to the ground, by making the extent of their surface counterbalance their weight. Thus gold, which is one of the heaviest of all substances, when spread out into thin leaf, is not attracted by gravity with sufficient force to overcome the resistance of the air; it therefore floats in the air, or falls slowly.

26. All substances are influenced by gravity, in exact proportion to their quantity of matter, and their distance from the central point of attraction.

1. Even air itself, light as it seems, is subject to this attraction. The air* probably extends to a height of more than forty-five miles above the surface of the earth. The pressure of the upper parts of the atmosphere on those beneath, renders the air near the surface of the earth much more dense than that in the upper regions. This pressure is caused by the attraction of the earth, or, what is the same thing, the weight of the air above; and it would cause the air to fall like other bodies completely to the earth, were it not for the elasticity of that portion which is near the surface.

2. The air therefore, of which the atmosphere is composed, exists in a state of compression, which causes it to be heaviest near the surface of the earth.

* We have no means of ascertaining the exact height to which the air extends. Sir John Herschel says, "Laying out of consideration all nice questions as to the probable existence of a definite limit to the atmosphere, beyond which there is absolutely and rigorously speaking *no* air, it is clear, that for all practical purposes we may speak of those regions which are more distant above the earth's surface than the hundredth part of its diameter as void of air, and of course, of clouds, (which are nothing but visible vapors, diffused and floating in the air, sustained by it, and rendering it turbid, as mud does water.) It seems probable, from many indications, that the greatest height at which visible clouds ever exist does not exceed ten miles; at which height the density of the air is about an eighth part of what it is at the level of the sea." Although the exact height to which the atmosphere extends has never been ascertained, it ceases to reflect the sun's rays at a greater height than forty-five miles.

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26. In what proportion are all substances influenced by gravity? Is air affected by it? How far does the air extend above the surface of the earth? What causes the air to be more dense at the surface of the earth? What causes this pressure? Why does not the air fall to the earth like other bodies? Where is the air heaviest? What effect have gravity and elasticity upon the air?

27. The specific gravity of bodies is a term used to xpress the relative weight of equal bulks of different oodies.*

1. If we take equal bulks of lead, wood, cork, and air, we find the lead to be the heaviest, then the wood, then the cork and lastly the air. Hence we say that the specific gravity of cork is greater than that of air, the specific gravity of wood is greater than that of cork, and the specific gravity of lead greater than that of wood, &c.

2. From what has now been said with respect to the attraction of gravitation and the specific gravity of bodies, it appears that although the earth attracts all substances, yet this very attraction causes some bodies to rise and others to fall.

3. Those bodies or substances, the specific gravity of which is greater than that of air, will fall, and those whose specific gravity is less than that of air, will rise; or rather, the air being more strongly attracted will get beneath them, and, thus displacing them, will cause them to rise. For the same reason, cork and other light substances will not sink in water, because the specific gravity of water being greater, the water is more strongly attracted, and will be drawn down beneath them. [For a table of the specific gravity of bodies, see Hydrostatics.]

4. The principle which causes balloons to rise, is the same which occasions the ascent of smoke, steam, &c. The materials of which a balloon is made, are heavier than air, but their extension is greatly increased, and they are filled with an elastic fluid of a different nature, specifically lighter than air, so that on the whole, the balloon when thus filled is much lighter than

* The quantity of matter in a body is estimated, not by its apparent size, but by its weight. Some bodies, as cork, feathers, &c., are termed light; others, as lead, gold, mercury, &c., are called heavy. The reason of this is, that the particles which compose the former are not closely packed together, and therefore they occupy considerable space; while in the latter they are joined more closely together, and occupy but little room. A pound of cork and a pound of lead, therefore, will differ very much in apparent size, while they are both equally attracted by gravity, that is, they weigh the same.

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27 What is specific gravity? Illustrate this. Does the attraction of the earth cause all bodies to fall? What bodies will fall? What rise? How does the air cause them to rise? Why do not cork and other light bodies sink in water? Explain the principle upon which balloons rise.

a portion of air of the same size or dimensions, and it will consequently rise.

5. Gravity, therefore, causes bodies which are lighter than air to ascend, those which are of equal weight with air to remain stationary, and those which are heavier than air to descend; but the rapidity of their descent is affected by the resistance of the air: which resistance is proportioned to the extent of the surface of the falling body.

CHAPTER IV.

MECHANICS, OR THE LAWS OF MOTION.

28. Mechanics is that branch of Natural Philosophy which relates to motion and the moving powers, their nature and laws, with their effects in machines, &c.

29. Motion is a continued change of place.

On account of the inertia of matter, a body cannot put itself in motion, nor when it is in motion can it stop itself.

30. The power which puts a body into motion is called a *force;* and the power which has a tendency to stop or impede motion is called *resistance.*

31. The motion of a body impelled by a single force is always in a straight line, and in the same direction in which the force acts.

32. The rapidity with which a body moves is called its velocity.

What effect has gravity on bodies lighter than the air? What effect on bodies of equal weight? What effect on those that are heavier? What affects the rapidity of their descent? To what is the resistance of the air proportioned?

28. What is Mechanics?

29. What is motion? Why cannot a body put itself in motion? Why cannot a body stop itself when in motion?

30. What is force? What is resistance?

31. When is the motion of a body in a straight line? In what direction will it move?

32. What is meant by velocity?

33. The velocity of a given body is proportional to the force by which it is put in motion.*

34. The velocity of a moving body is determined by the time that it occupies in passing through a given space. The greater the space, and the shorter the time, the greater is the velocity.

Thus, if one body move at the rate of six miles, and another twelve miles in the same time, the velocity of the latter is double that of the former.†

35. The velocity of a body is measured by the space over which it moves, divided by the time which it employs in the motion.

Thus, if a body move one hundred miles in twenty hours, the velocity is one hundred divided by twenty, that is, five miles an hour.

* The mean velocity of rivers is about four feet in a second; of a very rapid stream, about 13 feet; of a moderate wind, about 10 feet; of a storm, 54 feet; of a violent hurricane, 125 feet; of sound, 1142 feet; of atmospheric air rushing into a vacuum, 1280 feet; of a musket-ball, 1280 feet; of a rifle-ball, 1600; of a cannon-ball of 24 pounds, 2400 feet; of a point at the surface of the earth, under the equator, 1500 feet; of the earth's centre in its orbit round the sun, 101,061 feet.

The average rate of steamers between New York and Albany, exclusive of stoppages, is ten and a half miles per hour; of the mail trains on the great railroads, about 25 miles an hour; of the fastest sailing vessel, 15 feet in a second; of the swiftest race-horse, 42 feet in a second.

† Velocity is sometimes called absolute, and sometimes relative. Velocity is called absolute when the motion of a body in space is considered without reference to that of other bodies. When, for instance, a horse goes a hundred miles in ten hours, his absolute velocity is ten miles an hour. Velocity is called relative when it is compared with that of another body. Thus, if one horse travel only fifty miles in ten hours, and another one hundred in the same time, the absolute velocity of the first horse is five miles an hour, and that of the latter is ten miles; but their relative velocity is five miles.

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33. To what is the velocity of a moving body proportional?

34. How is the velocity of a moving body determined? If one body go through six miles in an hour, and another twelve, how does the velocity of the latter compare with that of the former? What is meant by absolute velocity? Give an example. When is the velocity of a body termed relative? Give an example.

35. How is the velocity of a body measured? Illustrate this.

36. The time employed by a body in motion may be ascertained by dividing the space by the velocity.

Thus, if the space be one hundred miles, and the velocity five miles in an hour, the time will be one hundred divided by five, which is twenty hours.

37. The space also may be ascertained by multiplying the velocity by the time.

Thus, if the velocity be five miles an hour, and the time twenty hours, the space will be twenty multiplied by five, which is one hundred miles.

38. There are three terms applied to motion to express its kind; namely, uniform, accelerated, and retarded motion.

Uniform motion is that of a body passing over equal spaces in equal times.

Accelerated motion is that in which the velocity continually increases as the body moves.

Retarded motion is that in which the velocity decreases as the body moves.

39. Uniform motion is produced by a force having acted on a body, and then ceasing to act

A ball struck by a bat, or a stone thrown from the hand, is in theory an instance of uniform motion; and if both the attraction of gravity and the resistance of the air could be entirely removed, it would proceed onwards in a straight line, and with a uniform motion forever. But as the resistance of the air and gravity tend to deflect it, it in fact becomes an instance first of retarded and then of accelerated motion.

40. Accelerated motion is produced by the continued action of one or more forces.

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36. How do you ascertain the time employed by a body in motion? Illustrate this.

37 How can you ascertain the space? Illustrate this.

38 How many terms are applied to motion to express its kind? Wha are they? What is uniform motion? Accelerated? Retarded?

39. How is uniform motion produced? Why is not a ball struck by a bat, or a stone thrown from the hand, an instance of uniform motion? How can it be made an instance?

40. How is accelerated motion produced?

1. Thus, when a stone falls from a height, the impulse which it receives from gravity would be sufficient to bring it to the ground with a uniform velocity. But the stone while falling at this rate is still acted upon by gravity with an additional force, which continues to impel it during the whole time of its descent.

2. *In the first second it falls sixteen feet, three times that distance in the next, five times in the third, seven times in the fourth, and so on, regularly increasing its velocity according to the number of seconds consumed in falling.*

3. The height of a building, or the depth of a well, may thus be measured by observing the length of time which a stone takes in falling from the top to the bottom.*

41. Retarded motion is produced when a body in motion encounters a force operating in an opposite direction.

1. Thus, when a stone is thrown perpendicularly upwards, the force of gravity is continually operating in the opposite direction, and attracting it downwards to the earth. The stone moves upwards slower and slower, until the upward motion ceases, and the body returns with accelerated motion to the earth. It is found that a body thrown perpendicularly upwards, takes the same length of time in ascending that it takes in descending.

2. Perpetual motion has never yet been produced by art; and the principles of mechanics seem to prove that such a motion is impossible; for although in many cases of bodies acting upon one another, there is a gain of absolute motion, yet the gain is always equal in opposite directions, so that the

* The spaces through which a body falls in equal successive portions of time, increase as the odd numbers 1, 3, 5, 7, &c.; that is, a falling body descends in the 2d second of its fall through 3 times, and in the 3d second through 5 times the space passed over in the first second. But the entire spaces through which a body will have fallen in any given number of seconds, increase as the squares of the times.

Give an instance of accelerated motion. How far does a stone fall the first second of time? The second? Third? Fourth? How can you measure the height of a building, or the depth of a well?

41. How is retarded motion produced? Give an example. How does the time of the ascent of a body thrown perpendicularly upwards, compare with that of its descent? Why cannot perpetual motion be produced?

quantity of direct motion is never increased. But nature abounds with examples of perpetual motion, as for instance, the motion of the heavenly bodies, described in the science of astronomy.

42. The momentum of a body is its quantity of motion, or the force with which it would strike against another body. It, is measured by multiplying its weight by its velocity.*

Thus, if a body weighing six pounds move at the rate of two miles in a second of time, its momentum may be represented by six multiplied by two, which is twelve. Hence a small or a light body may be made to strike against another body with a greater force than a heavy one, simply by giving it sufficient velocity.

43. The *action* of a body is the effect which it produces upon other bodies. *Reaction* is the effect which it receives from the body on which it acts.

Thus, when a body in motion strikes against another body, it acts upon it, or produces action; but it also meets with resistance from the body which is struck, and this resistance is the reaction of the body.

44. Action and reaction are always equal, but in opposite directions.

1. Experiments to show the mutual action and reaction of bodies, are made with both elastic and non-elastic bodies. Fig. 4

* The quantity of motion communicated to a body does not affect the duration of the motion. If but little motion be communicated, the body will move slowly. If a great degree be imparted, it will move rapidly. But in both cases the motion will continue until it is destroyed by some external force.

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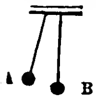
42. What is the momentum of a body? How can the momentum of a body be ascertained? *Note.* Does the quantity of motion communicated to a body affect the duration of the motion? If but little motion is communicated, how will the body move? If a great degree? How long will the motion continue? How can a light body be made to have a greater momentum than a heavy one? Give an instance of this.

43 What is meant by action? Reaction? Illustrate this.

44 How do action and reaction compare?

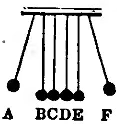
represents two ivory balls, A and B, of equal weight, &c., suspended by threads. If the ball A be drawn a little on one side and then let go, it will strike against the other ball B, and drive it off to a distance equal to that through which the first ball fell; but the motion of A will be stopped, because when it strikes B it receives in return a blow equal to that which it gave, but in a contrary direction, and its motion is thereby stopped, or rather, given to B. Therefore, when a body strikes against another, the quantity of motion communicated to the second body is lost by the first; but this loss proceeds, not from the blow given by the striking body, but from the reaction of the body which it struck.

Fig. 4.



2. Fig. 5 represents six ivory balls, of equal weight, suspended by threads. If the ball A be drawn out of the perpendicular, and let fall against B, it will communicate its motion to B, and receive a reaction from it which will stop its own motion. But the ball B cannot move without moving C; it will therefore communicate the motion which it received from A to C, and receive from C a reaction which will stop its motion. In like manner the motion and reaction are received by each of the balls, D, E, F; but as there is no ball beyond F to act upon it, F will fly off.

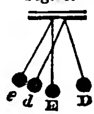
Fig. 5.



N. B. This experiment can be accurately performed by those bodies only which are perfectly elastic.

3. Fig. 6 represents two balls of clay, (which are not elastic,) of equal weight, suspended by strings. If the ball D be raised and let fall against E, only part of the motion of D will be destroyed by it, (because the bodies are non-elastic,) and the two balls will move on together to *d* and *e*, which are less distant from the vertical line than the ball D was before it fell. Still, however, action and reaction are equal, for the action on E is only enough to make it move through a smaller space, but so much of D's motion is now also destroyed.*

Fig. 6.



* Figs. 4 and 5, as has been explained, show the effect of action and reaction in elastic bodies, and Fig. 6 shows the same effect in non-elastic

Explain Fig. 4. Fig. 5 Fig. 6.

4. It is upon the principle of action and reaction, that birds are enabled to fly. They strike the air with their wings, and the reaction of the air enables them to rise, fall, or remain stationary at will, by increasing or diminishing the force of the stroke of their wings.*

5. It is likewise upon the same principle of action and reaction, that fishes swim, or, rather, make their way through the water; namely, by striking the water with their fins.†

6. Boats are also propelled by oars on the same principle, and the oars are lifted out of the water, after every stroke, so as completely to prevent any reaction in a backward direction.

45. Motion may be caused either by action or reaction. When caused by action it is called incident, and when caused by reaction it is called reflected motion.‡

bodies. When the elasticity of a body is imperfect, an intermediate effect will be produced; that is, the ball which is struck will rise higher than in case of non-elastic bodies, and less so than in that of perfectly elastic bodies; and the striking ball will be retarded more than in the former case, but not stopped completely, as in the latter. They will, therefore, both move onwards after the blow, but not together, or to the same distance; but in this, as in the preceding cases, the whole quantity of motion destroyed in the striking ball, will be equal to that produced in the ball struck. Connected with "the Boston school apparatus" is a stand with ivory balls, to give a visible illustration of the effects of collision.

* The muscular power of birds is much greater in proportion to their weight than that of man. If a man were furnished with wings sufficiently large to enable him to fly, he would not have sufficient strength, or muscular power, to put them in motion.

† The power possessed by fishes, of sinking or rising in the water, is greatly assisted by a peculiar apparatus furnished them by nature, called an air-bladder, by the expansion or contraction of which they rise or fall, on the principle of specific gravity.

‡ The word *incident* implies *falling upon*, or *directed towards*. The word *reflected* implies *turned back*. Incident motion is motion directed towards any particular object, against which a moving body strikes. Reflected motion is that which is caused by the reaction of the body which is struck. Thus, when a ball is thrown against a surface, it rebounds or

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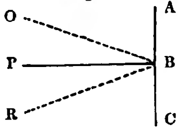
Upon what principle do birds fly? Explain how. Upon what principle do fishes swim? Upon what principle do boats move upon the water? Explain how.

45. How may motion be caused? When caused by action what is it called? When caused by reaction what is it termed?

46. The angle* of incidence is the angle formed by the line which the incident body makes in its passage towards any object, with a line perpendicular to the surface of the object.

Fig. 7.



Thus, in Fig. 7, the line A B C represents a wall, and P B a line perpendicular to its surface. O is a ball moving in the direction of the dotted line, O B. The angle O B P is the angle of incidence.

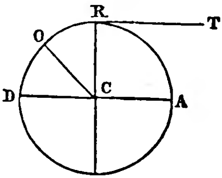
is turned back. This return of the ball is called reflected motion. As reflected motion is caused by reaction, and reaction is caused by elasticity, it follows, that reflected motion is always greatest in those bodies which are most elastic. For this reason, a ball filled with air rebounds better than one stuffed with bran or wool, because its elasticity is greater. For the same reason, balls made of caoutchouc, or India-rubber, will rebound more than those which are made of most other substances.

* As this book may fall into the hands of some who are unacquainted with geometrical figures, a few explanations are here subjoined.

1. An angle is the opening made by two lines which meet each other in a point. The size of the angle depends upon the opening, and not upon the length of the lines.

2. A circle is a perfectly round figure, every part of the outer edge of which, called the circumference, is equally distant from a point within, called the centre. (See Fig. 8.)

Fig. 8.



3. The straight lines drawn from the centre to the circumference are called radii. [The singular number of this word, is radius.] Thus, in Fig. 8, the lines CD, CO, CR, and CA, are radii.

4. The lines drawn through the centre, and terminating in both ends at the circumference, are called diameters. Thus, in the same figure, D A is a diameter of the circle.

5. The circumference of all circles is divided into 360 equal parts, called degrees. The diameter of a circle divides the circumference into two equal parts of 180 degrees each.

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46. What is the angle of incidence? (*Note.*—1. What is an angle? Upon what does the size of an angle depend? 2. What is a circle? 3. What are radii? What lines in Fig. 8 are radii? 4. What are diameters? In Fig. 8, what line is the diameter? 5. How is the circumference of all circles divided? Into how many parts does the diameter of a circle divide it?

47. The angle of reflection is the angle formed by the perpendicular with the line made by the reflected body as it leaves the surface against which it struck.

Thus, in Fig. 7, the angle P B R is the angle of reflection.

48. The angles of incidence and reflection are always equal to one another.

1. Thus, in Fig. 7, the angle of incidence, O B P, and the angle of reflection P B R, are equal to one another; that is, they contain an equal number of degrees.

6. All angles are measured by the number of degrees which they contain. Thus, in Fig. 8, the angle R C A, as it includes one quarter of the circle, is an angle of 90 degrees, which is a quarter of 360. And the angles R C O and O C D are angles of 45 degrees.

7. Angles of 90 degrees are right angles; angles of less than 90 degrees, acute angles, and angles of more than 90 degrees are called obtuse angles. Thus, in Fig. 8, R C A is a right angle, O C R acute, and O C A an obtuse angle.

8. A perpendicular line is a line which makes an angle of 90 degrees on each side of any other line or surface; therefore, it will incline neither to the one side nor to the other. Thus, in Fig. 8, R C is perpendicular to D A.

9. The tangent of a circle is a line which touches the circumference, without cutting it when lengthened at either end. Thus, in Fig. 8, the line R T is a tangent.

10. A square is a figure having four equal sides, and four equal angles. These will always be right angles. (See Fig. 9.)

11. A parallelogram is a figure whose opposite sides are equal and parallel. (See Figs. 10 and 11.) A square is also a parallelogram.

12. A rectangle is a parallelogram whose angles are right angles.

13. The diagonal of a square, of a parallelogram, or a rectangle, is a line drawn through either of them, and terminating at the opposite angles. Thus, in Figs. 9, 10, and 11, the line A C is the diagonal of the square, parallelogram, or rectangle.

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6. How are all angles measured? Illustrate this by Fig. 8. 7. H many degrees do right angles contain? Acute? Obtuse? Illustrate these angles by Fig. 8. 8. What is a perpendicular line? What line is perpendicular in Fig. 8? 9. What is a tangent? What line is a tangent in Fig. 8? 10. What is a square? 11. What is a parallelogram? 12. A rectangle? 13. What is a diagonal? What lines are diagonals in Figs 9, 10, and 11?) Explain the angle of incidence by Fig. 7.

47. What is the angle of reflection? Illustrate this by Fig. 7.

48. How do the angles of incidence and reflection compare with each other? Illustrate this by Fig. 7

2. From what has now been stated with regard to the angles of incidence and reflection, it follows, that when a ball is thrown perpendicularly against an object which it cannot penetrate, it will return in the same direction; but if it be thrown obliquely, it will return obliquely on the opposite side of the perpendicular. The more obliquely the ball is thrown, the more obliquely it will rebound.*

COMPOUND MOTION.

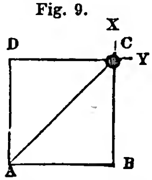
49. Compound motion is caused by the operation of two or more forces at the same time.

50. When a body is struck by two equal forces in opposite directions, it will remain at rest.

51. A body struck by two forces in different directions, will move in a line between them. This line will be the diagonal of a parallelogram, having for its sides the lines through which the body would pass, if urged by each of the forces separately.

1. Let Fig. 9 represent a ball struck by the two equal forces, X and Y. In this figure, the forces are inclined to each other at an angle of 90 degrees, or a right angle. Suppose that the force X would send it from C to B, and the force Y, from C to D. As it cannot obey both, it will go between them to A, and the line C A, through which it passes, represents the diagonal of the square, A B C D.

Fig. 9.



The time occupied in its passage from C

* It is from a knowledge of these facts that skill is acquired in many different sorts of games, as Billiards, Bagatelle, &c. A ball may also, on the same principle, be thrown from a gun against a fortification, so as to reach an object out of the range of a direct shot.

What follows from what has been stated with regard to the angles of incidence and reflection?

49. What is compound motion?

50. In what direction will a body, struck by two equal forces in opposite directions, move?

51. When struck by two forces inclined to each other, how will it move? What is this line called? Illustrate these, first, by Fig. 9, which represents a ball struck by two equal forces in different directions.

to A will be the same as the force X would require to send it to B, or the force Y to send it to D.

2. If the two forces acting on a body are unequal, but still operate at right angles to each other, the body will move from C to A as represented in Fig. 10; in which it is to be observed that the force Y is as much greater than the force X, as the length of the side C D of the rectangle A B C D, exceeds the length of the side C B.

Fig. 10.

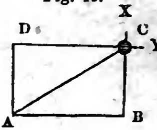
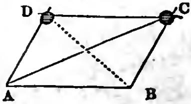


Fig. 11.



3. When two forces operate in the direction of an acute angle, (see Fig. 11,) the body will move as represented by C A, in the parallelogram A B C D.

4. If the forces operate in the direction of an obtuse angle, the body will move as represented by D B in the same figure.

52. Circular motion is motion around a central point, and is caused by two forces operating at the same time, by one of which it is projected forward in a straight line, while by the other it is deflected towards a fixed point.

The whirling of a ball, fastened to a string held by the hand, is an instance of circular motion. The ball is urged by two forces, of which one is the force of projection, and the other the string which confines it to the hand. The two forces act at right angles to each other, and (according to No. 51) the ball will move in the diagonal of a parallelogram. But, as the force which confines it to the hand only keeps it within a certain distance, without drawing it nearer to the hand, the motion of the ball will be through the diagonals of an indefinite number of minute parallelograms, formed by every part of the circumference of the circle.

53. There are three different centres which require to be distinctly noticed; namely, the centre of magnitude, the centre of gravity, and the centre of motion.

Second, by Fig. 10, which represents a ball struck by two unequal forces, acting at right angles. Third, by Fig. 11, where the forces operate in the direction of an acute angle. Fourth, by Fig. 11, where the forces operate in the direction of an obtuse angle.

52. What is circular motion? How is it caused? Illustrate this.

53. How many different centres are there which require to be noticed? Define each of them.

The centre of magnitude is the central point of the bulk of a body.

The centre of gravity is the point about which all the parts balance each other.

The centre of motion is the point around which all the parts of a body move.

When the body is not of a size nor shape to allow every point to revolve in the same plane, the line around which it revolves is called the axis of motion.*

54. The centre or the axis of motion is generally supposed to be at rest.

Thus the axis of a spinning top is stationary, while every other part is in motion around it. The axis of motion and the centre of motion are terms which relate only to circular motion.

55. The two forces by which circular motion is produced, are called *central* forces. Their names are the centripetal force and the centrifugal force.†

56. The centripetal force is that which confines a body to the centre around which it revolves.

The centrifugal force is that which impels the body to fly off from the centre.

57. If the centrifugal force of a revolving body be destroyed, the body will immediately approach the centre which attracts it; but if the centripetal force be

* Circles may have a centre of motion; spheres or globes have an axis of motion. Bodies that have only length and breadth may revolve around their own centre, or around axes; those that have the three dimensions of length, breadth, and thickness, must revolve around axes.

† The word *centripetal* means seeking the centre, and *centrifugal* means flying from the centre. In circular motion, these two forces constantly balance each other; otherwise the revolving body will either approach the centre or recede from it, according as the centripetal or centrifugal force is the stronger.

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54. Is the centre or axis of motion supposed to be at rest, or does it move? To what do the terms centre of motion and axis of motion relate?

55. What are the two forces called which produce circular motion? What is the name of each? What do the words centripetal and centrifugal mean?

56. Define a centripetal force. Also a centrifugal force.

57. If the centrifugal force be destroyed, to what point will the body tend?

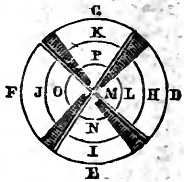
destroyed, the body will fly off in the direction of a tangent to the curve which it describes in its motion.

Thus, when a mop filled with water is turned swiftly round by the handle, the threads which compose the head will fly off from the centre; but being confined to it at one end, they cannot part from it; while the water they contain, being unconfined, is thrown off in straight lines.

58. The parts of a body which are farthest from the centre of motion, move with the greatest velocity; and the velocity of all the parts diminishes, as their distance from the axis of motion diminishes.

Fig. 12 represents the vanes of a windmill. The circles denote the paths in which the different parts of the vanes move. M is the centre or axis of motion around which all the parts revolve. The outer part revolves in the circle D E F G, another part revolves in the circle H I J K, and the inner part in the circle L N O P. Consequently, as they all revolve around M in the same time, the velocity of the parts which revolve in the outer circle is as much greater than the velocity of the parts which revolve in the inner circle, L N O P, as the diameter of the outer circle is greater than the diameter of the inner.

Fig. 12.



59. As the earth revolves round its axis, it follows, from the preceding illustration, that the portions of the earth which move most rapidly are nearest to the equator, and that the nearer any portion of the earth is to the poles, the slower will be its motion.

60. Curvilinear motion requires the action of two forces; for, the impulse of one single force always produces motion in a straight line.

What would be its direction if the centripetal force were destroyed? Give an example.

58. What parts of a body move with the greatest velocity? In what proportion does the velocity of all the parts diminish? What does Fig. 12 represent?

59. What follows, with regard to the motion of the earth, from the illustration of Fig. 12?

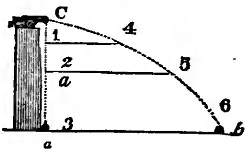
60. Of what is curvilinear motion always the result? Why?

61. A ball thrown in a horizontal direction is influenced by three forces; namely, first, the force of projection, (which gives it a horizontal direction;) second, the resistance of the air through which it passes, which diminishes its velocity, without changing its direction; and third, the force of gravity, which finally brings it to the ground.

62. The force of gravity is neither increased nor diminished by the force of projection.*

Fig. 13 represents a cannon, loaded with a ball, and placed on the top of a tower, at such a height as to require just three seconds for another ball to descend perpendicularly. Now suppose the cannon to be fired in a horizontal direction, and at the same instant the other ball to be dropped towards the ground. They will both reach the horizontal line at the base of the tower at the same instant. In this figure C *a* represents the perpendicular line of the falling ball. C *b* is the curvilinear path of the projected ball, 3 the horizontal line at the base of the tower. During the first second of time, the falling ball reaches 1, the next second 2, and at the end

Fig. 13.



* The action of gravity being always the same, the shape of the curve of every projectile (see No. 63) depends on the velocity of its motion; but, whatever this velocity be, the moving body, if thrown horizontally from the same elevation, will reach the ground at the same instant. Thus, a ball from a cannon, with a charge sufficient to throw it half a mile, will reach the ground at the same instant of time that it would had the charge been sufficient to throw it one, two, or six miles, from the same elevation. The distance to which a ball will be projected, will depend entirely on the force with which it is thrown, or on the velocity of its motion. If it moves slowly, the distance will be short—if more rapidly, the space passed over in the same time will be greater; but in both cases the descent of the ball towards the earth, in the same time, will be the same number of feet, whether it moves fast or slow, or even whether it move forward at all, or not.

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61. How many forces act upon a ball thrown in a horizontal direction? What are they? Why do bodies fall to the ground?

62. Does the force of gravity either increase or decrease the force of projection? Give an illustration

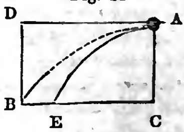
of the third second it strikes the ground. Meantime, that projected from the cannon, moves forward with such velocity, as to reach 4 at the same time that the falling ball reaches 1. But the projected ball falls downward exactly as fast as the other, since it meets the line 1 4, which is parallel to the horizon, at the same instant. During the next second the ball from the cannon reaches 5, while the other falls to 2, both having an equal descent. During the third second the projected ball will have spent nearly its whole force, and therefore its downward motion will be greater while the motion forward will be less than before. *Hence it appears that the horizontal motion does not interfere with the action of gravity, but that a projectile descends with the same rapidity while moving forward that it would if it were acted on by gravity alone.* This is the necessary result of the action of two forces.

63. A projectile is a body thrown into the air, as a rocket, a ball from a gun, or a stone from the hand.

The force of gravity and the resistance of the air cause projectiles to form a curve both in their ascent and descent; and in descending, their motion is gradually changed from an oblique towards a perpendicular direction.

In Fig. 14 the force of projection would carry a ball from A to D, while gravity would bring it to C. If these two forces alone prevailed, the ball would proceed in the dotted line to B. But as the resistance of the air operates in direct opposition to the force of projection, instead of reaching the ground at B, the ball will fall somewhere about E.*

Fig. 14



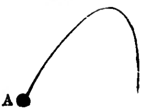
64. When a body is thrown in a horizontal direction, or upwards or downwards *obliquely*, its course will

* It is calculated that the resistance of the air to a cannon-ball of two pounds weight, with the velocity of two thousand feet in a second, is more than equivalent to sixty times the weight of the ball.

63. What is a projectile? What lines do projectiles describe? From what cause? Give the illustration. How great is the resistance of the air calculated to be to a cannon-ball of two pounds weight, with the velocity of 2000 feet in a second?

be in the direction of a curve-line, called a *parabola*;* (see Fig. 15,) but when it is thrown *perpendicularly* upwards or downwards, it will move perpendicularly, because the force of projection and that of gravity are in the same line of direction.

Fig. 15.



* The science of *gunnery* is founded upon the laws relating to projectiles. The force of gunpowder is accurately ascertained, and calculations are predicated upon these principles, which enable the engineer to direct his guns in such a manner as to cause the fall of the shot or shells in the very spot where he intends. The knowledge of this science saves an immense expenditure of ammunition, which would otherwise be idly wasted without producing any effect. In attacks upon towns and fortifications, the skilful engineer knows the means he has in his power, and can calculate, with great precision, their effects. It is in this way that the art of war has been elevated into a science, and much is made to depend upon skill, which, previous to the knowledge of these principles, depended entirely upon physical power.

The force with which balls are thrown by gunpowder is measured by an instrument called the *Ballistic pendulum.* It consists of a large block of wood suspended by a rod in the manner of a pendulum. Into this block the balls are fired, and to it they communicate their own motion. Now the weight of the block and that of the ball being known, and the motion or velocity of the block being determined by machinery, or by observation, the elements are obtained by which the velocity of the ball may be found; for, *the weight of the ball is to the weight of the block as the velocity of the block is to the velocity of the ball.* By this simple apparatus, many facts relative to the art of gunnery may be ascertained. If the ball be fired from the same gun, at different distances, it will be seen how much resistance the atmosphere opposes to its force at such distances. Rifles and guns of smooth bores may be tested, as well as the various charges of powder best adapted to different distances and different guns. These, and a great variety of other experiments, useful to the practical gunner or sportsman, may be made by this simple means.

The velocity of balls impelled by gunpowder from a musket with a common charge, has been estimated at about 1650 feet in a second of time, when first discharged. The utmost velocity that can be given to a cannon-ball, is 2000 feet per second; and this only at the moment of its leaving the gun.

In order to increase the velocity from 1650 to 2000 feet, one half more

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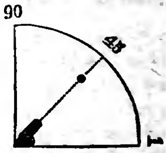
64. When a body is thrown horizontally, or upwards or downwards obliquely, in what curve will it move? In what line will it move when thrown upwards or downwards obliquely?

65. The random of a projectile is the horizontal distance from the place whence it is thrown, to the place where it strikes. The greatest random takes place at an angle of 45 degrees—that is, when a gun is pointed at this angle with the horizon, the ball is thrown to the greatest distance.

Fig 16.



Let Fig. 16 represent a gun or a carronade, from which a ball is thrown at an angle of 45 degrees with the horizon. If the ball be thrown at any angle above 45 degrees, the random will be the same as it would be at the same number of degrees below 45 degrees.*

66. When the centre of gravity of a body is supported, the body itself will be supported; but when the centre of gravity is unsupported, the body will fall.†

powder is required; and even then, at a long shot, no advantage is gained; since, at the distance of 500 yards, the greatest velocity that can be obtained is only 1200 or 1300 feet per second. Great charges of powder are therefore not only useless, but dangerous; for, though they give little additional force to the ball, they hazard the lives of many by their liability to burst.

Experiment has also shown, that, although long guns give a greater velocity to the shot than short ones, still, that on the whole, short ones are preferable; and, accordingly, armed ships are now almost invariably furnished with short guns, called carronades.

The length of sporting guns has also been greatly reduced, of late years. Formerly, the barrels were from four to six feet in length; but the best fowling-pieces of the present day have barrels of two feet, or two and a half, only, in length. Guns of about this length are now universally employed for such game as woodcocks, partridges, grouse, and such birds as are taken on the wing, with the exceptions of ducks and wild geese, which require longer and heavier guns.

* A knowledge of this fact, and calculations predicated on it, enables the engineer so to direct his guns, as to reach the object of attack when within the range of shot.

† The Boston School Apparatus contains a set of eight illustrations for

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65. What is the random of a projectile? At what angle does the greatest random take place?

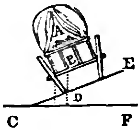
66. When the centre of gravity of a body is supported, will the body stand or fall? What if the centre be unsupported?

A line drawn from the centre of gravity, perpendicular to the horizon, is called the line of direction.*

67. When the line of direction falls within the base† of any body, the body will stand; but when that line falls outside of the base, the body will fall or be overset.

1. Fig. 18 represents a loaded wagon on the declivity of a hill. The line C F represents a horizontal line, D E the base of the wagon. If the wagon be loaded in such a manner that the centre of gravity be at B, the perpendicular B D will fall within the base, and the wagon will stand. But if the load be altered so that the centre of gravity be raised to A, the perpendicular A C will fall outside of the base, and the wagon will be overset. From this it follows that a wagon, or any carriage, will be most firmly supported when the line of direction of the centre of gravity falls exactly between the wheels; and that is the case on a level road. The centre of gravity in the human body, is between the hips, and the base is the feet.

Fig. 18.



So long as we stand uprightly, the line of direction falls within this base. When we lean on one side, the centre of gravity not being supported, we no longer stand firmly.

2. A rope-dancer performs all his feats of agility, by dexterously supporting the centre of gravity. For this purpose he carries a heavy pole in his hands, which he shifts from side to side as he alters his position, in order to throw the weight to the side which is deficient; and thus, by changing the

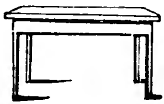
the purpose of giving a clear idea of the centre of gravity, and showing the difference between the centre of gravity and the centre of magnitude.

* The line of direction is the line which the centre of gravity would describe if the body were permitted to fall.

† The base of a body is its lowest side. The base of a body standing on wheels or legs, is represented by lines drawn from the lowest part of one wheel or leg, to the lowest part of the other wheel or leg.

Thus, in Figs. 17 and 18, D E represents the base of the wagon and of the table.

Fig. 17.



What is the line of direction?

67. If the line of direction falls within the base, will the body stand or fall? Give an illustration.

situation of the centre of gravity, he keeps the line of direction within the base, and he will not fall.*

A spherical body will roll down a slope, because the centre of gravity is not supported.†

68. When a body is of uniform density, the centre of gravity is in the same point with the centre of magnitude.

When one part of the body is composed of heavier materials than another part, the centre of gravity (being the centre of the weight of the body) no longer corresponds with the centre of magnitude. Thus, the centre of gravity of a cylinder plugged with lead, is not in the same point as the centre of magnitude.

Bodies, therefore, consisting of but one kind of substance, as wood, stone, or lead, and whose densities are consequently uniform, will stand more firmly than bodies composed of a variety of substances, of different densities.

* The shepherds in the south of France afford an interesting instance of the application of the art of balancing to the common business of life. These men walk on stilts from three to four feet high, and their children, when quite young, are taught to practise the same art. By means of these odd additions to the length of the leg, their feet are kept out of the water, or the heated sand, and they are also enabled to see their sheep at a greater distance. They use these stilts with great skill and care, and run, jump, and even dance on them with great ease.

† A cylinder can be made to roll up a slope, by plugging one side of it with lead; the body being no longer of a uniform density, the centre of gravity is removed from the middle of the body to some point in the lead, as that substance is much heavier than wood. Now, in order that the cylinder may roll down the plane, as it is here situated, the centre of gravity must rise, which is impossible; the centre of gravity must always descend in moving, and will descend by the nearest and readiest means, which will be by forcing the cylinder up the slope, until the centre of gravity is supported, and then it stops.

A body also in the shape of two cones united at their bases, can be made to roll up an inclined plane formed by two bars with their lower ends inclined towards each other. This is illustrated by a simple contrivance in the "Boston School Set," and the fact illustrated is called "*the mechanical paradox.*"

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68. If a body is of uniform density, what centres will coincide? Give an example in which the centres of magnitude and gravity will not coincide

69. Bodies that have a narrow base are easily overset; for if they are in the least degree inclined, the line of direction will fall outside of the base, and their centre of gravity will not be supported.*

The broader the base, and the nearer the centre of gravity to the ground, the stronger will be the edifice.

For this reason a pyramid,† having a broad base and but little elevation, is the firmest of all structures.

70. When two bodies are fastened together, they are to be considered as forming but one body, and have but one centre of gravity. If the two bodies be of equal weight, the centre of gravity will be in the middle of the line which unites them. But if one be heavier than the other, the centre of gravity will be as much nearer to the heavier one as the heavier exceeds the light one in weight.

1. Fig. 19 represents a bar with an equal weight fastened at each end: the centre of gravity is at A, the middle of the bar, and whatever supports this centre will support both the bodies and the pole.

Fig. 19.

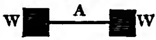
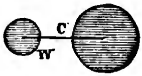


Fig. 20.



2. Fig. 20 represents a bar with an unequal weight at each end. The centre of gravity is at C nearer to the larger body.

* A person can carry two pails of water more easily than one, because the pails balance each other, and the centre of gravity remains supported by the feet. But a single pail throws the centre of gravity on one side, and renders it more difficult to support the body.

† A cone has also the same degree of stability; but, strictly speaking, a cone is a pyramid with an infinite number of sides.

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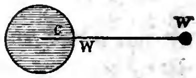
69. What shaped bodies are easily overturned? What bodies must stand more firmly than others? Why? Why do bodies which have a narrow base overturn more easily than those which have broad bases? Why can a person carry two pails of water more easily than one? Why is a pyramid the firmest of all structures?

70. If two bodies of equal weight are fastened together, where is the centre of gravity? If one be heavier than the other? What does Fig 19 represent? Fig. 20? Fig. 21?

3. Fig. 21 represents a bar with unequal weights at each end, but the larger weight exceeds the less in such a degree that the centre of gravity is within the larger body at C.

Fig. 21.

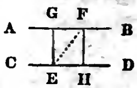


RESULTANT MOTION.

71. Resultant motion is the effect or result of two motions compounded into one.

If two men be sailing in separate boats, in the same direction, and at the same rate, and one toss an apple to the other, the apple would appear to pass directly across from one to the other, in a line of direction perpendicular to the side of each boat. But its real course is through the air in the diagonal of a parallelogram, formed by the lines representing the course of each boat, and perpendiculars drawn to those lines from the spot where each man stands as the one tosses and the other catches the apple. In Fig. 22 the lines A B and C D represent the course of each boat; E the spot where the man stands who tosses the apple; while the apple is in its passage, the boats have passed from E and G, to H and F respectively. But the apple having a motion, with the man, that would carry it from E to H and likewise a projectile force which would carry it from E to G, cannot obey them both, but will pass through the dotted line E F, which is the diagonal of the parallelogram E G F H.*

Fig. 22.



* On the principle of resultant motion, if two ships in an engagement be sailing before the wind, at equal rates, the aim of the gunners will be exactly as though they both stood still. But if the gunner fire from a ship standing still, at another under sail, or a sportsman fire at a bird on the wing, each should take his aim a little forward of the mark, because the ship and the bird will pass a little forward while the shot is passing to them.

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71. What is resultant motion? Give the examples of this kind of motion.

THE PENDULUM.

72. The Pendulum* consists of a weight or ball suspended by a rod, and made to swing backwards and forwards.

73. The motions of a pendulum are called its vibrations, and they are caused by gravity.† The part of a circle through which it moves, is called its *arc*.

74. The vibrations of pendulums of equal length, are

* The pendulum was invented by Galileo, a great astronomer of Florence, in the beginning of the seventeenth century. Perceiving that the chandeliers suspended from the ceiling of a lofty church vibrated long and with great uniformity, as they were moved by the wind or by any accidental disturbance, he was led to inquire into the cause of their motion, and this inquiry led to the invention of the pendulum. From a like apparently insignificant circumstance arose the great discovery of the principle of gravitation. During the prevalence of the plague, in the year 1665, Sir Isaac Newton retired into the country to avoid the contagion. Sitting in his orchard, one day, he observed an apple fall from a tree. His inquisitive mind was immediately led to consider the cause which brought the apple to the ground, and the result of his inquiry was the discovery of that grand principle of gravitation, which may be considered as the first and most important law of material nature. Thus, out of what had been before the eyes of men, in one shape or another, from the creation of the world, did these philosophers bring the most important results.

† When a pendulum is raised from its perpendicular position, its weight will cause it to fall, and, in the act of falling, it acquires a degree of motion which impels it to a height beyond the perpendicular almost as great as that to which it was raised. Its motion being thus spent, gravity again acts upon it to bring it to its original perpendicular position, and it again acquires an impetus in falling which carries it nearly as high on the opposite side. It thus continues to swing backwards and forwards, until the resistance of the air wholly arrests its motion. In the construction of clocks, an apparatus connected with the weight or the spring is made to act on the pendulum with such a force, as to enable it to overcome the resistance of the air, and keep up a continued motion.

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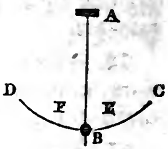
72 Of what does a pendulum consist? By whom was the pendulum invented? What led him to the discovery? By whom was the principle of gravitation discovered? What led him to the discovery?

73 What are the movements of the pendulum called? What is meant by its arc? What causes its vibrations?

very nearly equal, whether they move through a greater or less part of their arcs.

In Fig. 23, A B represents a pendulum. D F E C the arc in which it vibrates. If the pendulum be raised to E it will return to F, if it be raised to C it will return to D in nearly the same length of time, because that in proportion as the *arc* is more extended, the steeper will be its beginnings and endings, and, therefore, the more rapidly will it fall.

Fig. 23.



75. The time occupied in the vibration of a pendulum, depends upon its length. The longer the pendulum, the slower are its vibrations.

76. The length of a pendulum which vibrates sixty times in a minute (or, in other words, which vibrates seconds) is about 39 inches. But in different parts of the earth this length must be varied. A pendulum to vibrate seconds at the equator must be shorter than one which vibrates seconds at the poles.*

77. A clock is regulated by lengthening or shortening the pendulum. By lengthening the pendulum, the clock is made to go slower; by shortening it, it will go faster.†

* The equatorial diameter of the earth exceeds the polar diameter by about 34 miles; consequently, the poles must be nearer to the centre of the earth's attraction than the equator, and gravity must also operate with greater force at the poles than at the equator. Hence, also, the length of a pendulum, to vibrate in any given time, must vary with the latitude of the place.

† The pendulum of a clock is made longer or shorter, by means of a

74. How do the vibrations of pendulums of equal length compare? Illustrate by Fig. 23.

75. Upon what does the time of the vibrations of a pendulum depend?

76. What is the length of a pendulum which vibrates sixty times in a minute? Do different situations affect the vibrations? How can a pendulum which vibrates seconds at the equator be made to vibrate seconds at the poles?

77. How is a clock regulated? What effect has the lengthening of the pendulum? The shortening? What is a clock? Of what use is the weight? What do the wheels show? Why do clocks go slower in summer than in winter? How does a watch differ from a clock?

THE MECHANICAL POWERS.

78. The Mechanical Powers are certain contrivances designed to increase or to diminish force, or to alter its direction.

There are five things in mechanics which require a distinct consideration, namely:

First, the power that acts.

Secondly, the resistance which is to be overcome by the power.

Thirdly, the centre of motion, or, as it is sometimes called, the fulcrum.*

Fourthly, the respective velocities of the power and the resistance; and,

Fifthly, the instruments employed in the construction of the machine.

1. The power that acts is the muscular strength of men, or

screw beneath the weight or ball of the pendulum. The clock itself is nothing more than a pendulum connected with wheel-work, so as to record the number of vibrations. A weight is attached, in order to counteract the retarding effect of friction, and the resistance of the air. The wheels show how many swings or beats of the pendulum have taken place in a given time, because, at every beat, the tooth of a wheel is allowed to pass. Now if this wheel have sixty teeth, it will turn round once in sixty vibrations of the pendulum, or in sixty seconds; and a hand, fixed on the axis of the wheel projecting through the dial-plate, will be the second-hand of the clock. Other wheels are so connected with the first, and the number of teeth in them is so proportioned, that the second-wheel turns sixty times slower than the first, and to this is attached the minute-hand; and the third wheel, moving twelve times slower than the second, carries the hour-hand. On account of the expansion of the pendulum by heat, and its contraction by cold, clocks will go slower in summer than in winter, because the pendulum is thereby lengthened at that season.

A watch differs from a clock, in having a vibrating wheel instead of a pendulum. This wheel is moved by a spring, called the *hair-spring*. The place of the weight is supplied by another larger spring, called the *main-spring*.

* The word fulcrum means a prop, or support.

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78. What are the mechanical powers? How many things are to be considered in order to understand the power of a machine? What is the first? Second? Third? Fourth? Fifth?

animals, the weight and momentum of solid bodies, the elastic force of steam, springs, the pressure of the air, &c.

2. The resistance to be overcome is the attraction of gravity, or of cohesion, the inertness of matter, &c.

3. The centre of motion, or the fulcrum, is the point about which all the parts of the body move.

4. The velocity is the rapidity with which an effect is produced.

5. The instruments are the mechanical powers which enter into the construction of the machine.*

79. There are six mechanical powers, namely, the Lever, the Pulley, the Wheel and Axle, the Inclined Plane, the Wedge, and the Screw.

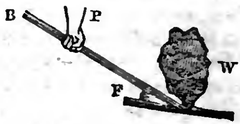
80. The Lever† is an inflexible bar, moveable on a fulcrum, or prop.

There are three kinds of levers, called the first, second, and third kinds, according to the respective position of the fulcrum, the power, and the weight.

81. In a lever of the first kind, the weight is at one end, the power at the other, and the fulcrum between them.

Fig. 24 represents a lever of the first kind, resting on the fulcrum F, and moveable upon it. W is the weight to be moved, and P is the power which moves it. *The advantage gained in raising a weight by the use of this kind of lever, is in proportion as the distance of the power from the fulcrum exceeds that of the weight from the fulcrum.* Thus, in this figure, if the distance between P and F be double that be-

Fig. 24.



* All machines and instruments are constructed on the principle of some one or more of the mechanical powers.

† The lever is made in a great variety of forms, and of many different

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What is the power that acts? What is the resistance to be overcome? What is the fulcrum? What is the velocity?

79. How many mechanical powers are there? What are they?

80. What is a lever? How many kinds of levers are there? How do they differ?

81. What is a lever of the first kind? What figure illustrates this? Explain it by the figure. To what is the advantage gained by this lever proportional?

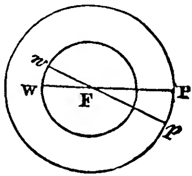
tween W and F, then a man, by the exertion of a force of 100 pounds with the lever, can move a weight of 200 pounds. From this it follows that *the nearer the power is applied to the end of the lever, the greater is the advantage gained.* Thus, a greater weight can be moved by the same power, when applied at B, than when it is exerted at P.*

2. The common steelyard, an instrument for weighing articles, is constructed on the principle of the lever of the first kind. It consists of a rod or bar, marked with notches to designate the pounds and ounces, and a weight which is moveable along the notches. The bar is furnished with three hooks,

materials; and is much used in almost every kind of mechanical operation. Sometimes it is detached from the fulcrum, but most generally the fulcrum is a pin or rivet by which the lever is permanently connected with the framework of other parts of the machinery.

* *It is a fundamental principle in mechanics, that what is gained in power is lost in time.* To illustrate this principle, (Fig. 25,) W represents the weight, F the fulcrum, P the power, and the bar W F P the lever. To raise the weight W to *w*, the power P must descend to *p*. But as the radius of the circle in which the power P moves is double that of the radius of the circle in which the weight W moves, the arc P *p* is double the arc W *w*; or, in other words, the distance P *p* is double the distance of W *w*. Now, as these distances are traversed in the same time by the power and the weight respectively, it follows, that the velocity of the power must be double the velocity of the weight; that is, the power must move at the rate of two feet in a second, in order to move the weight one foot in the same time.

Fig. 25.



This principle applies not only to the lever, but to all the mechanical powers, and to all machines constructed on mechanical principles.

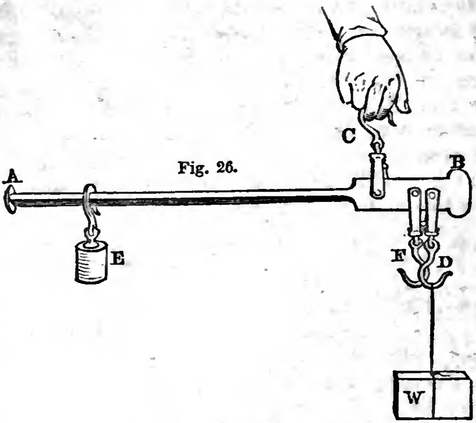
When two weights are equal, and the fulcrum is placed exactly in the centre of the lever between them, they will mutually balance each other; or, in other words, the centre of gravity being supported, neither of the weights will sink. This is the principle of the common scale for weighing.

To gain power by the use of the lever, the fulcrum must be placed near the weight to be moved, and the power at the greater distance from it. *The force of the lever, therefore, depends on its length, together with the power applied, and the distance of the weight from the fulcrum.*

What follows from this? What is meant by an inflexible bar? *Note* What is a fundamental principle in Mechanics? Illustrate this by the figure. Does this principle apply to all the mechanical powers?

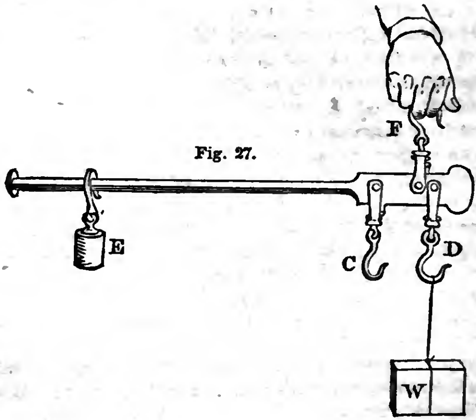
on the longest of which, the article to be weighed is always to be hung. The other two hooks serve for the handle of the in-

Fig. 26.



strument when in use. The pivot of each of these two hooks serves for the fulcrum. When suspended by the hook C, as in Fig. 26, it is manifest that a pound weight at E will balance as many pounds at W, as the distance between the pivot of D, and the pivot of C, is contained in the space between the pivot of C and the ring from which E is suspended.

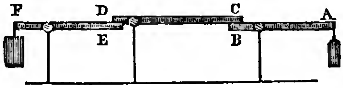
Fig. 27.



3. The same instrument may be used to weigh heavy articles, by using the middle hook for a handle, where, as will be seen in the figure, the space between the pivot of F (which in this case is the fulcrum) and the pivot of D (from which the weight is suspended) being lessened, is contained a greater number of times in the distance between the fulcrum and the notches on the bar. The steelyard is furnished with two sets of notches on opposite sides of the bar. An equilibrium will always be produced when the product of the weights on the opposite sides of the fulcrum into their respective distances from it, are equal to one another.

4. A balance, or pair of scales, is a lever of the first kind, with equal arms. Steelyards, scissors, pincers, snuffers, and a poker used for stirring the fire, are all levers of the first kind. The longer the handles of scissors, pincers, &c., and the shorter the points, the more easily are they used. A compound lever, represented in Fig. 28, consists of several levers, so arranged that the shorter arm of one may act on the longer arm of the other. Great power is obtained in this way; but its exercise is limited to a very small space.

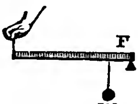
Fig. 28.



82. In a lever of the second kind, the fulcrum is at one end, the power at the other, and the weight between them.

1. Let Fig. 29 represent a lever of the second kind. F is the fulcrum, P the power, and W the weight. The advantage gained by a lever of this kind is in proportion as the distance of the power from the fulcrum exceeds that of the weight from the fulcrum. Thus in this figure, if the distance from P to F, is four times the distance from W to F, then a power of one pound at P will balance a weight of four pounds at W.

Fig. 29



2. On the principle of this kind of lever, two persons carry-

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Explain the common steelyard in Fig. 26. Also in Fig. 27. What is a balance, or pair of scales? Give some examples of levers of the first kind.

82. What is a lever of the second kind? What figure illustrates this? To what is the advantage gained by this lever proportional? Give some examples of levers of the second kind.

ing a heavy burden, suspended on a bar, may be made to bear unequal portions of it, by placing it nearer to the one than the other.

3. Two horses, also, may be made to draw unequal portions of a load, by dividing the bar attached to the carriage in such a manner that the weaker horse may draw upon the longer end of it.

4. Oars, rudders of ships, doors turning on hinges, and cutting-knives, which are fixed at one end, are constructed upon the principle of levers of the second kind.*

83. In a lever of the third kind, the fulcrum is at one end, the weight at the other, and the power is applied between them.

1. In levers of this kind *the power must always exceed the weight, in the same proportion as the distance of the weight from the fulcrum exceeds that of the power from the fulcrum.*

2. In Fig. 30, F is the fulcrum, W the weight, and P the power between the fulcrum and the weight; and the power must exceed the weight in the same proportion that the distance between W and F exceeds the distance between P and F.

Fig. 30.

3. A ladder which is to be raised by the strength of a man's arms, represents a lever of this kind, where the fulcrum is that end which is fixed against the wall: the weight may be considered as at the top part of the ladder, and the power is the strength applied in raising it.

4. The bones of a man's arm, and most of the moveable bones of animals, are levers of the third kind. But the loss of power in limbs of animals is compensated by the beauty and compactness of the limbs, as well as the increased velocity of their motion. The wheels in clock and watch work, and in various kinds of machinery, may be considered as levers of

* It is on the same principle that, in raising a window, the hand should be applied to the middle of the sash, as it will then be easily raised; whereas, if the hand be applied nearer to one side than the other, the centre of gravity being unsupported, will cause the further side to bear against the frame, and obstruct its free motion.

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83. What is a lever of the third kind? In what proportion must the power exceed the weight in this lever? Explain Fig. 30. Give some examples of levers of the third kind.

this kind, when the power that moves them acts on the pinion, near the centre of motion, and the resistance to be overcome acts on the teeth at the circumference. But here the advantage gained is the change of slow into rapid motion. The sails of vessels are constructed on the principle of the lever.*

84. The Pulley is a small wheel turning on an axis, with a string or rope in a groove running around it.

There are two kinds of pulleys—the fixed and the moveable. The fixed pulley is a pulley that has no other motion than a revolution on its axis, and it is used only for changing the direction of motion.

Fig. 31 represents a fixed pulley. P is a small wheel turning on its axis, with a string running round it in a groove. W is a weight to be raised, F is the force or power applied. It is evident that, by pulling the string at F, the weight must rise just as much as the string is drawn down. As, therefore, the velocity of the weight and the power is precisely the same, it is manifest that they balance each other, and that no mechanical advantage is gained. But this pulley is very useful for changing the direction of motion. If, for instance, we wish to raise a weight to the top of a high building, it can be done with the assistance of a fixed pulley, by a man standing below.† A curtain, or a sail, also, can be raised by means of a fixed pulley, without ascending with it, by drawing down a string running over the pulley.

Fig. 31

85. The moveable pulley differs from the fixed pulley

* It may perhaps assist the memory to retain the relative positions of the weight the power and the fulcrum in the three kinds of levers, if the initials be presented to the eye as follows:

First kind,	W. F. P.
Second "	F. W. P.
Third "	F. P. W.

† The fixed pulley operates on the same principle as a lever of the first kind with equal arms, where the fulcrum being in the centre of gravity, the power and the weight are equally distant from it, and no mechanical advantage is gained.

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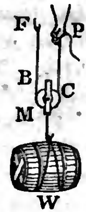
84. What is a pulley? How many kinds of pulleys are there? What are they? What is a fixed pulley? Explain Fig. 31 What advantage is gained by this pulley? What is the use of this pulley? Upon what principle does the fixed pulley operate?

by being attached to the weight; it therefore rises and falls with the weight.

Fig. 32 represents a moveable pulley, with the weight W attached to it by a hook below. One end of the rope is fastened at F; and as the power P draws the weight upwards, the pulley rises with the weight. Now, in order to raise the weight one inch, it is evident that both sides of the string must be shortened; in order to do which, the power P must pass over two inches. As the velocity of the power is double that of the weight, it follows that a power of one pound will balance a weight on the moveable pulley of two pounds.

Fig. 32.

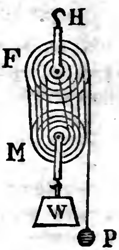


86. The power gained by the use of pulleys is ascertained by multiplying the number of moveable pulleys by 2.*

1. A weight of 72 pounds may be balanced by a power of 9 pounds with four pulleys; by a power of 18 pounds with two pulleys; or by a power of 36 pounds with one pulley. But in each case the space passed over by the power must be double the space passed over by the weight, multiplied by the number of moveable pulleys. That is, to raise the weight one foot, with one pulley, the power must pass over two feet, with two pulleys four feet, with four pulleys eight feet.

2. Fig. 33 represents a system of fixed and moveable pulleys In the block F, there are four fixed pulleys, and in the block M there are four moveable pulleys, all turning on their common axis, and rising and falling with the weight W. The moveable pulleys are connected with the fixed ones by a string attached to the hook H, passing over the alternate grooves of the pulleys in each block, forming eight cords, and terminating at the power P. Now to raise the weight one foot, it is evident that each of the eight cords must be shortened one foot, and, consequently, that the power P must descend eight times that distance. The

Fig. 33.



* This rule applies only to the moveable pulleys in the *same* block

85. How does the moveable pulley differ from the fixed pulley? Explain Fig. 32.

86. How can the power gained by the use of the moveable pulley be ascertained? What illustration of this is given? What does Fig. 33 represent?

power, therefore, must pass over eight times the distance that the weight moves.

87. Pulleys act on the same principle with the lever, the deficiency of the strength of the power being compensated by its superior velocity.

Now, as we cannot increase our natural strength, but can increase the velocity of motion, it is evident that we are enabled, by pulleys and other mechanical powers, to reduce the resistance or weight of any body to the level of our strength.

1. *Practical use of Pulleys.* Pulleys are used to raise goods into warehouses, and in ships, &c. to draw up the sails. Both kinds of pulleys are in these cases advantageously applied; for the sails are raised up to the masts by the sailors on deck, by means of the fixed pulleys, while the labor is facilitated by the mechanical power of the moveable ones.

2. Both fixed and moveable pulleys are constructed in a great variety of forms, but the principle on which all kinds are constructed, is the same. What is generally called a *tackle and fall,* or a block and tackle, is nothing more than a pulley. Pulleys have likewise lately been attached to the harness of a horse, to enable the driver to govern the animal with less exertion of strength.

3. It may be observed, in relation to the mechanical powers in general, that power is always gained at the expense of time and velocity; that is, the same power which will raise one pound in one minute, will raise two pounds in two minutes, six pounds in six minutes, sixty pounds in sixty minutes, &c.; and that the same quantity of force used to raise two pounds one foot, will raise one pound two feet, &c. And, further, it may be stated that the product of the weight, multiplied by the velocity of the weight, will always be equal to the product of the power multiplied by the velocity of the power. Hence we have the following rule. *The power is in the same proportion to the weight as the velocity of the weight is to the velocity of the power.*

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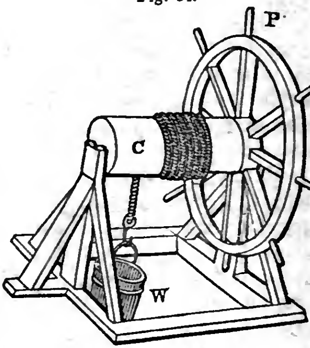
87. Upon what principle do pulleys act? What advantage is gained by the use of pulleys and other mechanical powers? What are some of the practical uses of the pulley? What is a tackle and fall? Is there any time or velocity gained by the power in the mechanical powers? To what is the product of the weight, multiplied by its velocity, always equal? What rule is given?

88. The wheel and axle consists of two wheels of different sizes, revolving together around the same centre of motion.

The place of the smaller wheel is generally supplied by a cylinder,* which forms the axle.

1. The wheel and axle, though made in many forms, will easily be understood by inspecting Figs. 34 and 35. In Fig. 34, P represents the larger wheel, where the power is applied; C the smaller wheel or cylinder, which is the axle, and W the weight to be raised. *The advantage gained is in proportion as the circumference of the wheel is greater than that of the axle.* That is, if the circumference of the wheel be six times the circumference of the axle, then a power of one pound applied at the wheel will balance a power of six pounds on the axle.

Fig. 34.



2. Sometimes the axle is constructed with a winch or handle, as in Fig. 35, and sometimes the wheel has projecting spokes, as in Fig. 34.

3. The principle upon which the wheel and axle is constructed is the same with that of the other mechanical powers, the want of power being compensated by velocity. It is evident (from the Figs. 34 and 35) that the velocity of the circumference of the wheel is as much greater than that of the axle as it is further from the centre of motion; for the wheel describes a great circle in the same time that the

* A cylinder is a long circular body of uniform diameter, with extremities forming equal and parallel circles.

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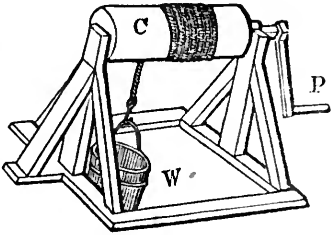
88 Of what does the wheel and axle consist? What is a cylinder? What figures illustrate the wheel and axle? Explain. To what is the advantage gained in proportion? What does Fig. 34 represent? Fig. 35? Upon what principle is the wheel and axle constructed? Explain by Figs 34 and 35.

axle describes a small one; therefore the power is increased in the same proportion as the circumference of the wheel is greater than that of the axle. If the velocity of the wheel be twelve times greater than that of the axle, a power of one pound on the wheel will support a weight of twelve pounds on the axle.

Fig. 35.



89. The wheel and axle are constructed on the same principle with the lever; the axle acting the part of the shorter arm of the lever, the wheel that of the longer arm.

1. The capstan,* on board of ships and other vessels, is constructed on the principle of the wheel and axle. It consists of an axle placed uprightly, with a head or drum, pierced with holes for the lever, or levers, which supply the place of the wheel.

2. Windmills, lathes, the common windlass,* used for drawing water from wells, and the large wheels in mills, are all constructed on the principle of the wheel and axle.

3. Wheels are a very essential part to most machines; they are applied in different ways, but when affixed to the axle their mechanical power is always in the same proportion; that is, as the circumference of the wheel exceeds that of the axle, so much will the power be increased. Therefore the larger the wheel and the smaller the axle, the greater will be the power obtained.

4. Fly-wheels are heavy wheels used to accumulate power

* The difference between a capstan and a windlass lies only in the position of the wheel. If the wheel turn horizontally it is called a capstan; if vertically, a windlass.

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89. Upon what principle are the wheel and axle constructed? Explain how Upon what principle is the capstan on board of vessels constructed Of what does it consist? What other things are mentioned as constructed upon this principle? Are wheels an essential part to most machines? Are they applied in more than one way? When they are affixed to the axle, in what proportion is the power increased?

and distribute it equally among all the parts of a machine. They are caused to revolve by a force applied to the axle; and when once set in motion continue by their inertia to move for a long time. As their motion is steady and without sudden jerks, they serve to steady the power, and cause a machine to work with regularity.

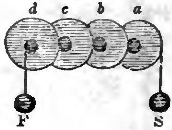
5. Cranks are sometimes connected with the axle of a wheel, either to give or to receive its motion. They are made by bending the axle in such a manner as to form four right angles facing in different directions, as is represented in Fig. 36. This is seen in lathes and many other kinds of machinery. Cranks are often used to change the motion from rectilinear to circular, or from circular to rectilinear.

Fig 36.

6. In connexion with the wheel and axle, it is proper to mention the subject of complex wheel-work. It has already been stated that the velocity of the wheel is greater than that of the axle; and that this velocity is in proportion to the relative size of the wheel compared with that of the axle. Advantage is taken of this circumstance in the construction of machinery, by such an arrangement of the parts as will enable us to increase or lessen the speed at pleasure. For it is evident that if the power be applied to the axle, and machinery attached to the wheel, rapid motion will be produced; and on the contrary, if the power be applied to the wheel and the machinery to the axle, slow motion will be produced.

7. Fig. 37 represents four wheels with their axles, each wheel acting on the axle of the adjoining wheel. F is the power applied to the axle of the wheel *d*. Now, supposing the circumference of each wheel to be six times the circumference of each axle, it is evident that each time the wheel *d* revolves it must cause the wheel *c* to make six revolutions, because the circumference of the wheel *d* is

Fig. 37.



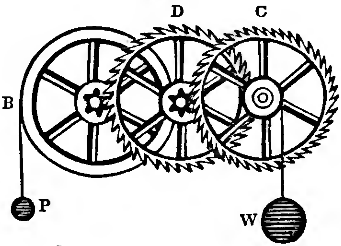
What are fly-wheels, and for what are they used? How are they made to revolve? When once set in motion, what causes them to move on for some time? Of what service are they in a machine? For what are cranks sometimes connected with the axle of a wheel? How are they made? What does Fig. 36 represent? For what are cranks often used? How does the velocity of the wheel compare with that of the axle? To what is this velocity in proportion? Is any advantage taken of this in driving machinery where the speed is to be increased or diminished?

six times the circumference of the axle of *c*. In like manner the circumferences of the wheels *c* and *b*, acting respectively on the circumferences of the axles of the adjoining wheel, will communicate a velocity six times greater than their own, and while the wheel *d* makes one revolution the wheel *c* will make six, *b* thirty-six, and *a* two hundred and sixteen revolutions.

8. Reversing the figure, and applying the power at S which communicates with the circumference of the wheel *a*, it follows that *a* must perform six revolutions while *b* is performing one, thirty-six while *c*, and two hundred and sixteen, while *d* performs one revolution. It will thus be perceived that a rapid or a slow motion may be communicated by various combinations of the wheel and axle.

9. The usual way of transmitting the action of the axles to the adjoining wheels is by means of teeth or cogs, raised on their surfaces. The cogs on the surface of the wheels are generally called teeth, and those on the surface of the axle are called leaves. The axle itself, when furnished with leaves, is called a *pinion*.

Fig. 38.



10. Fig. 38 represents a connexion of cogged wheels. The wheel B being moved by a string around its circumference is a simple wheel without teeth. Its axle being furnished with cogs or *leaves*, to which the teeth of the wheel D are fitted, communicates its motion to D, which, in like manner, moves the wheel C. The power P and the weight W must be attached to the circumference of the wheel or of the axle according as a slow or a rapid motion is desired.

11. Wheels are sometimes turned by bands, as in Fig. 39;

How would rapid motion be produced? Slow motion? Explain Fig. 37. What is the usual way of transmitting the action of the axles to the adjoining wheels? What are the cogs on the surface of the wheel called? Those on the axle? What is a pinion? Explain Fig. 38. By what are wheels sometimes turned?

and the motion communicated may be direct or reversed by attaching the band as represented in Figs. 39 and 40. When the wheel and the axle from which it receives motion are intended to revolve in the same direction, the strap is not crossed, but is applied as in Fig. 39. But when the wheel is to revolve in a direction contrary to the revolution of the axle, the strap is crossed, as in Fig. 40.

Fig. 39.

Fig. 40.

12. Different directions may be given to the motion produced by wheels, by varying the position of their axles, and causing them to revolve in different planes, as in Fig. 41; or by altering the shape and position of the cogs, as in Fig. 42.

Fig. 41.

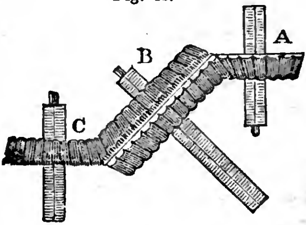
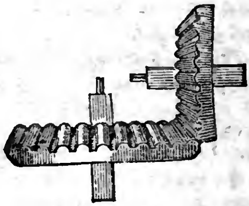


Fig. 42.



90. The inclined plane consists of a plain surface inclined to the horizon, and the advantage gained by the inclined plane is in proportion as the length of the plane exceeds its perpendicular height.

1. Fig. 43 represents an inclined plane. C A its height, C B its length, and W a weight which is to be moved on it. If the length C B be four times the height C A, then a power of one pound at C will balance a weight of four pounds on the inclined plane C B.

Fig. 43.

What figure represents one? In what way can the motion be made direct or reversed? What does Fig. 39 represent? Fig. 40? In what way can different directions be given to the motion produced by wheels? What does Fig. 41 represent? Fig. 42?

90. What is an inclined plane? What figure represents an inclined plane? Explain the figure. To what is the advantage gained by the use of the inclined plane in proportion?

2. The greater the inclination of the plane, the greater must be its perpendicular height, compared with its length; and, of course, the greater must be the power to elevate a weight along its surface.

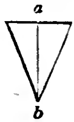
3. Instances of the application of the inclined plane are very common. Sloping planks or pieces of timber leading into a cellar, and on which casks are rolled up and down; a plank or board with one end elevated on a step, for the convenience of trundling wheelbarrows, or rolling barrels into a store, &c., are inclined planes.

4. The advantage gained by the use of the inclined plane, like that of the other mechanical powers, is attended by a loss of time; for the weight, instead of moving directly up the ascent, must move the whole length of the plane.

5. Chisels and other cutting instruments, which are *chamfered* or sloped only on one side, are constructed on the principle of the inclined plane.

91. The wedge consists of two inclined planes united at their bases; and the advantage gained by the use of the wedge is in proportion as the length exceeds one half the thickness of its converging sides.

Fig. 44.



1. Fig. 44 represents a wedge. The line *a b* represents the base of each of the inclined planes of which it is composed, and at which they are united.

2. The wedge is a very important mechanical power, used to split rocks, timber, &c., which could not be effected by any other power.

3. Axes, hatchets, knives, and all other cutting instruments chamfered, or sloped on both sides, are constructed on the principle of the wedge.

92. The screw consists of an inclined plane, wound round a cylinder, thus producing a circular inclined

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What follows from the greater or less inclination of the plane? Give some instances of the application of the inclined plane. Is any time gained by the use of the inclined plane? Upon what principle are chisels and other cutting instruments, which are sloped only on one side, constructed?

91. Of what does the wedge consist? What does Fig. 44 represent? To what is the advantage gained by the wedge in proportion? Of what use is the wedge? Give some examples of the wedge.

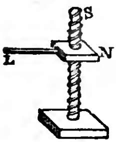
92 Of what does the screw consist?

plane, and forming what is called the threads of the screw.

The advantage gained in the use of the screw is in proportion as the circumference described by the handle exceeds the distance between the threads of the screw.

The screw is generally composed of two parts, the screw and the nut; or, as they are generally called, the convex and concave screw.

Fig. 45.



1. Fig. 45 represents the screw and the nut. S is the convex screw, (which is an inclined plane wound round a cylinder,) N is the nut, or concave screw, which has a spiral groove, to which the thread of the convex screw is accurately fitted. L is a lever attached to the nut, to which the power is applied. By turning the lever in one direction the nut ascends, and by turning it in the opposite direction, the nut descends on the screw.* In this figure the screw is fixed, and the nut is moveable.

Fig. 46.

2. Fig. 46 represents another screw, which is moveable. The nut is fixed to the frame, and the screw ascends or descends as the lever L is turned.

* Although the screw is mentioned as one of the six mechanical powers, it is, in reality a compound power, consisting of a lever and an inclined plane. The power of the screw being estimated by the distance of the threads, the closer the threads the greater is the power; but here, again, the increase of power is procured by an increase of velocity, for a loss of time. For if the threads be a quarter of an inch apart, the power must move through the whole circumference of the circle described by the lever, in order to move the resistance a quarter of an inch. The screw, with its appendage the lever, is therefore used for the purpose of moving large or heavy bodies through small distances. Its power may be increased by lengthening the lever. The screw is applied to presses of all kinds where great power is required, such as bookbinders' presses, cider and wine presses, &c.

Of how many parts is it generally composed? What are they? What figure represents the screw and the nut? Explain the figure. How does Fig. 45 differ from Fig. 46? *Note.* Is the screw a simple or compound power? How is the power of the screw estimated? How does the closeness of the thread affect the power? What is the use of the screw? How can its power be increased? To what is the screw applied?

3. By friction in machinery is meant the resistance which bodies meet with in rubbing against each other.

4. There are two kinds of friction, the rolling and the sliding. The rolling friction is caused by the rolling of a circular body. The sliding friction is produced by the sliding or dragging of a body over a flat surface. The sliding friction is overcome with more difficulty than the rolling. In calculating the power of a machine, an allowance must always be made for friction. It is usually computed that friction destroys one-third of the power of a machine.*

5. Friction is caused by the unevenness of the surfaces which come into contact;† and it is diminished in proportion as the surfaces are smooth and well polished. Oil, grease, black-lead, or powdered soap-stone, is used to lessen friction,

* When finely polished iron is made to rub on bell metal, the friction is said to be reduced to about one-eighth. Mr. Babbit of Boston has prepared a composition for the wheel-boxes of locomotive engines and other machinery, which it is said has still further reduced the amount of friction. This composition is now much in use. As the friction between rolling bodies is much less than in those that drag, the axle of large wheels is sometimes made to move on small wheels or rollers. These are called friction wheels, or friction rollers. They turn round their own centre as the wheel continues its motion.

† All bodies, how well soever they may be polished, have inequalities in their surfaces, which may be perceived by a microscope. When, therefore, the surfaces of two bodies come into contact, the prominent parts of the one will often fall into the hollow parts of the other, and cause more or less resistance to motion. Friction increases, 1st, as the weight or pressure is increased; 2d, as the areas of the surfaces in contact are increased; 3d, as the roughness of the surface is increased. Friction may be diminished, 1st, by lessening the weight of the body in motion; 2d, by mechanically reducing the asperities of the sliding surfaces; 3d, by lessening the amount of surface of homogeneous bodies in contact with each other; 4th, by converting a sliding into a rolling motion; 5th, by applying some suitable unguent.

What is meant by friction in machinery? How many kinds of friction are there? What are they? How is the rolling friction produced? The sliding? Which is overcome with the less difficulty, the rolling or sliding? What allowance must always be made, in calculating the power of a machine? What proportion of the power is usually computed to be destroyed by friction? Between which is friction the less, rolling bodies or those that slide? What causes friction? In what proportion is it diminished? In what manner can it be lessened?

because they act as a polish by filling up the cavities of the rubbing surfaces, and thus making them slide more easily over each other.

6. From what has been stated with regard to the mechanical powers, it appears that by their aid a man is enabled to perform works to which his unassisted natural strength is wholly inadequate. But the power of all machines is limited by the strength of the materials of which they are composed. Iron, which is the strongest of all substances, will not resist a strain beyond a certain limit. Its cohesive attraction may be destroyed, and it can withstand no resistance which is stronger than its cohesive attraction. Besides the strength of the materials, it is necessary, also, to consider the *time* which is expended in the application of mechanical assistance. Archimedes is said to have boasted to Hiero, king of Syracuse, that, if he would give him a place to stand upon, he would move the whole world. In order to do this, Archimedes must himself have moved over as much more space than he moved the world, as the weight of the world exceeded his own weight; and it has been computed that he must have moved with the velocity of a cannon ball for a million of years, in order to move the earth the twenty-seven millionth part of an inch.

7. Wheels are used on vehicles to diminish the friction of the road. The larger the circumference of the wheel, the more readily it will overcome any obstacles, such as stones, or inequalities in the road.*

93. A medium† is the substance, solid or fluid, which surrounds a body.

* In descending a steep hill, the wheels of a carriage are often *locked*, (as it is called,) that is, fastened in such a manner as to prevent their turning; and thus the rolling is converted into the sliding friction, and the vehicle descends more safely.

Castors are put on the legs of tables and other articles of furniture, to facilitate the moving of them; and thus the sliding is converted into the rolling friction.

† The plural of this word is *media.*

What is the use of wheels? In what proportion do they overcome the obstacles, such as stones, &c., in the road? Why, in descending a steep hill, are the wheels of a carriage often locked? How do castors, which are put upon furniture, facilitate the moving of it? How is the motion of all bodies influenced?

93. What is meant by a medium? Give examples.

Thus, air is the medium which surrounds a bird when flying; water is the medium which surrounds the fish when swimming, &c.

94. The motion of all bodies is influenced by the medium in which they move; and the resistance of a medium is in exact proportion to its density.

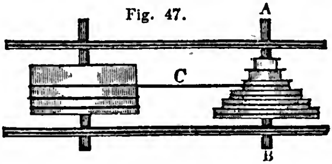
A body falling through water meets with more resistance than when falling through air, because water is a denser medium than air. If a machine could be worked *in vacuo*, (that is, in a vacuum, or a space where there is neither air nor any thing else to impede it,) and without friction, it would be perfect.

95. The main-spring of a watch consists of a long ribbon of steel, closely coiled, and contained in a round box. It is employed instead of a weight, to keep up the motion.

1. As the spring, when closely coiled, exerts a stronger force than when it is partly loosened, in order to correct this inequality, the chain through which it acts is wound upon an axis surrounded by a spiral groove, (called a *fusee*,) gradually increasing in diameter from the top to the bottom; so that, in proportion as the strength of the spring is diminished, it may act on a larger lever, or a larger wheel and axis.

2. Fig. 47 represents a spring coiled in a round box. A B is the fusee, surrounded by a spiral groove, on which the chain C is wound. When the watch is recently wound, the spring is in the greatest state of tension, and will, therefore, turn the fusee by the smallest groove, on the principle of the wheel and axle. As the spring loses its force by being partly unwound, it acts upon the larger circles of the fusee; and the

Fig. 47.



94. To what is the resistance of a medium in proportion? What illustration is given? When would a machine be perfect?

95. Of what does the main-spring of a watch consist? What is its use? Does the spring exert a stronger force when closely coiled, or when partly loosened? What is done in order to correct this inequality? What does Fig. 47 represent? Explain.

want of strength in the spring is compensated by the mechanical aid of a larger wheel and axle in the larger grooves. By this means the spring is made at all times to exert an equal power upon the fusee. The motion is communicated from the fusee by a cogged wheel which turns with the fusee.

96. The name of *governor* has been given to an ingenious piece of mechanism, invented by Mr. James Watt, which is used to regulate the supply of power in machinery; as that of steam in steam-engines, and of water in water-mills.

Fig. 48.

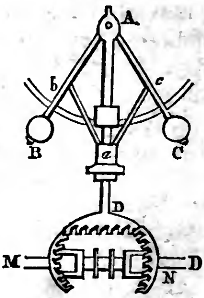


Fig. 48 represents a governor. A B and A C are two levers or arms, loaded with heavy balls at their extremities B and C, and suspended by a joint at A upon the extremity of a revolving shaft, A D. At *a* is a collar, or sliding box, connected with the levers by the rods *b a* and *c a,* with joints at their extremities. When the shaft A D revolves rapidly, the centrifugal force of the balls B and C will cause them to diverge in their attempt to fly off, and thus raise the collar *a*, by means of the rods *b a* and *c a*. On the contrary, when the shaft A D revolves slowly, the weights B and C will fall by their own weight, and the rods *b a* and *c a* will cause the collar *a* to descend. The steam-valve in a steam-engine, or the sluice-gate of a water-wheel, being connected with the collar *a,* the supply of steam or water, which puts the works in motion, is thus regulated.*

* In manufactures, there is one certain and determinate velocity with which the machinery should be moved, and which, if increased or diminished, would render the machine unfit to perform the work it is designed to execute. Now, it frequently happens that the resistance is increased or diminished by some of the machines which are worked, being stopped, or others put on. The moving power, having this alteration in the resistance, would impart a greater or less velocity to the machinery, were it not for the regulating power of the governor, which increases or diminishes the supply of water or of steam, which is the moving power.

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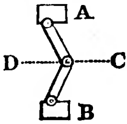
96. What is a governor? Explain Fig. 48. What is said in the note of the use of the governor?

97. The knee-joint, or, as it is sometimes called, the *toggle*-joint, consists of two rods or bars connected by a joint, and increasing rapidly in power as the two rods approach to the direction of a straight line.

Fig. 49.



1. Fig. 49 represents a toggle-joint. A C and B C are the two rods connected by a joint C. A moving force applied in the direction C D acts with great and constantly increasing power to separate the parts A and B.

2. The operation of the toggle-joint is seen in the iron joints which are used to uphold the tops of chaises. It is also used in various kinds of printing-presses, to obtain the greatest power at the moment of impression.

CHAPTER V.

HYDROSTATICS.*

98. Hydrostatics treats of the nature, gravity, and pressure of fluids.

99. A fluid is a substance which yields to the slightest pressure, and the particles of which, having but a slight degree of cohesion, move easily among themselves.

100. A liquid differs from a fluid in its degree of compressibility† and elasticity.

* Hydrostatics treats of the properties of fluids *at rest;* Hydraulics treats of fluids in motion.

† The experiments made at Florence many years ago seem to prove that some kinds of liquids—water, for instance—are wholly incompressible Later experiments, particularly those of Mr. Jacob Perkins, of Newbury-

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97. Of what does the knee-joint, or toggle-joint, consist? In what proportion does it increase in power? What does Fig. 49 represent? Explain the figure. Give an instance of the operation of the toggle-joint. What is its use in printing-presses?

98. Of what does Hydrostatics treat?

99. What is a fluid? Does the attraction of cohesion have much influence on the particles of fluids? What follows from this?

100 How do fluids differ from liquids? Can water be compressed;

1. The particles of fluids gravitate among themselves in a more perfect manner than solids; because the strong cohesion of the particles of solid bodies in some measure counteracts the effects of gravity.

2. From the slight degree of cohesion in the particles of fluids, it is inferred that they must be small, smooth, and globular; smooth, because there appears to be no friction among them; and globular, because their touching each other but by a point will account for the slightness of their cohesion.

3. Fluids cannot be formed into figures, or preserved in heaps, on account of their want of cohesion.

4. Fluids are subjected to a kind of attraction called capillary* attraction, by which they are raised above their levels in capillary tubes, or tubes the bores of which are exceedingly small. Thus, if a small glass tube be placed in water, the water on the inside will rise above the level of that on the outside of the tube.

5. The cause of this seems to be nothing more than the ordinary attraction of the particles of matter for each other. The sides of a small orifice are so near to each other as to attract the particles of the fluid on their opposite sides; and as all attraction is strongest in the direction of the greatest quantity of matter, the water is raised upwards, or in the direction of

port, (now in London,) have proved that water is capable of a considerable degree of compression. Fluids, in general, have a voluntary tendency to expand when at liberty; but liquids will not expand without a change of temperature. Heat is supposed to be the primary cause of the fluid form of bodies. It insinuates itself between the particles of bodies, and forces them asunder. Thus, for instance, ice, without heat, is a solid; with heat it becomes water, and, with a greater degree of heat, it expands into an elastic fluid, called *steam*.

* The word *capillary* is derived from the Latin word *capilla*, (hair,) and it is applied to this kind of attraction, because it is exhibited most prominently in tubes, *the bores of which are as fine as a hair*, and hence called capillary tubes.

What is supposed to be the primary cause of the fluid form of bodies? What effect has heat upon bodies? What illustration is given? Why do fluids gravitate in a more perfect manner than solids? What is inferred from the slight degree of cohesion in the particles of fluids? Why smooth? Why globular? Why cannot fluids be formed into figures, or preserved in heaps? What do you understand by capillary attraction? Explain the reason of it the length of the tube. On the outside of the tube, the opposite surfaces cannot act on the same column of water, and therefore the influence of attraction is here imperceptible in raising the fluid.

6. All porous substances, such as sponge, bread, linen, sugar, &c., may be considered as collections of capillary tubes; and, for this reason, water and other liquids will rise in them, when they are partly immersed.

7. It is on the same principle that the wick of a lamp will carry up the oil to supply the flame, although the flame is several inches above the level of the oil.* If the end of a towel happen to be left in a basin of water, it will empty the basin of its contents. On the same principle, when a dry wedge of wood is driven into the crevice of a rock, as the rain falls upon it, it will absorb the water, swell, and sometimes split the rock. In this manner, mill-stone quarries are worked in Germany.

8. A beautiful experiment, dependent on the same principle of capillary attraction, may be thus performed. Take two

* The reason why well-filled lamps will sometimes fail to give light, is, that the wick is too large for its tube, and being thus compressed, the capillary attraction is impeded by the compression. The remedy is to reduce the size of the wick. Another cause, also, that prevents a clear light, is, that the flame is too far from the surface of the oil. As capillary attraction acts only at short distances, the surface of the oil should always be within a short distance of the flame. But another reason which requires particular attention, is, that all kinds of oil usually employed for lamps contain a glutinous matter, of which no treatment can wholly divest them. This matter fills the pores or capillary tubes of the wick, and prevents the ascent of the oil to feed the flame. For this reason the wicks of lamps should be often renewed. A wick that has been long standing in a lamp, will rarely afford a clear and bright light. Another thing to be noticed by those who wish the lamp to perform its duty in the best possible manner, is, that the wick be not of such size as, by its *length* as well as its thickness, to fill the cup, and thereby leave no room for the oil. It must also be remembered, that although the wick when first adjusted may be of the proper size, the glutinous matter of the oil, filling its capillary tubes, causes the wick to swell, and thereby become too large for the tube, producing the same difficulty as has already been noticed in cases where the wick is too large to allow the free operation of capillary attraction

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Explain why the same takes place in all porous substances. Explain all the circumstances attending the burning of a lamp. Explain the experiment with the glass plates.

pieces of flat glass, joined together at one side, and separated at the other by a thin strip of wood, card, or other substance. When thus prepared, immerse the glass in colored water, having previously wet the inner surface. The water will then rise between the pieces of glass, forming a beautiful curve, the higher part appearing where the pieces of glass are in contact. This is exemplified by the glass plates in the "Boston School Set."

101. The level, or equilibrium of fluids, is the tendency of the particles so to arrange themselves that every part of the surface shall be equally distant from the centre of the earth; that is, from the point to which gravity tends.

All fluids have a tendency to preserve this equilibrium. Hence the surface of all fluids, when in a state of rest must partake of the spherical form of the earth. This level or equilibrium of fluids is the natural result of the independent gravitation of each particle. The particles of a solid body being united by cohesive attraction, if any one of them be supported, it will uphold those also with which it is united. But when any particle of a fluid is unsupported, it is attracted down to the level of the surface of the fluid; and the readiness with which fluids yield to the slightest pressure will enable the particle by its own weight, to penetrate the surface of the fluid and mix with it.

102. Fluids of different densities all preserve their own equilibrium.

If a quantity of mercury, water, oil, and air, be put into the same vessel, they will arrange themselves in the order of their specific gravities. The mercury will sink to the bottom, the water will stand above the mercury, the oil above the water, and the air above the oil; and the surface of each fluid will partake of the spherical form of the earth, to which they all respectively gravitate.

103. A water-level is an instrument constructed on the

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101. What is meant by the level or equilibrium of fluids? Have all fluids a tendency to preserve this equilibrium? What follows from this? Of what is this level or equilibrium of fluids the natural result? How does the gravitation of solid bodies differ from that of fluids?

102. Do fluids of different densities all preserve their own equilibrium? What illustration is given to prove this?

principle of the equilibrium of fluids. It consists of a glass tube, partly filled with water, and closed at both ends. When the tube is not perfectly horizontal,—that is, if one end of the tube be lower than the other,—the water will run to the lower end. By this means the level of any line to which the instrument is applied may be ascertained.

Fig. 50 represents a water-level. A B is a glass tube partly filled with water. C is a bubble of air occupying the space not filled by the water. When both ends of the tube are on a level, the air-bubble will remain in the centre of the tube; but if either end of the tube be depressed, the water will descend and the air-bubble will rise. The glass tube when used is generally set in a wooden or a brass box. It is an instrument much used by carpenters, masons, surveyors, &c.

Fig. 50.

104. Solid bodies gravitate in masses, their parts being so connected as to form a whole, and their weight may be regarded as concentrated in a point called the centre of gravity; while each particle of a fluid may be considered as a separate mass, gravitating independently.

It is for this reason that a body of water, in falling, does less injury than a solid body of the same weight. But if the water be converted into ice, the particles losing their fluid form, and being united by cohesive attraction, gravitate unitedly in one mass.

105. Fluids not only press downwards like solids, but also upwards, sidewise,* and in every direction.

* If the particles of fluids were arranged in regular columns as in Fig. 51, there would be no *lateral* pressure; for when one particle is perpendicularly above the other, it can press only *downwards*. But if the particles be ar-

Fig. 51.

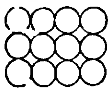
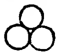


Fig 52.



103. Upon what principle is a water-level constructed? Of what does it consist? For what is it used? What figure represents a water-level? Explain the figure.

104. In what manner do solid bodies gravitate? What is the centre of gravity? What effect has gravity on the particles of fluids?

105. How is the pressure of fluids exerted?

So long as the equality of pressure is undisturbed, every particle will remain at rest. If the fluid be disturbed by agitating it, the equality of pressure will be disturbed, and the fluid will not rest until the equilibrium is restored.

1. The downward pressure of fluids is shown by making an aperture in the bottom of a vessel of water. Every particle of the fluid above the aperture will run downwards through the opening.

2. The lateral pressure is shown by making the aperture at the side of the vessel. The fluid will then escape through the aperture at the side.

3. The upward pressure is shown by taking a glass tube, open at both ends, inserting a cork in one end, (or stopping it with the finger,) and immersing the other in the water. The water will not rise in the tube. But the moment the cork is taken out, (or the finger removed,) the fluid will rise in the tube to a level with the surrounding water.

106. The pressure of a fluid is in proportion to the perpendicular distance from the surface; that is, the deeper the fluid the greater will be the pressure. This pressure is exerted in every direction, so that all the parts at the same depth press each other with equal force.

1. A bladder, filled with air, being immersed in water, will be contracted in size, on account of the pressure of the water

ranged as in Fig. 52, where a particle presses between two particles beneath, these last must suffer a *lateral* pressure. In whatever manner the particles are arranged, if they be globular, as is suppoed, there must be spaces between them. See Fig. 1, page 20.

How long will the particles of fluids remain at rest? Explain Fig. 51. What does Fig. 52 represent? If the equality of the pressure be undisturbed, what will follow? If the fluid be agitated, when will it again come to a state of rest? How is the downward pressure of fluids shown? The lateral pressure? The upward pressure?

106. To what is the pressure of a fluid in proportion? In what direction is this pressure exerted? What illustrations are given to prove this? Why can a bottle, filled with water, or any other liquid, be let down to any depth without injury?

in all directions; and the deeper it is immersed, the more will it be contracted.

2. An empty bottle, being corked, and by means of a weight let down to a certain depth in the sea, will either be broken by the pressure, or the cork will be driven into it, and the bottle be filled with water. This will take place even if the cork be secured with wire and sealed. But a bottle filled with water, or any other liquid, may be let down to any depth without damage, because, in this case, the internal pressure is equal to the external.*

* "*Experiments at sea.*—We are indebted t a friend, who has just arrived from Europe, says the Baltimore Gazette for the following experiments made on board the Charlemagne:

"26th of September, 1836, the weather being calm, I corked an empty wine-bottle, and tied a piece of linen over the cork; I then sank it into the sea six hundred feet; when drawn immediately up again, the cork was inside, the linen remained as it was placed, and the bottle was filled with water.

"I next made a noose of strong twine around the bottom of the cork, which I forced into the empty bottle, lashed the twine securely to the neck of the bottle, and sank the bottle six hundred feet. Upon drawing it up immediately, the cork was found inside, having forced its way by the twine, and in so doing had broken itself in two pieces; the bottle was filled with water.

"I then made a stopper of white pine, long enough to reach to the bottom of the bottle; after forcing this stopper into the bottle, I cut it off about half an inch above the top of the bottle and drove two wedges, of the same wood, into the stopper. I sank it six hundred feet, and upon drawing it up immediately the stopper remained as I placed it, and there was about a gill of water in the bottle, which remained unbroken. The water must have forced its way through the pores of the wooden stopper, although wedged as aforesaid; and had the bottle remained sunk long enough, there is no doubt that it would have been filled with water."

Similar experiments were made by the author of this work, in a voyage to the West Indies in the year 1839, first with an empty bottle and then with a bottle filled with water from the tanks on the deck; in both cases the bottle being closely stopped and the cork covered with canvass. The empty bottle was drawn from a depth of six hundred feet filled with water, and the full bottle with brackish water, the water from the tank having been compressed, and water from the depths of the ocean mixing with it.

It is the opinion of some philosophers, that the pressure at very great

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What experiment is mentioned in the note? What opinion have some philosophers expressed?

107. From what has now been stated, it appears that the lateral pressure proceeds entirely from the pressure downwards, or, in other words, from the weight of the liquid above; and that consequently the lower an orifice is made in a vessel containing water or any other liquid, the greater will be the force and velocity with which the liquid will rush out.

Fig. 53.

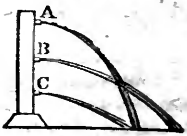

Fig. 53 represents a vessel of water, with orifices at the side at different distances from the surface. The different curves in the figure, described by the liquid in running out of the vessel, show the action of gravity and the effects produced by the force of the pressure on the liquid at different depths. At A the pressure is the least, because there is less weight of fluid above. At B and C the fluid is driven outwards by the weight of that portion above, and the force will be strongest at C.

108. As the lateral pressure arises solely from the downward pressure, it is not affected by the width nor the length of the vessel in which it is contained, but merely by its depth; for as every particle acts independently of the rest, it is only the column of particles above the orifice that can weigh upon and press out the water.

109. The lateral pressure on one side of a cubical vessel will be equal only to half of the pressure downwards; for every particle at the bottom of the vessel is pressed upon by a column of the whole depth of the fluid, while the lateral pressure diminishes from the bottom upwards to the surface, where the particles have no pressure.

depths of the sea is so great, that the water is condensed into a solid state; and that at or near the centre of the earth, if the fluid could extend so deeply, this pressure would convert the whole into a solid mass of fire.

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107. What causes the lateral pressure? What follows from this? Explain Fig. 53.

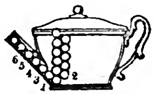
108. Does the length or the width of the vessel in which a fluid is contained have any effect upon the lateral pressure? By what is it affected?

109. How does the lateral pressure on one side of a cubical vessel compare with the pressure downwards? How would you explain this?

110. The upward pressure of fluids, although *apparently* in opposition to the principles of gravity, is but a necessary consequence of the operation of that principle; or, in other words, *the pressure upwards as well as the pressure downwards* is caused by gravity.

When water is poured into a vessel with a spout, (like a tea-pot, for instance,) the water rises in the spout to a level with that in the body of the vessel. The particles of water at the bottom of the vessel are pressed upon by the particles above them, and to this pressure they will yield, if there is any mode of making way for the particles above them. As they cannot descend through the bottom of the vessel they will change their direction and rise in the spout. Fig. 54 represents a tea-pot, and the columns of balls represent the particles of water magnified. From an inspection of the figure it appears that the particle numbered 1, at the bottom, will be pressed laterally, by the particle numbered 2, and by this pressure forced into the spout, where meeting with the particle 3 it presses it upwards, and this pressure will be continued from 3 to 4, from 4 to 5, and so on till the water in the spout has risen to a level with that in the body of the vessel. If water be poured into the spout the water will rise in the same manner in the body of the vessel; from which it appears that *the force of pressure depends entirely on the height, and not on the length or breadth of the column of fluid.*

Fig. 54.



111. One principle in hydrostatics, is so remarkable, that it is named the hydrostatic paradox. It is this. *That any quantity of fluid, however small, may be made to balance and support any other quantity, however large.*

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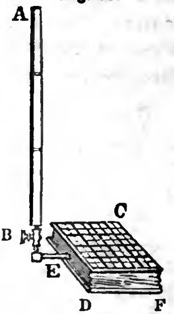
110. What causes the upward and downward pressure? Illustrate this by Fig. 54.

111. Upon what does the force of pressure depend? What is meant by the hydrostatic paradox? What is the use of the hydrostatic bellows? What figure represents the hydrostatic bellows? Explain the figure. What is the fundamental principle of Mechanics? Is this the principle of the hydrostatic bellows?

Fig. 55 represents the hydrostatic bellows.* A B is a long tube, *one inch square.* C D E F are the bellows, consisting of two boards, *eight inches square,* connected by broad pieces of leather, or india-rubber cloth, in the manner of a pair of common bellows. One pound of water poured into the tube will raise 64 pounds on the bellows. If a smaller tube be used the same quantity of water will fill it higher, and consequently will raise a greater weight; but if a larger tube be used it will of course not fill it so high, and consequently will not raise so great a weight; because it is the *height not the quantity which causes the pressure.*†

Fig. 55.



* This is the form of the Hydrostatic bellows in the original "Boston School Set." By means of a straight jet substituted for the tube, it was designed to illustrate a principle in Hydraulics also.

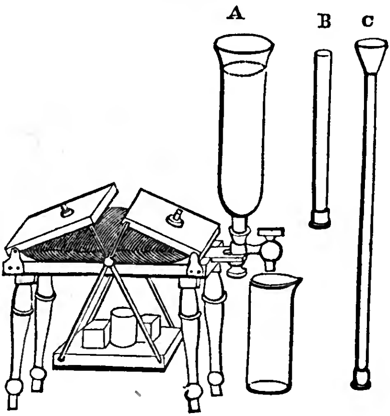
† The Hydrostatic bellows may be constructed in a variety of forms, the simplest of which consists, as in the figure, of two boards connected together by broad pieces of leather, or india-rubber cloth, in such a manner as to allow the upper board to rise and fall like the common bellows. A perpendicular tube is so adjusted to this apparatus, that water poured into the tube, passing between the boards, will separate them by its upward pressure, even although the upper board is loaded with a considerable weight.

[N. B. A small quantity of water must be poured into the bellows to separate the surfaces before they are loaded with the weight.]

The force of pressure exerted on the bellows by the water poured into the tube, is estimated by the comparative size of the tube and the bellows Thus, if the tube be one inch square, and the top of the bellows twelve inches, thus containing 144 square inches, a pound of water poured into the tube will exert a pressure of 144 pounds on the bellows. Now it will be clearly perceived that *this pressure is caused by the height of the column of water in the tube.* A pound, or a pint of water will fill the tube 144 times as high as the same quantity would fill the bellows. To raise a weight of 144 pounds on the bellows to the height of one inch, it will be necessary to pour into the tube as much water as would fill the tube were it 144 inches long. It will thus be perceived that *the fundamental principle of the laws of motion is here also in full force; namely, that what is gained in power is lost either in time or in space;* for, while the water in the bellows is rising to the height of one inch, that in the tube passes over 144 inches.

Fig. 56 is an apparatus* to show that *liquids press according to the height and not the quantity.* A and B are two vessels of unequal size but of the same length. These may successively be screwed to the apparatus and filled with water. Weights may then be added to the suspended scale until the pressure is counterbalanced. It will then be perceived that although A is ten times larger than B, the water will stand at the same height in both, *because they are of the same length.* If C be used instead of A or B, the apparatus may be used as the hydrostatic bellows.

Fig. 56



112. If water be confined in any vessel, and a pressure to any amount be exerted on a square inch of that water, a pressure to an equal amount will be transmitted to every square inch of the surface of the vessel in which the water is confined.†

* This apparatus, belonging to the "Boston School Set," unites simplicity with convenience. Instead of two boards, connected with leather, an india-rubber bag is placed between two boards, and the boards are made to rise or fall as the water runs into or out of the bag. It is an apparatus easily repaired, and the bag may also be used for gas, or for experiments in Pneumatics.

† This property of fluids seems to invest us with a power of increasing the intensity of a pressure exerted by a comparatively small force, without any other limit than that of the strength of the materials of which the engine itself is constructed. It also enables us with great facility to transmit

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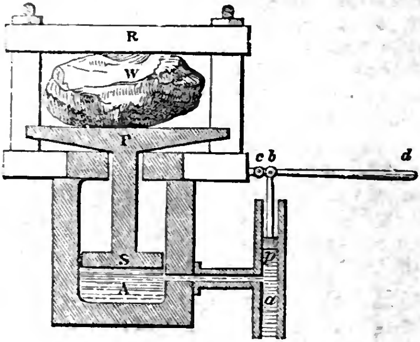
112. What fact is mentioned in this number with regard to the pressure on water?

1. It is upon this principle that Bramah's hydrostatic press, represented in Fig. 57, is constructed. The main features of this apparatus are as follows: *a* is a narrow and A a large metallic cylinder having communication one with the other. Water stands in both the cylinders. The piston S carries a strong head P, which works in a frame opposite to a similar plate, R. Between the two plates the substance W to be compressed is placed.

Fig. 57



In the narrow tube *a* is a piston *p*, worked by a lever *c b d*, its short arm *c b* driving the piston, while the power is applied at *d*. The pressure exerted by the small piston *p* on the water at *a* is transmitted with equal force throughout the entire mass of the fluid, while the surface at A presses up the piston S with a force proportioned to its area. For instance, if the cylinder *a* of the force-pump has an area of half an inch while the great cylinder has an area of 200 inches, then the pressure of the water in the latter on the piston S, will be (1 half inch multiplied by 400 half inches) equal to 400 times that on *p*.

2. Next, suppose the arms of the lever to be to each other as 1 to 50, and that at *d*, the extremity of the longer arm, a

the motion and force of one machine to that of another, in cases where local circumstances preclude the possibility of instituting any ordinary mechanical connection between the two machines. Thus, merely by means of water-pipes, the force of a machine may be transmitted to any distance, and over inequalities of ground, or through any other obstructions.

Upon what principle is Bramah's hydrostatic press constructed? What figure represents this? Explain the figure. To what uses is this press applied?

man works with a force of 50 pounds, the piston *p* will consequently descend on the water with a force of 2000 pounds. Deducting $\frac{1}{4}$ for the loss of power caused by the different impediments to motion, and one man would still be able to exert a force of three quarters of a million of pounds by means of this machine. This press is used in pressing paper, cloth, hay, gunpowder, &c.; also in uprooting trees, testing the strength of ropes, &c.

113. A fluid specifically lighter than another fluid will float upon its surface.*

114. A body specifically lighter than a fluid will sink in the fluid until it has displaced a portion of the fluid equal in weight to itself.

If a piece of cork is placed in a vessel of water, about one third part of the cork will sink below, and the remainder will stand above the surface of the water; thereby displacing a portion of water equal in bulk to about a third part of the cork, and this quantity of water is equal in weight to the whole of the cork; because the specific gravity of water is about three times as great as that of cork.†

* The slaves in the West Indies, it is said, steal rum by inserting the long neck of a bottle, full of water, through the top aperture of the rum-cask. The water falls out of the bottle into the cask, while the lighter rum ascends in its stead.

† It is on the same principle that boats, ships, &c., although composed of materials heavier than water, are made to float. From their peculiar shape, they are made to set lightly on the water. The extent of the surface presented to the water counterbalances the weight of the materials, and the vessel sinks to such a depth as will cause it to displace a portion of water equal in weight to the whole weight of the vessel. From a knowledge of the specific gravity of water, and the materials of which a vessel is composed, rules have been formed by which to estimate the tonnage of vessels; that is to say, the weight which the vessel will sustain without sinking.

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113. When will one fluid float upon another?

114. What is stated with regard to a body specifically lighter than a fluid? What illustration is given of this? How do the specific gravities of water and cork compare with each other? Upon what principle is it that boats, ships, &c., are made to float upon the water? What rules have been formed from the knowledge of the specific gravity of water and the materials of which vessels are composed?

115. The standard which has been adopted to estimate the specific gravity of bodies, is rain or distilled water.*

Taking a certain quantity of rain or distilled water, we find that a *quantity* of gold, *equal in bulk*, will weigh nearly twenty times as much as the water; of lead, nearly twelve times as much; while oil, spirit, cork, &c., will weigh less than the water.†

* As heat expands and cold condenses all metals, their specific gravity cannot be the same in summer that it is in winter. For this reason they will not serve as a standard to estimate the specific gravity of other bodies. The reason that *distilled* water is used is, that spring, well, or river water is seldom perfectly pure; and the various substances mixed with it affect its weight. The cause of the ascent of steam, or vapor, may be found in its specific gravity. It may here be stated that rain, snow, and hail are formed by the condensation of the particles of vapor in the upper regions of the atmosphere. Fine watery particles coming within the sphere of each other's attractions, unite in the form of a drop, which being heavier than the air, falls to the earth. Snow and hail differ from rain only in the different degrees of temperature at which the particles unite. When rain, snow, or hail fall, part of it reascends in the form of vapor. and forms clouds; part is absorbed by the roots of vegetables, and part descends into the earth and forms springs. The springs form brooks, rivulets, rivers, &c., and descend to the ocean, where being again heated by the sun, the water rising in the form of vapor, again forms clouds, and again descends in rain, snow, hail, &c. The specific gravity of the watery particles which constitute vapor, is less than that of the air near the surface of the earth; they will, therefore, ascend until they reach a portion of the atmosphere of the same specific gravity with themselves. But the constant accession of fresh vapor from the earth, and the loss of heat, causes several particles to come within the sphere of each other's attraction, as has been stated above, and they unite in the form of a drop, the specific gravity of which being greater than that of the atmosphere, it will fall in the form of rain. Water, as it descends in rain, snow, or hail, is perfectly pure, but when it has fallen to the earth, it mixes with the various substances through which it passes, which gives it a species of flavor, without affecting its transparency.

† The following table shows the specific gravity of the substances therein mentioned. It is to be understood that all substances whose specific gravity is greater than water, will sink when immersed in it, and that all

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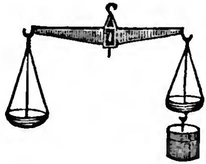
115. What standard has been adopted to estimate the specific gravity of substances in general? Why could not metals have been adopted? Why is distilled water used? What bodies will sink when immersed in water? What will float?

116. The specific gravity of bodies that will sink in water is ascertained by weighing them first in water, and then out of the water, and dividing the weight out of the water by the loss of weight in water.

Fig. 58.



1. Fig. 58 represents the scales for ascertaining the specific gravity of bodies. One scale is shorter than the other, and a hook is attached to the bottom of the scale to which substances, whose specific gravity is sought, may be attached and sunk in water.

2. Suppose a cubic inch of gold weighs 19 ounces when weighed out

whose specific gravity is less than that of water, will float in it. Let us then take a quantity of water which will weigh exactly one pound; a quantity of the substances specified in the table, of the same bulk, will weigh as follows:

Platinum, -	23. lbs.	Chalk, -	1.793 lbs.	Living men, -	.891 lbs.
Fine Gold, -	19.640 "	Coal, -	1.250 "	Ash, - - - -	.800 "
Mercury, -	14.019 "	Mahogany,	1.063 "	Beech, - - -	.700 "
Lead, - - -	11.525 "	Milk, - - -	1.034 "	Elm, - - - -	.600 "
Silver, - -	11.091 "	Box-wood, -	1.030 "	Fir, - - - -	.500 "
Copper, - -	9.000 "	Rain water, -	1.000 "	Cork, - - - -	.240 "
Iron, - - -	7.645 "	Oil, - - - -	.920 "	Common air, -	.0011 "
Glass, - - -	3.000 "	Ice, - - - -	.908 "	Hydrogen gas,	.000105
Marble, - -	2.705 "	Brandy, - -	.820 "		

A cubic foot of water weighs one thousand avoirdupois ounces. By multiplying the number opposite to any substance in the above table by one thousand, we obtain the weight of a cubic foot of that substance, in ounces Thus, a cubic foot of platinum is 23000 ounces in weight.

In the above table it appears that the specific gravity of *living men* is about one ninth less than that of common water. So long, therefore, as the lungs can be kept free from water, a person, although unacquainted with the art of swimming, will not completely sink, provided the hands and arms be kept under water.

The specific gravity of sea water is greater than that of the water of lakes and rivers, on account of the salt contained in it. On this account the water of lakes and rivers has less buoyancy, and it is more diffiult to swim in it.

What is the weight of a cubic foot of water? What is the use of the above table? How does the specific gravity of living men compare with that of water? Which is the greater, the specific gravity of sea water, or of lakes and rivers? Why?

116. How is the specific gravity of bodies that will sink in water ascertained? What illustration is given? Explain Fig 58

of the water, and but 18 ounces* when weighed in water—the loss in water is one ounce. The weight out of water, 19 ounces, being divided by one (the loss in water) gives 19. The specific gravity of gold, then, would be 19, or, in other words, gold is nineteen times heavier than water.

117. The specific gravity of a body that will not sink in water, is ascertained by dividing its weight by the sum of its weight, added to the loss of weight which it occasions in a heavy body previously balanced in water.†

* The gold will weigh less in the water than out of it, on account of the upward pressure of the particles of water, which in some measure supports it, and by so doing diminishes its weight. Now, as the upward pressure of these particles is exactly sufficient to balance the downward pressure of a quantity of water of exactly the same dimensions with the gold, it follows that the gold will lose exactly as much of its weight in water, as a quantity of water of the same dimensions with the gold will weigh. And this rule applies to all bodies heavier than water, that are immersed in it. *They will lose as much of their weight in water as a quantity of water of their own dimensions weighs.* All bodies, therefore, of the same size, lose the same quantity of their weight in water. Hence, *the specific gravity of a body is the weight of it compared with that of water.* As a body loses a quantity of its weight when immersed in water, it follows that when the body is lifted from the water, that portion of its weight which it had lost will be restored. This is the reason that a bucket of water, drawn from a well, is heavier when it rises above the surface of the water in the well, than it is while it remains below the surface. For the same reason our limbs feel heavy in leaving a bath.

† The method of ascertaining the specific gravities of bodies was discovered accidentally by Archimedes. He had been employed by the king of Syracuse to investigate the metals of a golden crown which he suspect-

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Why will gold weigh less in the water than out of it? How does this upward pressure of the particles compare with the downward pressure of a quantity of water of the same dimensions? What follows from this? What rule is given with regard to all bodies heavier than water that are immersed in it? What is the specific gravity of a body? What is the reason that a bucket of water, drawn from a well, is heavier when it rises above the surface of the water, than while it is below it?

117. How can the specific gravity of a body that will not sink in water be ascertained? What illustration is given? By whom was the method of ascertaining the specific gravities of bodies discovered? In what manner did he ascertain it?

If a body lighter than water weighs six ounces, and on being attached to a heavy body, balanced in water, is found to occasion it to lose twelve ounces of its weight, its specific gravity is determined by dividing its weight (six ounces) by the sum of its weight, added to the loss of weight it occasions in the heavy body, namely, six added to twelve, which, in other words, is 6 divided by 18, or $\frac{6}{18}$, which is $\frac{1}{3}$.

118. An hydrometer is an instrument to ascertain the specific gravity of liquids.

1. The hydrometer is constructed on the principle, that the greater the weight of a liquid, the greater will be its buoyancy.

2. The hydrometer is made in a variety of forms, but it generally consists of a hollow ball of silver, glass, or other material, with a graduated scale rising from the upper part. A weight is attached below the ball. When the instrument, thus constructed, is immersed in a fluid, the specific gravity of the fluid is estimated by the portion of the scale that remains above the surface of the fluid. The greater the specific gravity of the fluid, the less will the scale sink.

ed had been adulterated by the workmen. The philosopher labored at the problem in vain, till going one day into the bath, he perceived that the water rose in the bath in proportion to the bulk of his body. He instantly perceived that any other substance of equal size would raise the water just as much, though one of *equal* weight and *less* bulk could not produce the same effect. He then obtained two masses, one of gold and one of silver, each equal in weight to the crown, and having filled a vessel very accurately with water, he first plunged the silver mass into it, and observed the quantity of water that flowed over; he then did the same with the gold, and found that a less quantity had passed over than before. Hence he inferred that, though of equal weight, the bulk of the silver was greater than that of the gold, and that the quantity of water displaced was, in each experiment, equal to the bulk of the metal. He next made trial with the crown, and found that it displaced more water than the gold, and less than the silver, which led him to conclude, that it was neither pure gold nor pure silver.

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118. What is an hydrometer? Upon what principle is it constructed? Explain its construction. In what proportion does the scale sink?

CHAPTER VI.

HYDRAULICS.

119. Hydraulics treats of the motion of fluids, particularly of water; and the construction of all kinds of instruments and machines for moving them.

Water, in its motion, is retarded by the friction of the bottom and sides of the channel through which it passes. For this reason the velocity of the surface of a running stream is always greater than that of any other part.*

120. A fluid running from an orifice in a vessel is discharged with the greater rapidity when the vessel from which it flows is kept constantly full.

This is a necessary consequence of the law, that pressure is proportioned to the height of the column above.

121. When a fluid spouts from several orifices in the side of a vessel, it is thrown to the greatest distance from the orifice nearest to the centre.†

122. A vessel filled with any liquid will discharge a greater quantity of the liquid through an orifice to which

* In consequence of the friction of the banks and beds of rivers, and the numerous obstacles they meet in their circuitous course, their progress is slow. If it were not for these impediments, the velocity which the waters would acquire would produce very disastrous consequences. An inclination of three inches in a mile, in the bed of a river, will give the current a velocity of about three miles an hour.

† This is true only on the condition that the vessel be not elevated. If the vessel be elevated, the lowest orifice will discharge the fluid to the greatest distance, but when the vessel is placed low, the fluid will reach the plane before its projectile force is expended.

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119. Of what does Hydraulics treat? What retards the motion of water? Why does the surface of a canal or river have a greater velocity than any other part?

120. Does the fulness of a vessel from the orifice of which a fluid is running, have any effect upon its velocity?

121. When a fluid spouts from several orifices in the side of a vessel, from which is it thrown to the greatest distance?

a short pipe of peculiar shape is fitted, than through an orifice of the same size without a pipe.* But if the pipe project into the vessel, the quantity discharged will be diminished instead of increased by the pipe.

The quantity of a fluid discharged through a pipe or an orifice is increased by heating the liquid; because heat diminishes the cohesion of the particles, which exists, to a certain degree, in all liquids.

123. The velocity of a current of water may be ascertained by immersing in it a bent tube, shaped like a tunnel at the end which is immersed.

Fig. 59

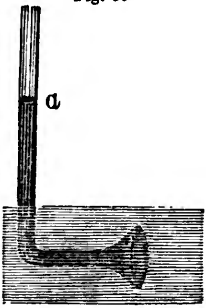

Fig. 59 is a tube shaped like a tunnel, with the larger end immersed in an opposite direction to the current. The rapidity of the current is estimated by the height to which the water is forced into the tube, above the surface of the current. By such an instrument the comparative velocity of different streams, or the same stream at different times, may be estimated.†

* This is caused by the cross-currents made by the rushing of the water from different directions towards the sharp-edged orifice. The pipe smooths the passage of the liquid.

† To measure the velocity of a stream at its surface, hollow floating bodies are used; as, for example, a glass bottle filled with a sufficient quantity of water to make it sink just below the level of the current, and having a small flag projecting from the cork. A wheel may also be caused to revolve by the current striking against boards projecting from the circumference of the wheel, and the rapidity of the current may be estimated by the number of the revolutions in a given time.

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122. What effect will a pipe, fitted to an orifice, have with regard to the quantity discharged? What will be the effect if the pipe project into the vessel? How can the quantity discharged through a pipe or orifice, be increased? Why will heat increase it?

123. How can the velocity of a current of water be ascertained? What does Fig. 59 represent? How is the rapidity of the current estimated? What is the use of the instrument?

124. Waves are caused by the friction between air and water.*

125. The instruments used for raising or drawing water or other liquids, are the common pump,† the chain pump, the forcing pump, the siphon, and the screw of Archimēdes.

126. The chain-pump is a machine by which the water is lifted through a box or channel, by boards fitted to the channel and attached to a chain. It has been used principally on board of ships.

Fig. 60.

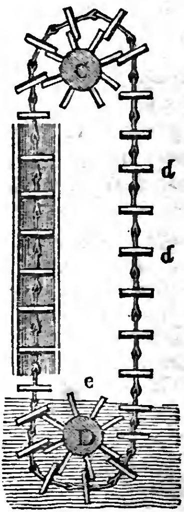


Fig. 60 represents a chain-pump. It consists of a square box through which a number of square boards or buckets, connected by a chain, is made to pass. The chain passes over the wheel C and under the wheel D, which is under water. The buckets are made to fit the box, so as to move with little friction. The upper wheel, C, is turned by a crank, (not represented in the Fig.) which causes the chain with the buckets attached to pass through the box. Each bucket, as it enters the box, lifts up the water above it, and discharges it at the top.

127. The screw of Archimēdes is a machine said to have been invented by the philosopher Archimēdes, for

* When oil is poured on the windward side of a pond, the whole surface will become smooth. The oil protects the water from the friction of the wind or air. It is said that boats have been preserved in a raging surf, in consequence of the sailors having emptied a barrel of oil on the water.

† The common pump, and the forcing pump, will be explained in connection with Pneumatics.

124. What causes waves? What is sometimes done to remove this friction?

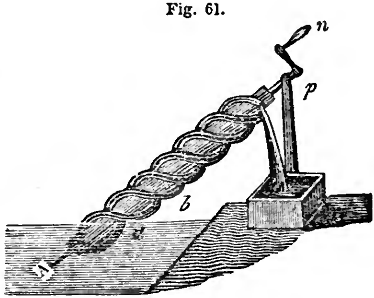
125. What instruments are used for raising liquids?

126. Where is the chain-pump used? What figure represents it? Explain the figure.

raising water and draining the lands of Egypt, about 200 years before the Christian era.

Fig. 61 represents the screw of Archimēdes. A single tube, or two tubes, are wound in the form of a screw around a shaft or cylinder, supported by the prop and the pivot A, and turned by the handle *n*. As the end of the tube dips into the water, it is filled with the fluid, which is forced up the tube by every successive revolution, until it is discharged at the upper end.

Fig. 61.



128. Springs and rivulets are formed by the water, from rain, snow, &c., which penetrates the earth, and descends until it meets a substance which it cannot penetrate. A reservoir is then formed by the union of small streams under ground, and the water continues to accumulate until it finds an outlet.

Fig. 62.

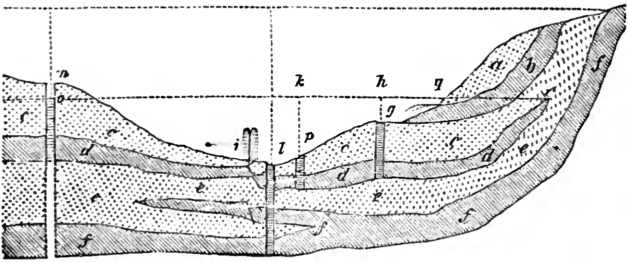


Fig. 62 represents a vertical section of the crust of the earth. *a*, *c*, and *e* are strata, either porous, or full of cracks,

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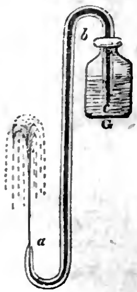
127. What is said of the screw of Archimēdes? Explain the use of the screw by Fig. 61

128. How are springs and rivulets formed? Explain Fig. 62

which permit the water to flow through, while *b*, *d*, and *f*, are impervious to the water. Now according to the laws of hydrostatics, the water at *b* will descend and form a natural spring at *g*; at *i* it will run with considerable force, forming a natural jet; and at *l*, *p*, and *g*, artesian wells may be dug, in which the water will rise to the respective heights *g h*, *p h*, and *l m*, the water not being allowed to come in contact with the porous soil through which the bore is made, but being brought in pipes to the surface; at *n* the water will ascend to about *o*, and there will be no fountain. This explains also the manner in which water is obtained by digging wells.

129. A spring will rise nearly as high, but cannot rise higher than the reservoir from whence it issues. Water may be conveyed over hills and valleys in bent pipes and tubes, or through natural passages, to any height which is not greater than the level of the reservoir from whence it flows.*

Fig. 63.



130. Fountains are formed by water carried through natural or artificial ducts from a reservoir. The water will spout through the ducts to nearly† the height of the surface of the reservoir.

A simple method of making an artificial fountain may be understood by Fig. 63. A glass siphon *a b c* is immersed in a vessel of water, and the air being exhausted from the siphon, a jet will be produced at *a*, proportioned to the fineness of the bore and the length of the tube.

* The ancient Romans, ignorant of this property of fluids, constructed vast aqueducts across valleys, at great expense, to convey water over them. The moderns effect the same object by means of wooden, metallic, or stone pipes.

† The resistance of the air prevents the fluids from rising to quite the same height with the reservoir.

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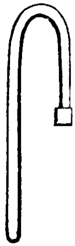
129. How high will a spring rise?

130. How are fountains formed? How high will the water spout through the ducts? What prevents the fluid from rising to the same height with the reservoir?

131. The siphon is a tube bent in the form of the letter U, one side being a little longer than the other.

Fig. 64

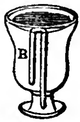


1. Fig. 64 represents a siphon. A siphon is used by filling it with water or some other fluid, then stopping both ends, and in this state immersing the shorter leg or side into a vessel containing a liquid. The ends being then unstopped, the liquid will run through the siphon until the vessel is emptied. In performing this experiment, *the end of the siphon which is out of the water must always be below the surface of the water.*

2. This instrument may also be used to show the equilibrium of fluids. For, if the tube be inverted and two liquids poured into it, they will rise in each side or leg of the siphon to different heights—the higher fluid standing at the highest level. The specific gravity of mercury being thirteen times greater than that of water, will balance thirteen times its bulk of water. Consequently water will rise thirteen times as high on one side of the siphon as the mercury on the other. But if one liquid only is poured into the siphon it will rise to the same height in both sides or legs of the siphon.

3. Tantalus' cup consists of a goblet containing a small figure of a man. A siphon is concealed within the figure, which empties the water from the goblet as fast as it is poured in, so that the glass can never be filled.

Fig. 65.



4. Fig. 65 represents the cup with the siphon. The figure of the man is omitted, in order that the position of the siphon may be seen.

132. Water, by means of its weight or its force when in motion, becomes a mechanical agent of great power. It is used to propel or turn wheels of different construction, which, being connected with machinery of various kinds, form mills, &c.

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131. What is the siphon? In what manner is the siphon used? How can the siphon be used to show the equilibrium of fluids? How high will the liquid rise in each side of the siphon? What is Tantalus' cup? What does Fig. 65 represent?

132 How, and for what purposes is water used as a mechanical agent?

There are three kinds of water-wheels, called undershot, overshot, and breast wheels.

133. The Overshot wheel is a wheel set in motion by the weight of water flowing upon it. It receives its motion at the top.

Fig. 66.

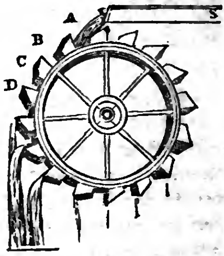

Fig. 66 represents the overshot wheel. It consists of a wheel turning on an axis, (not represented in the Fig.,) with compartments called buckets, *a b c d*, &c., at the circumference, which are successively filled with water from the stream S. The weight of the water in the buckets causes the wheel to turn, and the buckets being gradually inverted are emptied as they descend. It will be seen, from an inspection of the figure, that the buckets in the descending side of the wheel are always filled, or partly filled, while those in the opposite or ascending part are always empty until they are again presented to the stream. This kind of wheel is the most powerful of all the water-wheels.

134. The Undershot wheel is a wheel which is moved by the motion of the water. It receives its impulse at the bottom.

Fig. 67.

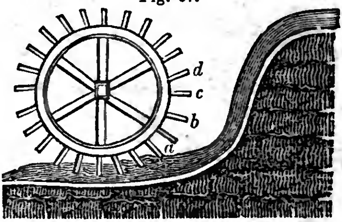

Fig. 67 represents the undershot wheel. Instead of buckets at the circumference, it is furnished with plane surfaces, called float-boards, *a b c d*, &c., which receive the impulse of the water, and cause the wheel to revolve.

How many kinds of water-wheels are there? What are they?

133. What is the overshot wheel? Where does it receive its motion? Explain Fig. 66. What causes the wheel to turn? How does this wheel compare in power with the other water-wheels?

134. What is the undershot wheel? Where does it receive its motion? What does Fig. 67 represent? How does this wheel differ from the overshot?

135. The Breast-wheel is a wheel which receives the water at about half its own height, or at the level of its axis. It is moved both by the weight and the motion of the water.*

Fig. 68

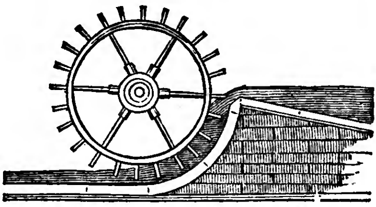

Fig. 68 represents a breast-wheel. It is furnished either with buckets, or with float-boards, fitting the water-course.

CHAPTER VII.

PNEUMATICS.

136. Pneumatics treats of the nature, mechanical properties, and effects of air and similar fluids, distinguished by the name of aëriform fluids.†

137. The air we breathe is an elastic fluid which surrounds the earth, extending to an indefinite distance above its surface, and constantly decreasing upwards in density.‡

* In all the wheels which have been described, the motion given to the wheel is communicated to other machinery or gearing, as it is called, by other wheels or pinions attached to the axis, such as have been described under the head of Mechanics.

† An aëriform fluid is a fluid in the form of air, and, like air, generally invisible.

‡ The terms "*rarefaction*" and "*rarefied*" are applied to air when it is expanded; and "*condensation*," or "*condensed*," when it is compressed.

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135. What is the breast-wheel? How is it set in motion? What figure represents the breast-wheel? To what is the motion given to the wheels which have been described, communicated?

136. Of what does Pneumatics treat?

137. What is the air which we breathe? How far does it extend above the surface of the earth?

It possesses many of the properties belonging to liquids in general, besides several others, the result, or, perhaps, the cause of its elasticity. Its specific gravity is eight hundred times less than that of water.*

138. Air, steam, vapor, gas, are all elastic fluids possessing the same mechanical properties.† Whatever, therefore, is stated in relation to air, belongs in common to all of these fluids.

139. Aëriform fluids have weight, but no cohesive attraction.

140. Air has two principal properties, namely, GRAVITY and ELASTICITY.‡

It has already been stated, that the air near the surface of the earth bears the weight of that which is above it. Being compressed, therefore, by the weight of that above it, it must exist in a condensed form near the surface of the earth, while in the upper regions of the atmosphere, where there is no pressure, it is highly rarefied. This condensation, or pressure, is very similar to that of water at great depths in the sea.

* The air is necessary to animal and vegetable life, and to combustion. It is a very heterogeneous mixture, being filled with vapors of all kinds It consists, however, of two principal ingredients, called oxygen and nitrogen, or azote; of the former of which there are 28 parts, aud of the latter, 72 in a hundred. The air is not visible, because it is perfectly transparent. It may be felt when it moves in the form of wind, or by swinging the hand rapidly backwards and forwards.

† The chemical properties of liquids, fluids, &c., are not treated in the sciences of Pneumatics, Hydraulics, or Hydrostatics, but belong peculiarly to the science of Chemistry. They are not, therefore, described in this work. But fluids possess all the properties of liquids, and the laws of Hydrostatics and Hydraulics apply to them as well as to liquids.

‡ Besides these two *principal* properties, the operations of which produce most of the phenomena of Pneumatics, it will be recollected that as air, although an invisible is yet a material substance, possessing all the

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Does it possess properties common to liquids in general? How does its specific gravity compare with that of water? Of what two principal ingredients does the air consist? What is the proportion of these parts to each other?

138. What other fluids are named belonging to the class of elastic fluids?

139. Have the air and other similar fluids weight? With what power alone has heat to contend in aëriform fluids?

140 What two principal properties has the air?

141. A column of air, having a base an inch square, and reaching to the top of the atmosphere, weighs about fifteen pounds. This pressure, like the pressure of liquids, is exerted equally in all directions.*

142. The elasticity of air and other aëriform fluids is that property by which they are increased or diminished in extension, according as they are compressed.†

This property exists in a much greater degree in air and other similar fluids than in any other substance. In fact it has no known limit; for when the pressure is removed from any portion of air, it immediately expands to such a degree that the smallest quantity will diffuse itself over an indefinitely large space. And, on the contrary, when the pressure is increased, it will be compressed into indefinitely small dimensions.‡

common properties of matter, it possesses also the common property of *impenetrability*. This will be illustrated by experiments.

* It has been computed that the weight of the whole atmosphere is equal to that of a globe of lead sixty miles in diameter, or to five thousand billions of tons.

† The pressure of the atmosphere caused by its weight is exerted on all substances, internally and externally, and it is a necessary consequence of its fluidity. The body of a man of common stature has a surface of about 2000 square inches; whence the pressure at 15 pounds per square inch will be 30,000 pounds. The reason why this immense weight is not felt, is, that the air within the body and its pores counterbalances the weight of the external air. When the external pressure is artificially removed from any part, it is immediately felt by the reaction of the internal air.

‡ Heat insinuates itself between the particles of bodies, and forces them asunder, in opposition to the attraction of cohesion and of gravity; it therefore exerts its power against both the attraction of gravitation and the attraction of cohesion. But as the attraction of cohesion does not exist in aëriform fluids, the expansive power of heat upon them has nothing to contend with but gravity. Any increase of temperature, therefore, expands an elastic fluid prodigiously, and a diminution of heat condenses it.

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141. What is the weight of a column of air one inch square at the base and reaching to the top of the atmosphere? Is the pressure exerted equally in all directions?

142. What is meant by the elasticity of the air? How do the aëriform fluids differ from liquids? When is the air said to be rarefied? When condensed? Is the air, near the surface of the earth, rare or dense?

143. Air becomes a mechanical agent by means of its weight, its elasticity, its inertia, and its fluidity.*

144. A vacuum is a space from which air and every other substance has been removed.

The Torricellian vacuum was discovered by Torricelli, and was obtained in the following manner. A tube, closed at one end, and about 32 inches long, was filled with mercury; the open end was then covered with the finger so as to prevent the escape of the mercury, and the tube inverted and plunged into a vessel of mercury; the finger was then removed and the mercury permitted to run out of the tube. It was found, however, that the mercury still remained in the tube to the height of about thirty inches, leaving a vacuum at the top of about two inches. This vacuum, called from the discoverer the Torricellian vacuum, is the most perfect that has been discovered.†

* *The fluidity of air invests it,* as it invests all other liquids, ***with the power of transmitting pressure.*** But it has already been shown, under the head of Hydrostatics, that fluidity is a necessary consequence of the independent gravitation of the particles of a fluid. It may, therefore, be included among the effects of weight.

The inertia of air is exhibited in the resistance which it opposes to motion, which has already been noticed under the head of Mechanics. This is clearly seen in its effect upon falling bodies, as will be exemplified in the experiments with the air-pump.

† As this is one of the most important discoveries of the science of Pneumatics, it is thought to be deserving of a labored explanation. The whole phenomenon is the result of the equilibrium of fluids. The atmosphere pressing by its weight (15 pounds on every square inch) on the surface of the mercury in the vessel, counterpoised the column of mercury in the tube when it was about 30 inches high, showing thereby that a column of the atmosphere is equal in weight to a column of mercury of the same base, having a height of 30 inches. Any increase or diminution in the density of the air produces a corresponding alteration in its weight, and consequently, in its ability to sustain a longer or a shorter column of mercury. Had water been used instead of mercury, it would have required a height of about 33 feet to counterpoise the weight of the atmospheric column. Other fluids may be used, but the perpendicular height of the column of any fluid, to counterpoise the weight of the atmosphere, must be as much

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143. How does the air become a mechanical agent?
144. What is a vacuum?

145. The barometer is an instrument to measure the weight of the atmosphere, and thereby to indicate the variations of the weather.*

1. Fig. 69 represents a barometer. It consists of a long glass tube, about thirty-three inches in length, closed at the upper end and filled with mercury. The tube is then inverted in a cup, or leather bag, of mercury, on which the pressure of the atmosphere is exerted. As the tube is closed at the top, it is evident that the mercury cannot descend in the tube without producing a vacuum. The pressure of the atmosphere (which is capable of supporting a column of mercury of about 30 inches in height) prevents the descent of the mercury; and the instrument, thus constructed, becomes an implement for ascertaining the weight of the atmosphere. As the air varies in weight or pressure, it must, of course, influence the mercury in the tube, which will rise or fall in exact proportion with the pressure. When the air is thin and light, the pressure is less, and the mercury will descend; and when the air is dense and heavy, the mercury will rise. At the side of the tube there is a scale, marked inches and tenths of an inch, to note the rise and fall of the mercury.†

Fig. 69

greater than that of mercury as the specific gravity of mercury exceeds that of the fluid employed.

* The elasticity of the air causes an increase or diminution of its bulk, according as it is affected by heat and cold; and this increase and diminution of bulk materially affect its specific gravity. The height of a column of mercury that can be sustained by a column of the atmosphere must, therefore, be affected by the state of the atmosphere. The instrument used to indicate these changes is called a *barometer,* from two Greek words signifying *a measure of the weight,* that is, of the atmosphere. A *Thermo*meter is a measure of the *heat,* and a *Hygro*meter a measure of the *moisture* of the atmosphere.

† Any other fluid may be used as well as mercury, provided the length

145. What is a barometer? What does the word barometer mean? What is a thermometer? What does the word thermometer mean? What is a hygrometer? What does the word hygrometer mean? What figure represents a barometer? Explain its construction. What height of mercury is the pressure of the atmosphere capable of sustaining? What effect has the pressure of the atmosphere on the mercury in the tube?

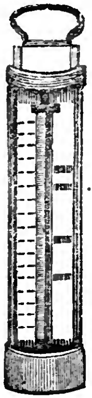
2. The pressure of the atmosphere on the mercury, in the bag or cup of a barometer, being exerted on the principle of the equilibrium of fluids, must vary according to the situation in which the barometer is placed. For this reason it will be the greatest in valleys and low situations, and least on the top of high mountains. Hence the barometer is often used to ascertain the height of mountains and other places above the level of the sea.*

of the tube be extended in proportion to the specific gravity of the fluid. Thus, a tube filled with water must be 33 feet long, because the atmosphere will support a column of water of that height. Mercury is used, therefore, in the construction of the barometer, because it does not require so long a tube as any other fluid. It may here be remarked, that the air is the heaviest in dry weather, and that, consequently, the mercury will then rise highest. In wet weather the dampness renders the air less salubrious, and it appears, therefore, more heavy then, although it is, in fact, much lighter. The greatest depression of the barometer occurs daily at about 4 o'clock, both in the morning and in the afternoon, and its highest elevation at about 10 o'clock morning and night. In summer, these extreme points are reached an hour or two earlier in the morning, and as much later in the afternoon.

* As the air diminishes in density, upwards, it follows, that it must be more rare upon a hill than on a plain. In very elevated situations it is so rare that it is scarcely fit for respiration, or breathing; and the expansion which takes place in the more dense air contained within the body is often painful: it occasions distention, and sometimes causes the bursting of the smaller blood-vessels, in the nose and ears. Besides, in such situations, we are more exposed both to heat and cold; for, though the atmosphere is itself transparent, its lower regions abound with vapors and exhalations from the earth, which float in it, and act in some degree as a covering, which preserves us equally from the intensity of the sun's rays, and from the severity of the cold.

In what proportion does the mercury rise and fall? In what way can barometers be made of other fluids? Why is mercury used in preference to any other fluid? Is the air heaviest in wet or dry weather? On what principle is the pressure of the atmosphere on the mercury, in the cup of a barometer, exerted? What follows from this? For what other purpose, besides measuring the pressure of the atmosphere, and foretelling the variations of the weather, is the barometer used? Is the air the more dense at the surface of the earth or upon a hill? What is a thermometer? What figure represents a thermometer? Explain its construction.

Fig. 70



3. The thermometer is an instrument used to indicate the temperature of the atmosphere. In appearance it resembles a barometer, but it is constructed on a different principle, and for a different purpose. It consists of a capillary tube, closed at the top, and terminated with a bulb, which is filled with mercury.* As heat expands and cold contracts most substances, it follows, that in warm weather the mercury must be expanded and will rise in the tube, and that in cold weather it will contract and sink. Hence the instrument becomes a correct measure for the heat and cold of the air. A scale† is placed at the side of the tube, to mark the degree of heat or cold, as it is indicated by the rise and fall of the mercury in the capillary tube.

4. The hygrometer, for measuring the degree of moisture in the air,‡ may be constructed of any thing which contracts and expands by the moisture or dryness of the atmosphere, such as most kinds of wood; catgut, twisted cord the beard of wild oats, &c.

* Any other liquid which is expanded by heat and contracted by cold, such as spirits of wine, &c., will answer instead of mercury.

† There are several different scales applied to the thermometer, of which those of Fahrenheit, Reaumur, Delisle, and Celsius are the principal. The thermometer in common use in this country, is graduated by Fahrenheit's scale, which, commencing with 0, or zero, extends upwards to 212 degrees, the boiling point of water, and downwards to 20 or 30 degrees. The scales of Reaumur and Celsius fix zero at the freezing point of water; and that of Delisle at the boiling point.

‡ By the action of the sun's heat upon the surface of the earth, whether land or water, immense quantities of vapor are raised into the atmosphere, supplying materials for all the water which is deposited again in the various forms of dew, fog, rain, snow, and hail. Experiments have been made to show the quantity of moisture thus raised from the ground by the heat of the sun. Dr. Watson found that an acre of ground, apparently dry, and burnt up by the sun, dispersed into the air sixteen hundred gal-

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What effect have heat and cold on most substances? What follows from this? Whose scale is generally used in this country? For what is the hygrometer used? Of what kind of substances may it be constructed? What experiment is given in the note to show the quantity of moisture raised from the ground by the heat of the sun?

146. The impenetrability of air prevents the ascent of water into any inverted vessel, unless the air is first permitted to escape.

1. If a tube, closed at one end, or an inverted tumbler, be inserted at its open end, in a vessel of water, the water will not rise in the tube or tumbler, to a level with the water in the vessel, on account of the impenetrability of the air within the tube. But if the tube be open at both ends, the water will rise, because the air can escape through the upper end. It is on this principle that the diving-bell (or the diver's bell, as it is sometimes called) is constructed.

2. Fig. 71 represents a diving-bell. It consists of a large heavy vessel, formed like a bell, (but may be made of any other shape,) with the mouth open. It descends into the water with

lons of water in the space of twelve hours. His experiment was thus made: he put a glass, mouth downwards, on a grass-plot, on which it had not rained for above a mouth. In less than two minutes the inside was covered with vapor; and in half an hour drops began to trickle down its inside. The mouth of the glass was 20 square inches. There are 1296 square inches in a square yard, and 4840 square yards in an acre. When the glass had stood a quarter of an hour, he wiped it with a piece of muslin, the weight of which had been previously ascertained. When the glass had been wiped dry, he again weighed the muslin, and found that its weight had been increased six grains by the water collected from 20 square inches of earth; a quantity equal to 1600 gallons, from an acre, in 12 hours. Another experiment, after rain had fallen, gave a much larger quantity. (See No. 9.)

When the atmosphere is colder than the earth, the vapor, which arises from the ground, or a body of water, is condensed and becomes visible This is the way that fog is produced. When the earth is colder than the atmosphere, the moisture in the atmosphere condenses in the form of dew, on the ground, or other surfaces.

Clouds are nothing more than vapor, condensed by the cold of the upper regions of the atmosphere.

Rain is produced by the sudden cooling of large quantities of watery vapor.

Snow and hail are produced in a similar manner, and differ from rain only in the degree of cold which produces them.

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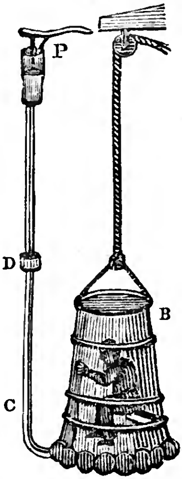
146. Is air impenetrable, like other substances? How is this shown? Upon what principle is the diving-bell constructed? What figure represents the diving-bell? Why does not the water rise in the bell? Explain the figure.

its mouth downwards. The air within it having no outlet is compelled, by the order of specific gravities, to ascend in the bell, and thus (as water and air cannot occupy the same space at the same time) prevents the water from rising in the bell. A person, therefore, may descend with safety in the bell to a great depth in the sea, and thus recover valuable articles that have been lost. A constant supply of fresh air is sent down, either by means of barrels, or by a forcing-pump. In the Fig., B represents the bell with the diver in it. C is a bent metallic tube attached to one side and reaching the air within; and P is the forcing-pump through which air is forced into the bell. The forcing-pump is attached to the tube by a joint at D. When the bell descends to a great depth, the pressure of the water condenses the air within the bell, and causes the water to ascend in the bell. This is forced out by constant accessions of fresh air, supplied as above mentioned. Great care must be taken that a constant supply of fresh air is sent down, otherwise the lives of those within the bell will be endangered. The heated and impure air is allowed to escape through a stop-cock in the upper part of the bell.

Fig 71.



147. Water is raised in the common pump by means of the pressure of the atmosphere on the surface of the water. A vacuum being produced by raising the piston or pump-box,* the water below is forced up by the atmospheric pressure, on the principle of the equilibrium

* In order to produce such a vacuum, it is necessary that the piston or box should be accurately fitted to the bore of the pump; for if the air above the piston has any means of rushing in to fill the vacuum, as it is produced by the raising of the piston, the water will not ascend. The piston is generally worked by a lever, which is the handle of the pump, not represented in the figure.

147. By what means is water raised in the common pump? How is the pressure removed?

of fluids. On this principle the water can be raised only to the height of about thirty-three feet, because the pressure of the atmosphere will sustain a column of water of that height only.

Fig. 72

Fig. 72 represents the common pump, called the sucking-pump. The body consists of a large tube, or pipe, the lower end of which is to be immersed in the water which it is designed to raise. P is the piston, V a valve* in the piston, which, opening upwards, admits the water to rise through it, but prevents its return. Y is a similar valve in the body of the pump, below the piston. When the pump is not in action the valves are closed by their own weight; but when the piston is raised it draws up the column of water which rested upon it, producing a vacuum between the piston and the lower valve Y. The water below, immediately rushes through the lower valve, and fills the vacuum. When the piston descends a second time, the water in the body of the pump passes through the valve V, and on the ascent of the piston is lifted up by the piston, and a vacuum is again formed below, which is immediately filled by the water rushing through the lower valve Y. In this manner the body of the pump is filled with water, until it reaches the spout S, where it runs out in an interrupted stream.†

* A valve is a lid or cover, so contrived as to open a communication in one way and close it in the other. Valves are made in different ways, according to the use for which they are intended. In the common pump, they are generally made of thick leather partly covered with wood. In the air-pump they are made of oiled silk, or thin leather softened witb oil. The clapper of a pair of bellows is a familiar specimen of a valve The valves of a pump are commonly called *boxes*.

† Although water can be raised by the atmospheric pressure only to the height of 33 feet above the surface, the common pump is so constructed, that after the pressure of the atmosphere has forced the water through the

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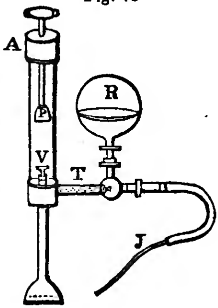
What figure represents the common pump? Explain it. Which of the mechanical powers is the handle of the pump? How high can water be raised by the common pump? Whv? Why is the common pump sometimes called the lifting-pump?

148. The forcing-pump differs from the common pump in having a forcing power added to raise the water to any desired height.

1. Fig. 73 represents the forcing-pump. The body and lower valve V are similar to those in the common pump. The piston P has no valve, but is solid; when, therefore, the vacuum is produced above the lower valve, the water on the descent of the piston is forced through the tube into the reservoir or air-vessel R, where it compresses the air above it. The air, by its elasticity, forces the water out through the jet J in a continued stream and with great force. It is on this principle that fire-engines are constructed.

Fig. 73



2. Sometimes a pipe with a valve in it is substituted for the air-vessel; the water is then thrown out in a continued stream, but not with so much force.

149. Wind is air put in motion.*

When any portion of the atmosphere is heated, it becomes rarefied, its specific gravity is diminished, and it consequently rises. The adjacent portions immediately rush into its place to restore the equilibrium. This motion produces a current which rushes into the rarefied spot from all directions. This is what we call wind. The portions north of the rarefied spot,

valve in the body of the pump, and the descent of the piston has forced it through the valve in the piston, it is *lifted* up, when the piston is raised. For this reason, this pump is sometimes called the *lifting* pump. The distance of the lower valve from the surface of the water must never exceed 32 feet; and in practice it must be much less.

* There are two ways in which the motion of the air may arise. It may be considered as an absolute motion of the air, rarefied by heat and condensed by cold; or it may be only an apparent motion, caused by the superior velocity of the earth in its daily revolution.

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148. How does the forcing-pump differ from the common pump? What figure represents the forcing-pump? Explain it.

149. What is wind? In what two ways may the motion of the air be explained? Explain the manner in which the air is put in motion.

produce a north wind; those to the south produce a south wind; while those to the east and west, in like manner, form currents moving in opposite directions. At the rarefied spot, agitated as it is by winds from all directions, turbulent and boisterous weather, whirlwinds, hurricanes, rain, thunder and lightning prevail. This kind of weather occurs most frequently in the torrid zone, where the heat is greatest. The air being more rarefied there than in any other part of the globe, is lighter, and, consequently, ascends: that about the polar regions is continually flowing from the poles to the equator, to restore the equilibrium; while the air rising from the equator flows in an upper current towards the poles, so that the polar regions may not be exhausted.* A regular east wind prevails

* From what has now been said, it appears that there is a circulation of air in the atmosphere; the air in the lower strata flowing from the poles to the equator, and in the upper strata flowing back from the equator to the poles. It may here be remarked, that the periodical winds are more regular at sea than on the land; and the reason of this is, that the land reflects into the atmosphere a much greater quantity of the sun's rays than the water; therefore, that part of the atmosphere which is over the land is more heated and rarefied than that which is over the sea. This occasions the wind to set in upon the land, as we find it regularly does on the coast of Guinea and other countries in the torrid zone. There are certain winds called trade-winds, the theory of which may be easily explained on the principle of rarefaction, affected as it is by the relative position of the different parts of the earth with the sun, at different seasons of the year and at various parts of the day. A knowledge of the laws by which these winds are controlled, is of importance to the mariner. When the place of the sun, with respect to the different positions of the earth at the different seasons of the year is understood, it will be seen that they all depend upon the same principle. The reason that the wind generally subsides at the going down of the sun, is, that the rarefaction of the air, in the particular spot which produces the wind, diminishes as the sun declines, and consequently, the force of the wind abates. The great variety of winds in the temperate zone is thus explained. The air is an exceedingly elastic fluid, yielding to the slightest pressure; the agitations in it, therefore, caused by the regular winds, whose causes have been explained, must extend every way to a great distance; and the air, therefore, in all climates will suffer more or less perturbation, according to the situation of the country, the position of mountains, valleys, and a variety of other causes. Hence every climate must be liable to variable winds. The

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How are the north, south, east, and west winds produced?

about the equator, caused by the rarefaction of the air produced by the sun in his daily course from east to west. This wind, combining with that from the poles, causes a constant northeast wind, for about thirty degrees north of the equator, and a southeast wind at the same distance south of the equator.

OF THE AIR-PUMP.

150. The air-pump is an instrument for exhausting the air from a vessel prepared for the purpose. This vessel is called a receiver, and is made of glass in order that the effects of the removal of the air may be seen.

Air-pumps are made in a great variety of forms; but all are constructed on the principle, that when any portion of confined air is removed, the residue immediately expanding, by its elasticity fills the space occupied by the portion that has been withdrawn.

1. From this statement it will appear that a perfect vacuum can never be obtained by the air-pump as at present constructed. But so much of the air within a receiver may be exhausted that the residue will be reduced to such a degree of rarity as to subserve most of the practical purposes of a vacuum. Fig. 74 represents a single barrel air-pump, used both for condensing and exhausting. A D is the stand or platform of the instrument, which is screwed down to the table by

quality of winds is affected by the countries over which they pass; and they are sometimes rendered pestilential by the heat of deserts, or the putrid exhalations of marshes and lakes. Thus, from the deserts of Africa, Arabia, and the neighboring countries, a hot wind blows, called *Samiel*, or *Simoom*, which sometimes produces instant death. A similar wind blows from the desert of Sahara, upon the western coast of Africa, called the *Harmattan*, producing a dryness and heat which is almost insupportable, scorching like the blasts of a furnace

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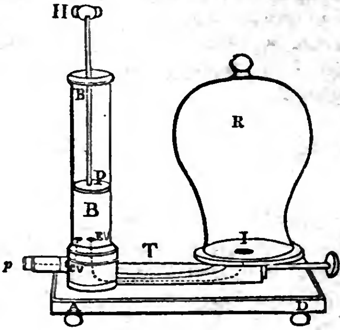
150. What is an air-pump? What is the vessel called from which the air is exhausted? On what principle are all air-pumps constructed? Can a perfect vacuum ever be obtained? Describe the air-pump represented by Fig. 74

Fig 74



means of a clamp, underneath, which is not represented in the figure. R is the glass vessel or bulbed receiver from which the air is to be exhausted. P is a solid piston, accurately fitted to the bore of the cylinder, and H the handle by which it is moved. The dotted line T, represents the communication between the receiver R and the barrel B; it is a tube through which the air, entering at the opening I, on the plate of the pump, passes into the barrel, through the exhausting valve E V. C V is the condensing valve, communicating with the barrel B by means of an aperture near E, and opening outwards through the condensing pipe *p*.

2. *The operation of the pump is as follows:* The piston P being drawn upwards by the handle H, the air in the receiver R, expanding by its elasticity, passes by the aperture I through the tube T, and through the exhausting valve E V into the barrel. On the descent of the piston, the air cannot return through that valve, because the valve opens *upwards* only: it must, therefore, pass through the aperture, by the side of the valve, and through the condensing valve C V into the pipe *p*, where it passes out into the open air. It cannot return through the condensing valve C V, because that valve opens *outwards* only. By continuing this operation, every ascent and descent of the piston P must render the air within the receiver R more and more rare, until its elastic power is exhausted. The receiver is then said to be exhausted; and although it still contains a small quantity of air, yet it is in so rare a state that the space within the receiver is considered a *vacuum*.*

3. From the explanation which has been given of the operation of this air-pump, it will readily be seen that, by removing the receiver R, and screwing any vessel to the pipe *p*, the air

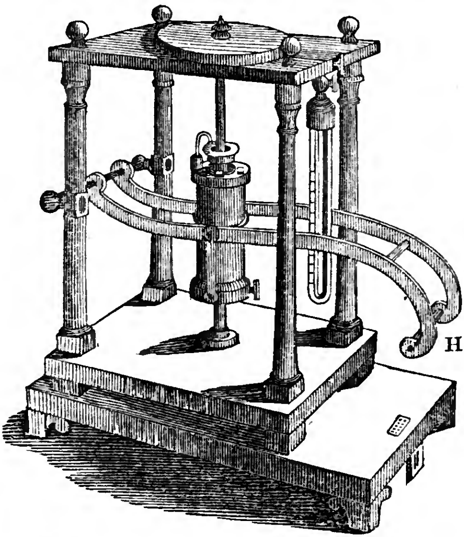
* The only known method of procuring a perfect vacuum, is that pursued by Torricelli, which has already been explained.

may be condensed in the vessel. Thus the pump is made to exhaust or to condense, without alteration.*

4. The double air-pump differs from the single air-pump, in having two barrels and two pistons; which, instead of being moved by the hand, are worked by means of a toothed wheel, playing in notches of the piston rods.

5. Fig. 75 represents Wightman's patent lever air-pump, belonging to "*the Boston School Set.*" This instrument is of

Fig. 75.



an improved construction, and differs from others in the facility with which it is worked. In this pump the piston is sta-

* Air-pumps in general are not adapted for condensation; that office being performed by an instrument called "*a condensing syringe,*" which *is an air-pump reversed, its valves being so arranged as to force air into a chamber, instead of drawing it out.* For this purpose, the valves open inwards in respect to the chamber, while in air-pumps they open outwards.

A gauge, constructed on the principle of the barometer, is sometimes adjusted to the air-pump for the purpose of exhibiting the degree of exhaustion tionary, while motion is given to the barrel by means of the lever H. The barrel is kept in a proper position by means of polished steel guides.*

151. By means of the air-pump, many interesting experiments may be performed, illustrating the gravity, elasticity, fluidity, and inertia of air.

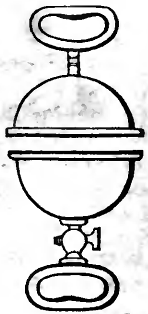
EXPERIMENTS ILLUSTRATING THE GRAVITY OF AIR.

1. Having adjusted the receiver to the plate of the air-pump, exhaust the air and the receiver will be held firmly on the plate. The force which confines it, is nothing more than the weight of the external air, which, having no internal pressure to contend with, presses with a force of nearly 15 pounds on every square inch of the external surface of the receiver.

N. B. The *exact* amount of pressure depends on the degree of exhaustion, being at its maximum of 15 pounds when there is a perfect vacuum. On readmitting the air the receiver may be readily removed.

2. THE MAGDEBURGH CUPS OR HEMISPHERES. Fig. 76 represents the Magdeburgh cups or hemispheres. They consist of two hollow brass cups, the edges of which are accurately fitted together. They each have a handle, to one of which a stop-cock is fitted. The stop-cock, being attached to one of the cups, is to be screwed to the plate of the air-pump, and left open. Having joined the other cup to that on the pump, exhaust the air from within them, turn the stop-cock to prevent its readmission, and screw the handle that had been removed to the stop-cock. Two persons may then attempt to draw the cups asunder. It will be found that great power is required to separate them; but, on readmitting the air between them, by turning the cock, they will fall asunder by

Fig. 76.

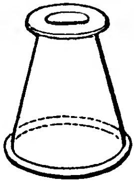


* Mr. Wightman has published a small volume, entitled, "A Companion to the Air-pump," which will be found a very convenient guide for the management of the pump, and the skilful performance of experiments

151. Give, in succession, the experiments made by means of the air pump. Of the receiver Of the Magdeburgh cups.

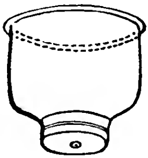
their own weight. When the air is exhausted from within them, the pressure of the surrounding air upon the outside keeps them united. This pressure being equal to a pressure of fifteen pounds on every square inch of the surface, it follows, that the larger the cups or hemispheres the more difficult it will be to separate them.*

Fig. 77.



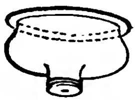
3. THE HAND-GLASS. Fig. 77 is nothing more than a tumbler, open at both ends, with the top and bottom ground smooth, so as to fit the brass plate of the air-pump. Placing it upon the plate, cover it closely with the palm of the hand, and work the pump. The air within the glass being thus exhausted, the hand will be pressed down by the weight of the air above it: on readmitting the air, the hand may be easily removed.

Fig. 78.



4. THE BLADDER-GLASS. Fig. 78 is a bell-shaped glass, covered with a piece of bladder, which is tied tightly around its neck. Thus prepared, it may be screwed to the plate of the air-pump, or connected with it by means of an elastic tube. On exhausting the air from the glass, the external pressure of the air on the bladder will burst it inwards with a loud explosion.

Fig. 79.



5. THE INDIA-RUBBER GLASS. Fig. 79 is a glass similar to the one represented in the last figure, covered with india-rubber. The same experiments may be made with this as were mentioned in the last article, but with different results. Instead of bursting, the india-rubber will be pressed inwards the whole depth of the glass.

* Otto Guericke, the inventor of the air-pump, prepared two hemispheres, two feet in diameter, and having accurately fitted them together, and exhausted the air, 30 horses harnessed to them were unable to separate them. When more horses were added, the hemispheres parted with a loud report.

Explain the experiment with the hand-glass. Of the bladder-glass. Of the india-rubber glass.

6. THE FOUNTAIN-GLASS AND JET. Fig. 80 represents the jet, which is a small brass tube. Fig. 81 is the fountain-glass. The experiment with these instruments is designed to show the pressure of the atmosphere on the surface of liquids. Screw the straight jet to the stop-cock, the stop-cock to the fountain-glass, with the straight jet inside of the fountain-glass, and the lower end of the stop-cock to the plate of the air-pump, and then open the stop-cock. Having exhausted the air from the fountain-glass, close the stop-cock, remove the glass from the pump, and, immersing it in a vessel of water, open the stop-cock. The pressure of the air on the surface of the water will cause it to rush up into the glass like a fountain.

Fig. 80.

Fig. 81.

7. PNEUMATIC SCALES FOR WEIGHING AIR. Fig. 82 represents the flask or glass vessel and scales for weighing air. Weigh the flask when full of air: then exhaust the air and weigh the flask again. The difference between its present and former weight is the weight of the air that was contained in the flask.

Fig. 82.

8. THE SUCKER. A circular piece of wet leather, with a string attached to the centre, being pressed upon a smooth surface, will adhere with considerable tenacity, when drawn upwards by the string. The string in this case must be attached to the leather so that no air can pass under the leather.

9. THE MERCURIAL OR WATER TUBE. Exhaust the air from a glass tube three feet long, fitted with a stop-cock at one end, and then immerse it in a vessel containing mercury or water. On turning the stop-cock, the mercury will rise to the height of nearly 30 inches; or, if immersed in water, the water will rise and fill the tube, and would fill it were it 30 feet long. This experiment shows the manner in which water is raised to the boxes or valves in common water-pumps.

Explain the experiment of the fountain-glass and jet. Explain the pneumatic scales for weighing air. Explain the sucker. Mercurial tube.

EXPERIMENTS SHOWING THE ELASTICITY OF AIR.

1. Place an india-rubber bag, or a bladder, partly inflated, and tightly closed, under the receiver, and on exhausting the air, the air within the bag or bladder expanding, will fill the bag. On readmitting the air, the bag will collapse. The experiment may also be made with some kinds of shrivelled fruit, if the skin be sound. The internal air expanding will give the fruit a fresh and plump appearance, which will disappear on the re-admission of the air.

2. The same principle may be illustrated by the india-rubber and bladder glasses, if they have stop-cocks to confine the air.

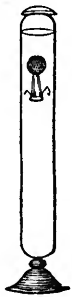
3. A small bladder partly filled with air may be sunk in a vessel of water by means of a weight, and placed under the receiver. On exhausting the air from the receiver, the air in the bladder will expand, and its specific gravity being thus diminished, the bladder with the weight will rise. On re-admitting the air the bladder will sink again.

4. AIR CONTAINED IN WATER AND IN WOOD. Place a vessel of water under the receiver, and on exhausting the air from the receiver, the air in the water previously invisible will make its appearance in the form of bubbles, presenting the semblance of ebullition.

5. A piece of light porous wood being immersed in the water below the surface, the air will be seen issuing in bubbles from the pores of the wood.

6. THE PNEUMATIC BALLOON. Fig. 83 represents a small glass balloon with its car immersed in a jar of water, and placed under a receiver. On exhausting the air, the air within the balloon expanding, gives it buoyancy, and it will rise in the jar. On readmitting the air the balloon will sink.

Fig. 83



7. The experiment may be performed without the air-pump by covering the jar with some elastic substance, as india-rubber. By pressing on the elastic covering with the finger the air will be condensed, the water will rise in the balloon, and it will sink. On removing the pressure, the air in the balloon expand-

Explain the first experiment.—2d. 3d. 4th. 5th. 6th. 7th ing, will expel part of the water and the balloon will rise. This is the more convenient mode of performing the experiment, as it can be repeated at pleasure without resort to the pump.*

8. The following is a full explanation:—The pressure on the top of the vessel first condenses the air between the cover and the surface of the water;—this condensation presses upon the water below, and as this pressure affects every portion of the water throughout its whole extent, the water, by its upward pressure, compresses the air within the balloon, and makes room for the ascent of more water into the balloon so as to alter the specific gravity of the balloon, and cause it to sink. As soon as the pressure ceases, the elasticity of the air in the balloon drives out the lately entered water, and restoring the former lightness to the balloon causes it to rise. If, in the commencement of this experiment, the balloon be made to have a specific gravity too near that of water, it will not rise of itself, after once reaching the bottom, because the pressure of the water then above it will perpetuate the condensation of the air which caused it to descend. It may even then, however, be made to rise, if the perpendicular height of the water above it be diminished by inclining the vessel to one side.

9. This experiment proves many things; namely:

First. The materiality of air, by the pressure of the hand

* This experiment exhibits the principle on which the well-known glass figure, called the Cartesian Devil, is constructed; and it may be thus explained: several images of glass, hollow within, and each having a small opening at the heel by which water may pass in and out, may be made to manœuvre in a vessel of water. Place them in a vessel in the same manner with the balloon, but by allowing different quantities of water to enter the apertures in the images, cause them to differ a little from one another in specific gravity. Then, when a pressure is exerted on the cover, the heaviest will descend first, and the others follow in the order of their specific gravity; and they will stop or return to the surface in reverse order, when the pressure ceases. A person exhibiting these figures to spectators who do not understand them, while appearing carelessly to rest his hand on the cover of the vessel, seems to have the power of ordering their movements by his will. If the vessel containing the figures be inverted, and the cover be placed over a hole in the table, through which, unobserved, pressure can be made by a rod rising through the hole, and obeying the foot of the exhibiter, the most surprising evolutions may be produced among the figures, in perfect obedience to the word of command.

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8. Explain, in full, the experiment of the glass figures. 9. Explain all that this experiment proves. Explain the condensing jar.

on the top being communicated to the water below through the air in the upper part of the vessel.

Secondly. The compressibility of air, by what happens in the globe before it descends.

Thirdly. The elasticity, or elastic force of air, when the water is expelled from the globe, on removing the pressure.

Fourthly. The lightness of air, in the buoyancy of the globe.

Fifthly. It shows that *the pressure of a liquid is exerted in all directions,* because the effects happen in whatever position the jar be held.

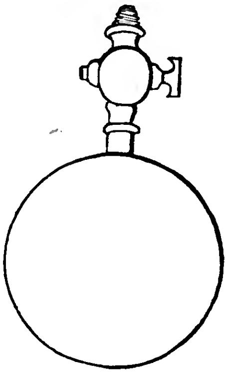
Sixthly. It shows *that pressure is as the depth,* because less pressure of the hand is required, the farther the globe has descended in the water.

Seventhly. It exemplifies many circumstances of *fluid support.* A person, therefore, who is familiar with this experiment, and can explain it, has learned the principal truths of Hydrostatics and Pneumatics.

EXPERIMENTS WITH CONDENSED AIR.

1. The Condensing and Exhausting Syringe. The condensing syringe is the air-pump reversed. The exhausting syringe is the simple air-pump without its plate or stand. These implements are used respectively with such parts of the apparatus as cannot conveniently be attached to the air-pump; and as an addition to such pumps as do not perform the double office of exhaustion and condensation. In some sets of apparatus the condensing and exhausting syringes are united, and are made to perform each office respectively, by merely reversing the part which contains the valve.

Fig. 84.



2. The Air-Chamber. The air-chamber, Fig. 83, is a hollow brass globe prepared for the reception of a stop-cock, and is designed for the reception of condensed air. It is made in different forms in different sets, and is used by screwing it to a condensing pump or a condensing syringe.

3. Straight and Revolving Jets from Condensed Air. Fill the air-chamber (Fig. 84) partly with water and then condense the air. Then confine the air by turning the cock; after which unscrew it from the air-pump, and screw on the straight or the revolving jet. Then open the stop-cock, and the water will be thrown from the chamber in the one case, in a straight continued stream, in the other in the form of a wheel. Figs. 85 and 86 represent a view of the straight and the revolving jets. In the revolving jet the water is thrown from two small apertures made at each end on opposite sides, to assist the revolution. The circular motion is caused by the reaction of the water on the sides of the arms opposite the jets; for as the water is forced into the tubes, it exerts an equal pressure on all sides of the tubes, and as the pressure is relieved on one side by the jet-hole, the arm is caused to revolve in a contrary direction. This experiment performed with the straight jet, illustrates the principle on which "Hero's ball" and Hero's fountain are constructed.

Fig. 85.

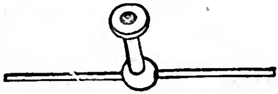


Fig. 86.

4. The Principle of the Air-gun. With the air-chamber as in the last experiments, a small brass cylinder or gun-barrel, Fig. 87, may be substituted for the jets, and loaded with a small shot or paper ball. On turning the cock quickly, the condensed air rushing out will throw the shot to a considerable distance. In this way the air-gun operates, an apparatus resembling the lock of a gun being substituted for the stop-cock, by which a small portion only of the condensed air is admitted to escape at a time, so that the chamber being once filled will afford two or three dozen discharges. The force of the air-gun has never been equal to more than a fifteenth of the force of a common charge of powder, and the loudness of the report made in its discharge is always as great in proportion to its force as that of the common gun.

Fig. 87.

5. Condensed air may be weighed in the air-chamber; but in estimating its weight, the temperature of the room must always be taken into consideration, as the density of air is materially affected by heat and cold.

Explain the jets. The air-gun.

EXPERIMENTS SHOWING THE INERTIA OF AIR.

THE GUINEA AND FEATHER DROP. The inertia of air is shown by the guinea and feather drop, exhibiting the resistance which the air opposes to falling bodies. This apparatus is made in different forms, some having shelves on which the guinea and feather rest; and when the air is exhausted they are made to fall by the turning of a handle. A better form is that represented in Fig. 88, in which the guinea and feather (or a piece of brass substituted for the guinea) are enclosed, and the apparatus being screwed to the plate of the pump, the air is exhausted; a stop-cock turned to prevent the readmission of the air, and the apparatus being then unscrewed, the experiment may be repeatedly showed by one exhaustion of the air. It will then appear that every time the apparatus is inverted, the guinea and the feather will fall simultaneously. The two forms of the guinea and feather drop are exhibited in Figs. 88 and 89, one of which, Fig. 88, is furnished with a stop-cock,* the other, Fig. 89, with shelves.

Fig. 88.

Fig. 89

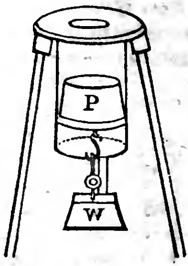
EXPERIMENTS SHOWING THE FLUIDITY OF AIR.

1. THE WEIGHT-LIFTER. The upward pressure of the air, one of the properties of its fluidity, may be exhibited by an apparatus called the weight-lifter, made in different forms, but all on the same pr[illegible]ple. The one represented in Fig. 90

* Most sets of philosophical apparatus are furnished with stop-cocks and elastic tubes, for the purpose of connecting the several parts with the pump or with one another. In selecting the apparatus, it is important to have the screws of the stop-cocks, and of all the apparatus of similar thread, in order that every article may subserve as many purposes as possible. This precaution is suggested by economy as well as by convenience.

Explain the experiment with the guinea and feather. Also the weight-lifter.

Fig. 90.



consists of a glass tube, of large bore, set in a strong case or stand, supported by three legs. A piston is accurately fitted to the bore of the tube, and a hook is attached to the bottom of the piston, from which weights are to be suspended. One end of the elastic tube is to be screwed to the plate of the pump, and the other end attached to the top of this instrument. The air being then exhausted from the tube, the weights will be raised the whole length of the glass. The number of pounds weight that can be raised by this instrument may be estimated by multiplying the number of square inches in the bottom of the piston by fifteen.

2. THE PNEUMATIC SHOWER-BATH. On the principle of the upward pressure of the air, the pneumatic shower-bath is constructed. It consists of a tin vessel perforated with holes in the bottom for the shower, and having an aperture at the top, which is opened or closed at pleasure by means of a spring valve. [Instead of the spring valve, a bent tube may be brought round from the top down the side of the vessel, with an aperture in the tube below the bottom of the vessel which may be covered with the thumb.] On immersing the vessel thus constructed in a pail of water, with the valve open, and the tube (if it have one) on the outside of the pail, the water will fill the vessel. The aperture then being closed with the spring or with the thumb, and the vessel being lifted out of the water, the upward pressure of the air will confine the water in the vessel. On removing the thumb, or opening the valve, the water will descend in a shower until the vessel is emptied.

MISCELLANEOUS EXPERIMENTS DEPENDING ON TWO OR MORE OF THE PROPERTIES OF AIR.

1. THE BOLT-HEAD AND JAR. Fig. 91, a glass globe with a long neck, called a bolt-head, (or any long-necked bottle,) partly filled with water, is inverted in a jar of water, (colored with a few drops of red ink or any coloring matter, in order that

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Explain the pneumatic shower-bath

the effects may be more distinctly visible,) and placed under the receiver. On exhausting the air in the receiver, the air in the upper part of the bolt-head expanding, expels the water, showing the elasticity of the air. On readmitting the air to the receiver, as it cannot return into the bolt-head, the pressure on the surface of the water in the jar, forces the water into the bolt-head, showing the pressure of the air caused by its weight. The experiment may be repeated with the bolt-head without any water, and on the re-admission of the air, the water will nearly fill the bolt-head, affording an accurate test of the degree of exhaustion.

Fig. 91

2. The Transfer of Fluids from one Vessel to another. The experiment may be made with two bottles tightly closed. Let one be partly filled with water, and the two connected by a bent tube, connecting the interior of the empty bottle with the water of the other, and extending nearly to the bottom of the water. On exhausting the air from the empty bottle, the water will pass to the other, and on readmitting the air the water will return to its original position, so long as the lower end of the bent tube is above the surface.

EXPERIMENTS WITH THE SIPHON.

1. Close the shorter end of the siphon with the finger or with a stop-cock, and pour mercury or water into the longer side. The air contained in the shorter side will prevent the liquid from rising in the shorter side. But if the shorter end be opened, so as to afford free passage outwards for the air, the fluid will rise to an equilibrium in both arms of the siphon.

2. Pour any liquid into the longer arm of the siphon until the shorter arm is filled. Then close the shorter end, to prevent the admission of the air; the siphon may then be turned n any direction and the fluid will not run out, on account o the pressure of the atmosphere against it. But if the shorter nd be unstopped, the fluid will run out freely.

Explain the transfer of fluids. Explain the first experiment with the s. hon. Also the second.

AIR ESSENTIAL TO ANIMAL LIFE.

If an animal be placed under the receiver, and the air exhausted, it will immediately droop, and if the air be not speedily readmitted it will die.

AIR ESSENTIAL TO COMBUSTION.

Place a lighted taper, cigar, or any other substance that will produce smoke, under the receiver, and exhaust the air; the light will be extinguished, and the smoke will fall, instead of rising. If the air be readmitted, the smoke will ascend.

THE PRESSURE OF THE AIR RETARDS EBULLITION.*

1. Ether, alcohol, and other distilled liquors, or boiling water, placed under the receiver, will appear to boil when the air is exhausted.

2. The existence of many bodies in a liquid form depends on the weight or pressure of the atmosphere upon them. The same force, likewise, prevents the gases which exist in fluid and solid bodies from disengaging themselves. If, by rarefying the air, the pressure on these bodies be diminished, they either assume the form of vapors, or else the gas detaches itself altogether from the other body. The following experiment proves this: place a quantity of lukewarm water, milk, or alcohol, under a receiver, and exhaust the air, and the liquid will either pass off in vapor, or will have the appearance of boiling.

3. An experiment to prove that the pressure of the atmosphere preserves some bodies in the liquid form, may thus be performed: fill a long vial, or a tube closed at one end, with water, and invert it in a vessel of water. The atmospheric pressure will retain the water in the vial. Then by means of a bent tube introduce a few drops of sulphuric ether, which, by reason of their small specific gravity, will ascend to the top

* EBULLITION. The operation of boiling. The agitation of liquor by heat, which throws it up into bubbles.

What takes place when an animal is placed under an exhausted receiver? Is air essential to combustion? How is this proved?

How is it shown that air prevents ebullition? Give the 1st, 2d, and 3d experiments.

of the vial, expelling an equal bulk of water. Place the whole under the receiver, and exhaust the air, and the ether will be seen to assume the gaseous form, expanding in proportion to the rarefaction of the air under the receiver, so that it gradually expels the water from the vial, and fills up the entire space itself. On readmitting the air, the ether becomes condensed, and the water will reascend into the vial.

4. A simple and interesting experiment connected with the science of chemistry, may thus be performed by means of the air-pump. A watch-glass, containing water, is placed over a small vessel containing sulphuric acid, and put under the bulbed receiver. When the air is exhausted, vapor will freely rise from the water, and be quickly absorbed by the acid. An intense degree of cold is thus produced, and the water will freeze.

5. In the above experiment, if ether be used instead of the acid, the ether will evaporate instead of the water, and in the process of evaporation, depriving the water of its heat, the water will freeze. These two experiments, apparently similar in effects, namely, the freezing of the water, depend upon two different principles which pertain to the science of chemistry.

THE PNEUMATIC PARADOX.

An interesting experiment, illustrative of the pneumatic paradox, may be thus performed:—Pass a small open tube, (as a piece of quill,) through the centre of a circular card two or three inches in diameter, and cement it, the lower end passing down, and the upper just even with the card. Then pass a pin through the centre of another similar card, and place it on the former with the pin projecting into the tube to prevent the upper card from sliding off. It will then be impossible to displace the upper card by blowing through the quill, on account of the adhesion produced by the current passing between the discs. On this principle, smoky chimneys have been remedied, and the office of ventilation more effectually performed.

Give the 4th experiment to show that air prevents ebullition. Also the fifth. Explain the pneumatic paradox.

CHAPTER VIII.

ACOUSTICS.

152. Acoustics is the science which treats of the nature and laws of sound. It includes the theory of musical concord or harmony.

153. Sound is caused by a tremulous or vibratory motion of the air.

1. If a bell be rung under an exhausted receiver, no sound can be heard from it; but when the air is admitted to surround the bell, the vibrations immediately produce sound.

2. Again, if the experiment be made by enclosing 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 not be heard if the outer receiver be well exhausted, and care be taken to prevent the vibrations from being communicated through any solid part of the apparatus; because there is no medium through which the vibrations of the bell, in the smaller receiver, can be communicated to the ear.

154. Sounds are louder when the air surrounding the sonorous body is dense, than when it is in a rarefied state.

For this reason the sound of a bell is louder in cold than in warm weather; and sound of any kind is transmitted to a greater distance in cold, clear weather, than in a warm sultry day. On the tops of mountains, where the air is rare, the human voice can be heard only at the distance of a few rods; and the firing of a gun produces a sound scarcely louder than the cracking of a whip.

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152. What is that science called which treats of the nature and laws of sound? What does it include?

153. What causes sound? What illustrations are given to prove this?

154. In what proportion are sounds loud or faint? Why does a bell sound louder in cold than in warm weather? Why is sound fainter on the top of a mountain than near the surface of the earth?

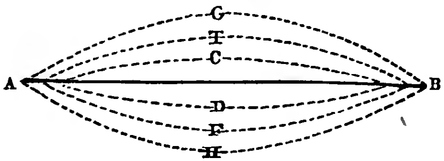
155. Sonorous bodies are those which produce clear, distinct, regular, and durable sounds, such as a bell, a drum, wind instruments, musical strings and glasses. These vibrations can be communicated to a distance not only through the air, but also through liquids and solid bodies.

156. Bodies owe their sonorous property to their elasticity.*

157. The sound produced by a musical string is caused by its vibrations; and the height or depth of the tone depends upon the rapidity of these vibrations. Long strings vibrate with less rapidity than short ones, and for this reason the low tones in a musical instrument proceed from the long strings, and the high tones from the short ones.

1. Fig. 92, A B represents a musical string. If it be drawn up to G, its elasticity will not only carry it back again, but will give it a momentum which will carry it to H, from whence it will successively return to T, F, C, D, &c., until the resistance of the air entirely destroys its motion.

Fig. 92



2. The vibrations of a sonorous body give a tremulous motion to the air around it, similar to the motion communicated to smooth water when a stone is thrown into it.

* Although it is undoubtedly the case that all sonorous bodies are elastic, it is not to be inferred that all elastic bodies are sonorous.

155. What are sonorous bodies?

156. To what do sonorous bodies owe their sonorous property? Are all elastic bodies sonorous?

157. What causes the sound produced by a musical string? Upon what does the height and depth of the tone depend? Which strings, in a musical instrument, produce the low tones? Why? Explain Fig. 92.

158. The science of harmony is founded on the relation which the vibrations of sonorous bodies have to each other.

Thus, when the vibrations of one string are double those of another, the chord of an octave is produced. If the vibrations of two strings be as two to three, the chord of a fifth is produced.* When the vibrations of two strings frequently coincide, they produce a musical chord; and when the coincidence of the vibrations is unfrequent, discord is produced.

159. The quality of the sound produced by strings depends upon their length, thickness, weight, and degree of tension. The quality of the sound produced by wind instruments depends upon their size, their length, and their internal diameter.

Long and large strings, when loose, produce the lowest tones; but different tones may be produced from the same string, according to the degree of tension. Large wind instruments, also, produce the lowest tones; but different tones may be produced from the same instrument, according to the distance of the aperture for the escape of the wind, from the aperture where it enters.

160. The quality of the sound of all musical instruments is affected by the changes in the temperature and specific gravity of the atmosphere.

As heat expands and cold contracts the materials of which

* When music is made by the use of strings, the air is struck by the body, and the sound is caused by the vibrations; when it is made by pipes, the body is struck by the air; but as action and reaction are equal, the effect is the same in both cases.

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158. Upon what is the science of harmony founded? How is the chord of an octave produced? How is the chord of a fifth produced? How is a musical chord produced? A discord?

159. Upon what does the quality of the sound produced by strings depend? Upon what does that produced by wind instruments depend? What strings produce the lowest tones? How may different tones be produced from the same string? How may different tones be produced from the same wind instrument?

160. What, in some degree, affects tho quality of the sound of all musical instruments? What effect have heat and cold on the materials of which the instrument is made? What follows from this?

the instrument is made, it follows, that the strings will have a greater degree of tension, and that pipes and other wind instruments will be contracted, or shortened, in cold weather. For this reason, most musical instruments are higher in tone (or sharper) in cold weather, and lower in tone (or more flat) in warm weather.

161. Sound is communicated more rapidly and with greater power through solid bodies, than through the air, or fluids. It is conducted by water about four times quicker than by air, and by solids about twice as rapidly as by water.

1. If a person lay his head on a long piece of timber, he can hear the scratch of a pin at the other end, while it could not be heard through the air.

2. If the ear be placed against a long, dry, brick wall, and a person strike it once with a hammer, the sound will be heard *twice*, because the wall will convey it with greater rapidity than the air, though each will bring it to the ear.

162. The Stethescope is an instrument depending on the power of solid bodies to convey sound.

It consists of a wooden cylinder, one end of which is applied firmly to the breast, while the other end is brought to the ear. By this means the action of the lungs may be distinctly heard. The instrument, therefore, becomes useful in the hands of a skilful physician, to ascertain the state of those organs.

163. Sound, passing through the air, moves at the rate of 1142 feet in a second of time. This is the case with all kinds of sound.

1. The softest whisper flies as fast as the loudest thunder,

Why are most musical instruments higher in tone, or sharper, in cold weather?

161. Through which is sound communicated more rapidly, and with greater power, through solid bodies, or the air? How fast is it conducted by water? How fast by solids? What examples are given to show that sound is communicated more rapidly through solid bodies than the air or fluids?

162. What is a stethescope? Of what does it consist? For what is it used?

163. How fast does sound move? Does the force or direction of the wind make any difference in its velocity?

and the force or direction of the wind makes but slight difference in its velocity.

2. This uniform velocity of sound enables us to determine the distance of an object from which it proceeds. If, for instance, the light of a gun, fired at sea, be seen a half of a minute before the report is heard, the vessel must be at the distance of six miles and a half. In the same manner, the distance of a thunder-cloud may be ascertained, by counting the seconds between the appearance of the lightning and the noise of the thunder, and multiplying them by 1142 feet.

164. An echo is produced by the vibrations of the air meeting a hard and regular surface, such as a wall, a rock, a mountain, and being reflected back to the ear, thus producing the same sound a second, and sometimes a third and fourth time.*

1. Speaking-trumpets are constructed on the principle of the reflection of sound.

2. The voice, instead of being diffused in the open air, is

* From this it is evident that no echo can be heard at sea, or on an extensive plain; because there is no object there to reflect the sound. An echo is heard only when a person stands in such a situation as to hear both the original and the reflected sound. The pupil will doubtless recollect what has been said in Mechanics with respect to the angles of incidence and reflection. Sound (as well as light, as will be explained under the head of Optics) is communicated and reflected by the same law, namely, that *the angles of incidence and reflection* are always equal. It is not difficult, therefore, to ascertain the direction in which sound will proceed, whether it be direct or reflected. It is related of Dionysius, the tyrant of Sicily, that he had a dungeon, (called the ear of Dionysius,) in which the roof was so constructed as to collect the words, and even the whispers, of the prisoners confined therein, and direct them along a hidden conductor to the place where he sat to listen: and thus he became acquainted with the most secret expressions of his unhappy victims.

What advantage results from this uniform velocity of sound? How can the distance of a thunder-cloud be ascertained?

164. How is an echo produced? *Note.* Why cannot an echo be heard at sea, or on an extensive plain? How must a person stand in order to hear an echo? By what law is sound communicated and reflected? What anecdote is related of Dionysius? Upon what principle are speaking-trumpets constructed? Explain the manner in which the vibrations of the air are reflected.

confined within the trumpet; and the vibrations which spread and fall against the sides of the instrument are reflected according to the angle of incidence, and fall in the direction of the vibrations, which proceed straight forward. The whole of the vibrations are thus collected into a focus; and if the ear be situated in or near that spot, the sound will be prodigiously increased.

3. Hearing-trumpets, or the trumpets used by deaf persons, are also constructed on the same principle; but as the voice enters the large end of the trumpet, instead of the small one, it is not so much confined, nor so much increased.

4. The musical instrument called the trumpet, acts, also, on the same principle with the speaking-trumpet, so far as its form tends to increase the sound.*

165. Sound, like light, after it has been reflected from several surfaces, may be collected into one point, as a focus, where it will be more audible than in any other part; and on this principle whispering-galleries may be constructed.

The famous whispering-gallery in the dome of St. Paul's church, in London, is constructed on this principle.† Persons at very remote parts of the building can carry on a conversation in a soft whisper, which will be distinctly audible to one another, while others in the building cannot hear it; and the ticking of a watch may be heard from side to side.

* The smooth and polished surface of the interior parts of certain kinds of shells, particularly if they be spiral or undulating, fit them to collect and reflect the various sounds which are taking place in the vicinity. Hence the Cyprias, the Nautilus, and some other shells, when held near the ear, give a continued sound, which resembles the roar of the distant ocean.

† There is a church in the town of Newburyport, in Massachusetts, which, as was accidentally discovered, has the same property as a whispering-gallery. Persons in opposite corners of the building, by facing the wall, may carry on a conversation in the softest whisper, unnoticed by others in any other part of the building. It is the building which contains in its cemetery the remains of the distinguished preacher, Whitfield.

Upon what principle are hearing-trumpets constructed? How far does the musical instrument, called the trumpet, act upon the principle of the speaking-trumpet? *Note.* How can the continued sound, given by some shells, when held near the ear, be explained?

165. Upon what principle may whispering-galleries be constructed?

166. Sounds may be conveyed to a much greater distance through continuous tubes than through the open air.

1. The tubes used to convey sounds are called acoustic tubes. They are much used in public houses, stores, counting-rooms, &c., to convey communications from one room to another.

2. The quality of sound is affected by the furniture of a room, particularly the softer kinds, such as curtains, carpets, &c., because, having little elasticity, they present surfaces unfavorable to vibrations.

3. For this reason, music always sounds better in rooms with bare walls, without carpets, and without curtains. For the same reason, a crowded audience increases the difficulty of speaking.

4. As a general rule, it may be stated, that *plane and smooth surfaces reflect sound without dispersing it; convex surfaces disperse it, and concave surfaces collect it.*

5. The air is a better conductor of sound when it is humid than when it is dry.

6. A bell can be more distinctly heard just before a rain; and sound is heard better in the night than in the day, because the air is generally more damp in the night.

7. The distance to which sound may be heard depends upon various circumstances, on which no definite calculations can be predicated. Volcanoes, among the Andes, in South America, have been heard at the distance of three hundred miles; naval engagements have been heard two hundred; and even the watchword "*All's well,*" pronounced by the unassisted human voice, has been heard from Old to New Gibraltar, a distance of twelve miles.

167. The sound of the human voice is produced by the vibration of two delicate membranes, situated at the top of the windpipe, and between which the air from the lungs passes.

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166. In what way can sounds be conveyed to a much greater distance than through the air? What are the tubes, used to convey sounds, called? Why do the softer kinds of furniture in a room affect the quality of the sound? What general rule is given with regard to the reflection of sound? Is the air a better conductor when it is humid, or when it is dry? Why can a sound be heard better in the night than in the day?

167. How is the sound of the human voice produced?

1. The tones are varied from grave to acute, by opening or contracting the passage; and they are regulated by the muscles belonging to the throat, by the tongue, and by the cheeks.

2. The management of the voice depends much upon cultivation; and although many persons can both speak and sing with ease, and with great power, without much attention to its culture, yet it is found that they who cultivate their voices by use, acquire a degree of flexibility and ease in its management, which, in a great measure, supplies the deficiency of nature.*

3. Ventriloquism† is the art of speaking in such a manner as to cause the voice to appear to proceed from a distance.

* The reader is referred to Dr. Rush's very valuable work on the "Philosophy of the Human Voice," for plain and practical instructions on this subject. Dr. Barber's "Grammar of Elocution," and Parker's "Progressive Exercises in Rhetorical Reading," likewise contain the same instructions in a practical form. To the work of Dr. Rush, both of the latter-mentioned works are largely indebted.

† The word ventriloquism literally means, "*speaking from the belly,*" and it is so defined in Chambers' Dictionary of Arts and Sciences. The ventriloquist, by a singular management of the voice, seems to have it in his power "*to throw his voice*" in any direction, so that the sound shall appear to proceed from that spot. The words are pronounced by the organs usually employed for that purpose, but in such a manner as to give little or no motion to the lips, the organs chiefly concerned being those of the throat and tongue. The variety of sounds which the human voice is capable of thus producing is altogether beyond common belief, and, indeed, is truly surprising. Adepts in this art will mimic the voices of all ages and conditions of human life, from the smallest infant to the tremulous voice of tottering age, and from the intoxicated foreign beggar to the high-bred, artificial tones of the fashionable lady. Some will also imitate the warbling of the nightingale, the loud tones of the whip-poor-will, and the scream of the peacock, with equal truth and facility. Nor are these arts confined to professed imitators; for in many villages boys may be found, who are in the habit of imitating the brawling and spitting of cats, in such a manner as to deceive almost every hearer.

The human voice is also capable of imitating almost every inanimate sound. Thus, the turning and occasional creaking of a grindstone, with the rush of the water, the sawing of wood, the trundling and creaking of a wheelbarrow, the drawing out of bottle-corks, and the gurgling of the flowing liquor, the sound of air rushing through a crevice on a wintry

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How are the tones varied and regulated? Upon what does the management of the voice depend? What is ventriloquism?

4. The art of ventriloquism was not unknown to the ancients; and it is supposed by some authors that the famous responses of the oracles at Delphi, at Ephesus, &c., were delivered by persons who possessed this faculty. There is no doubt that many apparently wonderful pieces of deception, which, in the days of superstition and ignorance, were considered as little short of miracles, were performed by means of ventriloquism. Thus houses have been made to appear haunted, voices have been heard from tombs, and the dead have been made to appear to speak, to the great dismay of the neighborhood, by means of this wonderful art.

5. Ventriloquism is, without doubt, in great measure the gift of nature; but many persons can, with a little practice, utter sounds and pronounce words without opening the lips or moving the muscles of the face; and this appears to be the great secret of the art.

CHAPTER IX.

PYRONOMICS, OR THE LAWS OF HEAT.

168. Pyronomics is the science which treats of the laws, the properties, and operations of heat.*

1. The nature of heat is unknown; but it has been proved that the addition of heat to any substance produces no perceptible alteration in the weight of that substance. Hence it is inferred that heat is imponderable.

2. Heat pervades all bodies, insinuating itself, more or less,

night, and a great variety of other noises of the same kind, are imitated by the voice so exactly, as to deceive any hearer who does not know whence they proceed.

* Heat is undoubtedly a positive substance or quality. Cold is merely negative, being only the absence of heat.

Was this art known to the ancients? What is supposed, by some authors, concerning the responses at Delphi, Ephesus, &c.? Is ventriloquism a natural gift, or an acquired one?

168. What is Pyronomics? What is said in regard to the nature of heat? Is it ponderable or imponderable?

between their particles, and forcing them asunder. Heat, and the attraction of cohesion, constantly act in opposition to each other; hence the more a body is heated, the more its particles will be separated.

3. The effect of heat in separating the particles of different kinds of substances is seen in the melting of solids, such as metals, wax, butter, &c. The heat insinuates itself between the particles, and forces them asunder. These particles then are removed from that degree of proximity to each other within which cohesive attraction exists, and the body is reduced to a fluid form. When the heat is removed the bodies return to their former solid state.*

4. Heat passes through some bodies with more difficulty

* Of all the effects of heat, that produced upon water is, perhaps, the most remarkable. The particles are totally separated and converted into steam or vapor, and their extension is wonderfully increased. The steam which arises from boiling water is nothing more than portions of the water heated. The heat insinuates itself between the particles of the water, and forces them asunder. When deprived of the heat, the particles will unite in the form of drops of water. This fact can be seen by holding a cold plate over boiling water. The steam rising from the water will be condensed into drops on the bottom of the plate. The air which we breathe generally contains a considerable portion of moisture. On a cold day, this moisture condenses on the glass in the windows, and becomes visible. We see it also collected into drops on the outside of a tumbler or other vessel containing cold water in warm weather. Heat also produces most remarkable effects upon air, causing it to expand to a wonderful extent, while the absence of heat causes it to shrink or contract into very small dimensions. The attraction of cohesion causes the small watery particles which compose mist or vapor to unite together in the form of drops of water. It is thus that rain is produced. The clouds consist of mist or vapor expanded by heat. They rise to the cold regions of the skies, where the particles of vapor lose their heat, and then, uniting in drops, fall to the earth. But so long as they retain their heat, the attraction of cohesion can have no influence upon them, and they will continue to exist in the form of steam, vapor, or mist.

What effect has heat upon bodies? What two forces continually act in opposition to each other? In what can the effect of heat be seen? How does it separate the particles? What would be the effect were the heat removed? Upon what has heat the most remarkable effect? How does it affect it? What effect has heat upon air? How is rain produced? What is stated with regard to heat?

than through others; but there is no kind of matter which can completely arrest its progress.*

169. The principal effects of heat are three, namely:
1st. Heat expands most substances.
2d. It converts them from a solid to a fluid state.
3d It destroys their texture by combustion.†

* The thermometer, an instrument designed to measure degrees of heat, has already been described, in connexion with the barometer, under the head of Pneumatics. Heat, under the name of *caloric*, is properly a subject of consideration in the science of Chemistry. It exists in two states, called, respectively, free heat and latent heat. Free heat, or free caloric, is that which is perceptible to the senses, as the heat of a fire, the heat of the sun, &c. Latent heat is that which exists in most kinds of substances, but is not perceptible to the senses, until it is brought out by mechanical or chemical action. Thus, when a piece of cold iron is hammered upon an anvil, it becomes intensely heated; and when a small portion of sulphuric acid, or vitriol, is poured into a vial of cold water, the vial and the liquid immediately become hot. A further illustration of the existence of latent or concealed heat is given at the fireside every day. A portion of cold fuel is placed upon the grate or hearth, and a spark is applied to kindle the fire which warms us. It is evident that the heat given out by the fuel, when ignited, does not all proceed from the spark, nor can we perceive it in the fuel; it must, therefore, have existed somewhere in a latent state. It is, however, the effects of free heat, or free caloric, which are embraced in the science of Pyronomics. The subject of latent heat belongs more properly to the science of Chemistry.

The terms heat and cold, as they are generally used, are merely relative terms; for a substance which in one person would excite the sensation of heat, might, at the same time, seem cold to another. Thus, also, to the same individual, the same thing may be made to appear, relatively, both warm and cold. If, for instance, a person were to hold one hand near to a warm fire, and the other on a cold stone, or marble slab, and then plunge both into a basin of lukewarm water, the liquid would appear cold to the warm hand and warm to the cold one.

† These effects do not take place in all substances. Some substances

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Can the progress of heat be arrested? What is caloric? In what two states does heat exist? What is free heat? Give some examples of free heat. What is latent heat? Give some examples of latent heat. How are the terms heat and cold generally used? What illustration of this is given?

169. What are the three principal effects of heat on bodies to which it is applied? Give an example of each effect.

170. Heat tends to diffuse itself equally through all substances.

1. If a heated body be placed near a cold one, the temperature of the former will be lowered, while that of the latter will be raised.

2. All substances contain a certain quantity of heat; but, on account of its tendency to diffuse itself equally, and the difference in the power of different substances, to conduct it, bodies of the same absolute temperature appear to possess different degrees of heat.

3. Thus, if the hand be successively applied to a woollen garment, a mahogany table, and a marble slab, all of which have stood for some time in the same room, the woollen garment will appear the warmest, and the marble slab the coldest of the three articles; but if a thermometer be applied to each, no difference in the temperature will be observed.

4. From this it appears, that *some substances conduct heat readily, and others with great difficulty.* The reason that the marble slab seems the coldest, is, that marble, being a good conductor of heat, receives the heat from the hand so readily that the loss is instantly felt by the hand; while the woollen garment, being a bad conductor of heat, receives the heat from the hand so slowly that the loss is imperceptible.

171. The different power of receiving and conducting heat, possessed by different substances, is the cause of the difference in the warmth of various substances used for clothing.

are incombustible; others cannot be transformed to a fluid state by any degree of heat yet produced artificially. The expansive effect of heat has but one known exception. The sources from which heat is derived are—

1st. From the sun in connexion with light;

2dly. From mechanical operations, such as friction, percussion, and compression;

3dly. From chemical operations, especially combustion;

4thly. From living animals and vegetables.

What are the sources of heat?

170. In what way does heat tend to diffuse itself? Why do bodies of the same absolute temperature appear to possess different degrees of heat? What illustration of this is given? What appears from this?

171. What causes the difference in the warmth of substances used for clothing?

1. Thus, woollen garments are warm garments, because they part slowly with the heat which they acquire from the body, and, consequently, they do not readily convey the warmth of the body to the air; while, on the contrary, a linen garment is a cool one, because it parts with its heat readily, and as readily receives fresh heat from the body. It is, therefore, constantly receiving heat from the body and throwing it out into the air, while the woollen garment retains the heat which it receives, and thus encases the body with a warm covering.

2. For a similar reason ice, in summer, is wrapped in woollen cloths. It is then protected from the heat of the air, and will not melt.

172. Heat is propagated in two ways, namely, by conduction and by radiation. Heat is propagated by conduction when it passes from one substance to another in contact with it. Heat is propagated by radiation when it passes through the air or any other elastic fluid.

173. Different bodies conduct heat with different degrees of facility. The metals are the best conductors, and among metals silver is the best conductor.

1. For this reason any liquid may be heated in a silver vessel more readily than in any other of the same thickness. The metals stand in the following order, with respect to their conducting power; namely, silver, gold, tin, copper, platina, steel, iron, and lead.

2. It is on account of the conducting power of metals* that

* Metals, on account of their conducting power, cannot be handled when raised to a temperature above 120 degrees of Fahrenheit. Water becomes scalding hot at 150 degrees, but air, heated far beyond the temperature of boiling water, may be applied to the skin without much pain. Sir Joseph Banks, with several other gentlemen, remained some time in a room when the heat was 52 degrees above the boiling point; but, though they could bear the contact of the heated *air*, they could not touch any metallic substance, as their watch-chains, money, &c. Eggs, placed on

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172. In what two ways is heat propagated? When is it propagated by conduction? When is it propagated by radiation?

173. Do all bodies conduct heat with the same degree of facility? What bodies are the best conductors? In what order do the metals stand with respect to their conducting power?

the handles of metal tea-pots and coffee-pots are commonly made of wood; since, if they were made of metal, they would become too hot to be grasped by the hand, soon after the vessel is filled with heated fluid. Wood conducts heat very imperfectly. For this reason wooden spoons and forks are preferred for ice. Indeed, so imperfect a conductor of heat is wood, that a stick of wood may be grasped by the hand while one end of the stick is a burning coal. Animal and vegetable substances, of a loose texture, such as fur, wool, cotton, &c., conduct heat very imperfectly; hence their efficacy in preserving the warmth of the body.

174. Heat is reflected from bright surfaces; while black or dark colored bodies absorb the heat that falls on them.

1. This is the reason why the bright brass andirons, or any other bright substances, placed near a hot fire, seldom become heated; while other dark substances, further removed from the fire, become too hot for the hand.

2. Snow or ice will melt under a piece of black cloth, when it will remain perfectly solid under a white one. The farmers in some of the mountainous parts of Europe, are accustomed to spread black earth, or soot, over the snow, in the spring, to hasten its melting, and enable them to commence ploughing early.

175. All bodies, when violently compressed or extended, become warm.

a tin frame, were roasted hard in twenty minutes; and a beef-steak was overdone in thirty-three minutes.

Chantrey, the celebrated sculptor, had an oven which he used for drying his plaster cuts and moulds. The thermometer generally stood at 300 degrees in it, yet the workmen entered, and remained in it some minutes without difficulty; but a gentleman once entering it with a pair of silver-mounted spectacles on, had his face burnt where the metal came in contact with the skin.

Is wood a good conductor of heat? Why are wool, fur, &c., so efficacious in preserving the warmth of the body? What is related in the note with regard to the conducting power of heat?

174. What bodies reflect the heat? What bodies absorb the heat? Why do bright bodies, when placed near the fire, seldom become heated? Will snow melt most readily under white or black cloth?

175. What effect is produced on all bodies when violently compressed or extended?

1. If a piece of india-rubber be quickly stretched and applied to the lip, a sensible degree of heat will be felt. An iron bar, on being hammered, becomes red-hot; and even water, when strongly compressed, gives out heat.

2. When air is forcibly compressed by driving down the piston of a syringe, nearly closed at the end, great heat is produced. Syringes have been constructed on this principle for procuring fire, the heat, thus produced, being sufficient to kindle dry tinder.

176. All substances, as they are affected by heat, may be divided into combustible and incombustible bodies.*

177. The pyrometer† is an instrument to show the expansion of bodies by the application of heat.

It consists of a metallic bar or wire, with an index connected with one extremity. On the application of heat the bar expands and turns the index to show the degree of expansion.

178. The most obvious and direct effect of heat on a body, is to increase its extension in all directions.

1. Coopers, wheelwrights, and other artificers, avail themselves of this property in fixing iron hoops on casks, and the tires or irons on wheels. The hoop or tire having been heated, expands, and being adapted in that state to the cask or the wheel, as the metal contracts in cooling, it clasps the parts very firmly together.‡

* Vegetable substances, charcoal, oils, most animal substances, as hair, wool, horn, fat, and all metallic bodies, are combustible. Stones, glass, salts, &c., are incombustible.

† Wedgewood's pyrometer, the instrument commonly used for high temperatures, measures heat by the contraction of clay.

‡ From what has been stated above, it will be seen, that an allowance should be made for the alteration of the dimensions in metallic beams or

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What experiments are here related to illustrate this? What is said of the air when strongly compressed?

176. Into what classes are all substances, as affected by heat, divided? What substances are combustible? What substances are incombustible?

177. What is a pyrometer? Of what does it consist? How does Wedgewood's pyrometer measure high temperatures?

178. What is the most obvious and direct effect of heat on a body What application of this principle is related in the note?

2. The effect of heat and cold,* in the expansion and contraction of glass, is an object of common observation; for it is this expansion and contraction which cause so many accidents with glass articles. Thus, when hot water is suddenly poured into a cold glass, of any form, the glass, if it have any thickness, will crack; and, on the contrary, if cold water be poured into a heated glass vessel, the same effect will be produced. The reason of which is this: heat makes its way but slowly through glass; the inner surface, therefore, when the hot water is poured into it, becomes heated, and, of course, distended before the outer surface, and the irregular expansion causes the vessel to break. There is less danger of fracture, therefore, when the glass is thin, because the heat readily penetrates it, and there is no irregular expansion.†

supporters, caused by the dilatation and contraction effected by the weather. In the iron arches of Southwark bridge, over the Thames, the variation of the temperature of the air causes a difference of height, at different times, amounting to nearly an inch. A happy application of this principle to the mechanic arts was made, some years ago, at Paris. The weight of the roof of a building, in the Conservatory of Arts and Trades, had pressed outwards the side-walls of the structure, and endangered its security. The following method was adopted to restore the perpendicular direction of the structure. Several apertures were made in the walls, opposite to each other, through which iron bars were introduced, which, stretching across the building, extended beyond the outside of the walls. These bars terminated in screws, at each end, to which large broad nuts were attached. Each alternate bar was then heated by means of powerful lamps, and their lengths being thus increased, the nuts on the outside of the building were screwed up close to it, and the bars were suffered to cool. The powerful contraction of the bars drew the walls of the building closer together and the same process being repeated on all the bars, the walls were gradually and steadily restored to their upright position.

* *Cold* is merely the absence of heat; or rather, more properly speaking, inferior degrees of heat are termed *cold.*

† The glass chimneys, used for oil and gas burners, are often broken by being suddenly placed, when cold, over a hot flame. The danger of fracture may be prevented (it is said) by making a minute notch on the bottom of the tube with a diamond. This precaution has been used in an

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What is said of the effect of heat and cold on glass? When hot water is suddenly poured into a cold glass, why will the glass crack? When cold water is applied to a heated glass, why will the glass crack?

179. The expansion caused by heat in solid and liquid bodies differs in different substances; but aëriform fluids all expand alike, and undergo uniform degrees of expansion at various temperatures.

The expansion of solid bodies depends, in some degree, on the cohesion of their particles; but as gases and vapors are destitute of cohesion, heat operates on them without any opposing power.

180. The density of all substances is augmented by cold, and diminished by heat.

There is a remarkable exception to this remark, and that is in the case of water; which, instead of contracting, expands at the freezing point, or when it is frozen. This is the reason why pitchers, and other vessels, containing water and other similar fluids, are so often broken when the liquid freezes in them. For the same reason, ice floats* instead of sinking in water; for as its density is diminished, its specific gravity is consequently diminished.

181. Different bodies require different quantities of heat to raise them to the same temperature; and those

establishment where six lamps were lighted every day, and not a single glass has been broken in nine years.

* Were it not for this remarkable property of water, large ponds and lakes, exposed to intense cold, would become solid masses of ice; for if the ice, when formed on the surface, were more dense (that is, more heavy) than the water below, it would sink to the bottom, and the water above, freezing in its turn, would also sink, until the whole body of the water would be frozen. The consequence would be the total destruction of all creatures in the water. But the specific gravity of ice causes it to continue on the surface, protecting the water below from congelation.

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179. Is the expansion caused by heat in solid and liquid bodies the same in all substances? How do aëriform fluids differ, in this respect, from solid and liquid bodies? Upon what does the expansion of solid bodies in some degree depend? Why has heat more power over gases and vapors?

180. What effect has heat and cold upon the density of all substances? What exception is there to this remark? Why are the vessels, containing water and other similar fluids, so often broken when the liquid freezes in them? Why does ice float upon the water, instead of sinking in it? What is stated in the note with regard to this property of water?

which are heated with most difficulty retain their heat the longest.

Thus oil becomes heated more speedily than water, and it likewise cools more quickly.

182. When heat is thrown upon a bright or polished surface it is reflected,* and the angle of reflection will be equal to the angle of incidence.

183. When a certain degree of heat is applied to water it converts it into steam or vapor.

184. 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. When closely confined, its elastic power is often sufficient to burst the vessel in which it is confined.

185. The elastic force of steam is increased by heat, and diminished by cold. The amount of pressure, therefore, which it will exert depends on the temperature at which it is formed.

186. The great and peculiar property of steam, on which its mechanical agencies depend, is its power of

* Advantage has been taken of this property of heat in the construction of a simple apparatus for baking. It is a bright tin case, having a cover inclined towards the fire in such a manner as to reflect the heat downwards. In this manner use is made both of the direct heat of the fire, and the reflected heat, which would otherwise pass into the room. The whole apparatus, thus connected with the culinary department, is called, in New England, "*The Connecticut baker.*"

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181. Can all bodies be raised to the same temperature by the same quantities of heat? What bodies retain their heat the longest?

182. What becomes of the heat which is thrown upon a bright or polished surface? How do the angles of incidence and reflection compare with each other?

183. When is water converted into steam or vapor?

184. How does the temperature of the steam compare with that of the liquid from which it is formed while it remains in contact with that liquid?

185. By what is the elasticity of steam increased and diminished? Upon what does the amount of pressure, which steam exerts, depend?

186. What is the great and peculiar property of steam, on which its mechanical agencies depend?

exerting a high degree of elastic force, and losing it instantaneously.

187. The steam-engine is a machine moved by the expansive force of steam.*

188. Steam occupies a space about 1700 times larger than it will when converted into water. If, therefore, the steam in a cylinder be suddenly converted into water, it will occupy a much smaller space, and produce a vacuum in the cylinder.

1. The mode in which steam is made to act, is by causing its expansive force to raise a solid piston accurately fitted to the bore of a cylinder, like that in the forcing-pump.

2. The piston-rod rises by the impulse of expanding steam, admitted into the cylinder below. When the piston is thus raised, if the steam below it 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. The admission of more steam below it will raise it again, and thus a continued motion of the piston, up and down, will be produced. This motion of the piston is communicated to wheels, levers, and other machinery, in such a manner as to produce the effect intended.†

3. The celebrated Mr. James Watt introduced two important improvements into the steam-engine. Observing that the cooling of the cylinder by the water thrown into it to condense the steam, lessened the expansibility of the steam; he contrived a method to withdraw the steam from the principal cylinder, after it had performed its office, into a condensing-

* Steam, as it issues into the air, is visible, and resembles smoke in its appearance, because the coldness of the air instantly condenses it into minute watery globules; but while performing its office, it is perfectly dry, that is, it contains no watery particles, but is expanded into so rare a state as to be absolutely invisible.

† This is the mode in which the engine of Newcomen and Savery, commonly called the atmospheric engine, was constructed.

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187. What is the steam-engine?

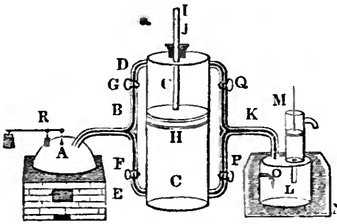
188. How much larger space does steam occupy than water? By what mode is steam made to act? By what impulse does the piston rise? What causes the piston to descend? What improvement did Mr Watt introduce into the steam-engine?

chamber, where it is reconverted into water, and conveyed back to the boiler.

4. The other improvement consists in substituting the expansive power of steam for the atmospheric pressure. This was performed by admitting the steam into the cylinder *above* the raised piston, at the same moment that it is removed from *below* it; and thus the power of steam is exerted in the *descending* as well as in the ascending stroke of the piston; and a much greater impetus is given to the machinery than by the former method. From the *double action* of the steam *above*, as well as *below* the piston, and from the condensation of the steam, after it has performed its office, this engine is called Watt's *double-acting condensing* steam-engine.

5. Fig. 93 represents that portion of the steam-engine in which steam is made to act, and propel such machinery as may be connected with it. The principal parts are the boiler, the cylinder and its piston, the condenser, the air-pump, the steam-pipe, the eduction-pipe, and the cistern. In this figure, A represents the boiler, C the cylinder, with H the piston, B the steam-pipe, with two *branches** communicating with the cylinder, the one above and the other below the piston. This pipe has two valves, F and G, which are opened and closed alternately by machinery connected with the piston. The steam is carried through this pipe by the valves, when open, to the cylinder both above and below the piston. K is the eduction-pipe, having two branches, like the steam-pipe, furnished with valves, &c., which are opened and shut by the same machinery. By the eduction-pipe the steam is led off from the cylinder as the piston ascends and descends.

Fig. 93.



* The steam and the eduction pipes are sometimes made in forms differing from those in the figure, and they differ much in different engines.

What does Fig. 93 represent? What are the principal parts? What does A represent? What does C represent? What does B represent? What does K represent? By what is the steam led off from the cylinder?

L is the condenser, and O a stop-cock for the admission of cold water. M is the air-pump. N is the cistern of cold water in which the condenser is immersed. R is the safety-valve. When the valves are all open, the steam issues freely from the boiler, and circulates through all the parts of the machine, expelling the air.* Now, the valves F and Q, being closed, and G and P remaining open, the steam presses upon the piston and forces it down. As it descends, it draws with it the end of the working-beam, which is attached to the piston-rod J, (but which is not represented in the figure.) To this working-beam, (which is a lever of the first kind,) bars or rods are attached, which, rising and falling with the beam and the piston, open the stop-cock O, admitting a stream of cold water, which meets the steam from the cylinder and condenses it, leaving no force below the piston to oppose its descent. At this moment the rods attached to the working-beam close the stop-cocks G and P, and open F and Q. The steam then flows in below the piston, and rushes from above it into the condenser, by which means the piston is forced up again with the same power as that with which it descended. Thus the steam-cocks G and P and F and Q are alternately opened and closed; the steam passing from the boiler drives the piston alternately upwards and downwards, and thus produces a regular and continued motion. This motion of the piston, being communicated to the working-beam, is extended to other machinery, and thus an engine of great power is obtained.

The air-pump M, the rod of which is connected with the working-beam, carries the water from the condenser back into the boiler, by a communication represented in Fig. 94.

* This process is called blowing out, and is heard when a steamboat is about starting.

What does L represent? What does O represent? What does M represent? What does N represent? What does R represent? When the valves are all open, what becomes of the steam? When the valves F and Q are closed, and G and P open, upon what does the steam press? What does the cylinder draw with it in its descent? Which of the mechanical powers is this working-beam? What are attached to this working-beam? What is their use? What becomes of the steam when the stop-cocks G and P are closed, and F and Q are open? How is the regular and continued motion produced? To what is this motion of the piston communicated? What is the use of the air-pump M? For what is the safety-valve R used?

The safety-valve R, connected with a lever of the second kind, is made to open when the pressure of the steam within the boiler is too great. The steam then rushing through the aperture under the valve, removes the danger of the bursting of the boiler.

189. The power of a steam-engine is generally expressed by the power of a horse, which can raise 33,000 lbs. to the height of one foot in a minute. An engine of 100 horse power, is one that will raise 3,300,000 lbs. to the height of one foot in one minute.

190. The steam-engine* is constructed in various forms; the principal of which are the high and the low pressure engines; or, as they are sometimes called, the non-condensing and the condensing engines.

1. The non-condensing or high-pressure engines differ from the low pressure or condensing engines in having no condenser. The steam, after having moved the piston, is let off into the open air. As this kind of engine occupies less space, and is much less complicated, it is generally used on railroads.

2. In the low pressure or condensing engines, the steam, after having moved the piston, is condensed, or converted into water, and then conducted back into the boiler.

* The steam-engine, as it is constructed at the present day, is the result of the inventions and discoveries of a number of distinguished individuals, at different periods. Among those who have contributed to its present state of perfection, and its application to practical purposes, may be mentioned the names of Somerset, the Marquis of Worcester, Savery, Newcomen, Fulton, and especially Mr. James Watt.

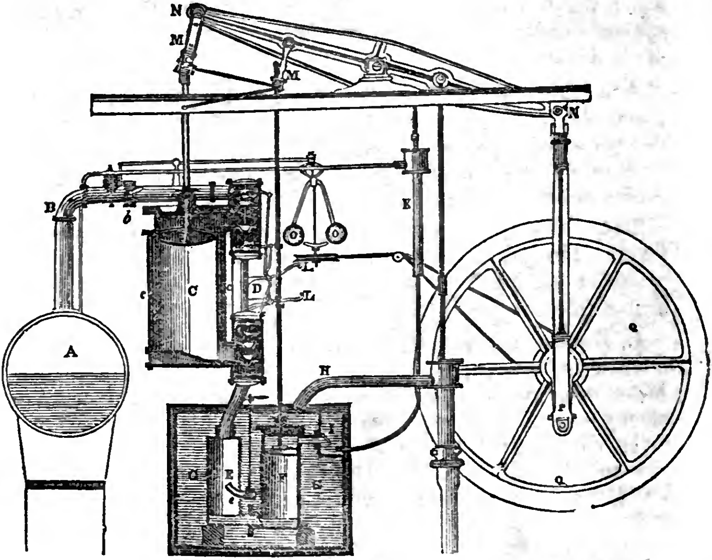
To the inventive genius of Watt, the engine is indebted for the *condenser, the appendages for parallel motion*, the application of the *governor*, and for the *double action*. In the words of Mr. Jeffrey it may be added, that, " by his admirable contrivances, and those of Mr. Fulton, it has become a thing alike stupendous for its force and its flexibility; for the pro-

189. How is the power of a steam-engine expressed? What is an engine of 100 horse power?

190. What are the principal forms in which the steam-engine is constructed? How do they differ from each other? What becomes of the steam after having moved the piston in the non-condensing engines? What kind of engines is generally used on railroads? What becomes of the steam after having moved the piston in the condensing engines?

WATT'S DOUBLE-ACTING CONDENSING STEAM-ENGINE.

Fig. 94.



3. Fig. 94 represents Watt's double-acting condensing steam-engine, in which A represents the boiler, containing a large quantity of water, which is constantly replaced as fast as portions are converted into steam. B is the steam-pipe, conveying the steam to the cylinder, having a steam-cock *b* to admit or exclude the steam at pleasure.

C is the cylinder, surrounded by the jacket *c c*, a space kept constantly supplied with hot steam, in order to keep the cylinder from being cooled by the external air. D is the

digious power it can exert, and the ease and precision and ductility with which it can be varied, distributed, and applied. The trunk of an elephant, that can pick up a pin, or rend an oak, is as nothing to it. It can engrave a seal, and crush masses of obdurate metal before it; draw out, without breaking, a thread as fine as gossamer, and lift up a ship of war like a bauble in the air. It can embroider muslin, and forge anchors; cut steel into ribands, and impel loaded vessels against the fury of the winds and waves."

eduction-pipe, communicating between the cylinder and the condenser. E is the condenser, with a valve *e*, called the injection-cock, admitting a jet of cold water, which meets the steam the instant that the steam enters the condenser. F is the air-pump, which is a common suction-pump, but is here called the air-pump because it removes from the condenser not only the water, but also the air, and the steam that escapes condensation. G G is a cold-water cistern, which surrounds the condenser, and supplies it with cold water, being filled by the cold-water pump, which is represented by H. I is the hot well, containing water from the condenser. K is the hot-water pump, which conveys back the water of condensation from the hot well to the boiler.

L L are levers, which open and shut the valves in the channel between the steam-pipe, cylinder, eduction-pipe, and condenser; which levers are raised or depressed by projections attached to the piston-rod of the pump. M M is an apparatus for changing the circular motion of the working-beam into parallel motion, so that the piston-rods are made to move in a straight line. N N is the working-beam, which being moved by the rising and falling of the piston, attached to one end, communicates motion to the fly-wheel by means of the crank P, and from the fly-wheel the motion is communicated by bands, wheels, or levers, to the other parts of the machinery. O O is the governor.

The governor being connected with the fly-wheel, is made to participate the common motion of the engine, and the balls will remain at a constant distance from the perpendicular shaft, so long as the motion of the engine is uniform; but whenever the engine moves faster than usual, the balls will recede farther from the shaft, and, by raising a valve connected with the boiler, will let off such a portion of the force as to reduce the speed to the rate required.

The steam-engine, thus constructed, is applied to boats to turn wheels having paddles attached to their circumference, which answer the purpose of oars. It is used also in work-

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What does Fig. 94 represent? What does A represent? What does B represent? What does C represent? What does D represent? What does E represent? What does F represent? What does G G represent? What does I represent? What does K represent? What does L L represent? What does M M represent? What does N N represent? What does O O represent? What is said of the governor?

shops, factories, &c.; and different directions and velocities may be given to the motion produced by the action of the steam on the piston, by connecting the piston to the beam with wheels, axles, and levers, according to the principles stated under the head of Mechanics.

191. The locomotive engine is a high-pressure steam-engine, mounted on wheels, and used to draw loads on a railroad, or other level roads. It is usually accompanied by a large wagon, called a *tender*, in which the wood and water, used by the engine, are carried.

Fig. 95 represents a side view of the internal construction of a locomotive steam-engine; in which F represents the fire-box, or place where the fire is kept; D the door through which the fuel is introduced. The spaces marked B are the interior of the boiler, in which the water stands at the height indicated by the dotted line. The boiler is closed on all sides, all its openings being guarded by valves. The tubes marked *p p* conduct the smoke and flame of the fuel through the boiler to the chimney C C, serving, at the same time, to communicate the heat to the remotest part of the boiler. By this arrangement none of the heat is lost, as these tubes are all surrounded by the water. S S S is the steam-pipe, open at the top V S, having a steam-tight cock, or regulator, V, which is opened and shut by the lever L, extending outside of the boiler, and managed by the engineer.

The operation of the machine is as follows: the steam being generated in great abundance in the boiler, and being unable to escape out of it, acquires a considerable degree of elastic force. If at that moment the valve V be opened, by the handle L, the steam entering the pipe S passes in the direction of the arrow, through the tube, and enters the valve-box at X. There a sliding-valve, which moves at the same time with the machine, opens for the steam a communication successively with each end of the cylinder below. Thus, in the figure, the entrance on the right hand of the sliding-valve is represented as being open, and the steam follows in the direction of the arrows into the cylinder, where its expansive force will move

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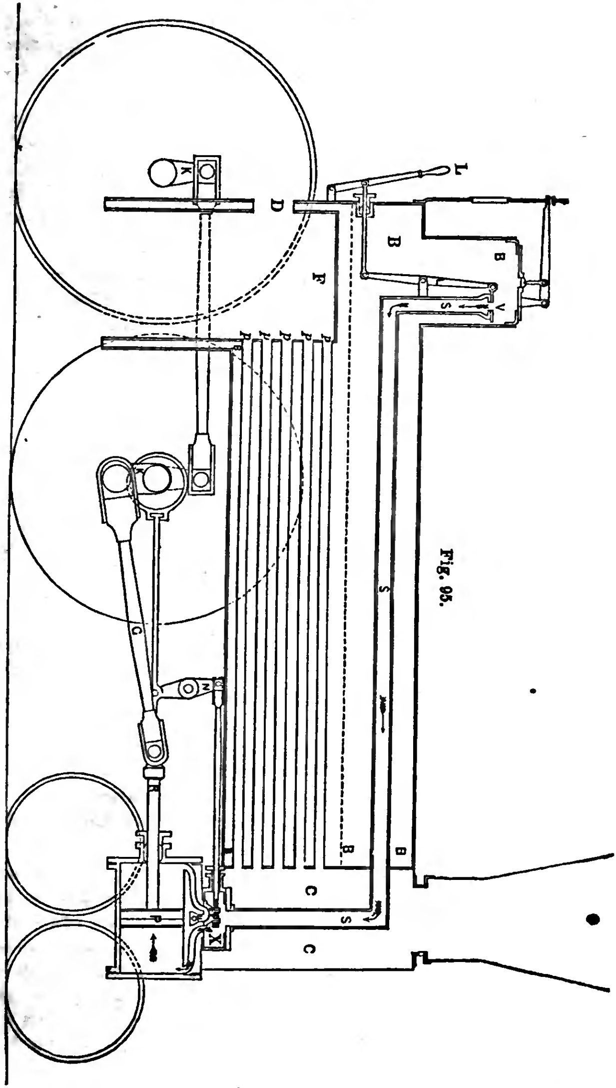
191. Describe the *locomotive* steam-engine. In Fig. 95, what do F and D represent? What do the following references respectively represent, namely, S S S? B B B? *p p p p?* C C? X? L? P? N N? G K K?

Fig. 95.



VIEW OF THE INTERNAL CONSTRUCTION OF HINKLEY & DRURY'S LOCOMOTIVE STEAM-ENGINE.

the piston *P* in the direction of the arrow. The steam or air on the other side of the piston passes out in the opposite direction, and is conveyed, by a tube passing through C C, into the open air.

The motion of the piston in the direction of the arrow, causes the levers N N to close the sliding-valve on the right, and open a communication for the steam on the opposite side of the piston *p*, where it drives the piston back towards the arrow, at the same time affording a passage for the steam on the right of the piston to pass into the open air.

Motion being thus given to the piston, it is communicated, by means of the rod R and the beam G, to the cranks K K, which, being connected with the axle of the wheel, causes it to turn, and thus move the machine.

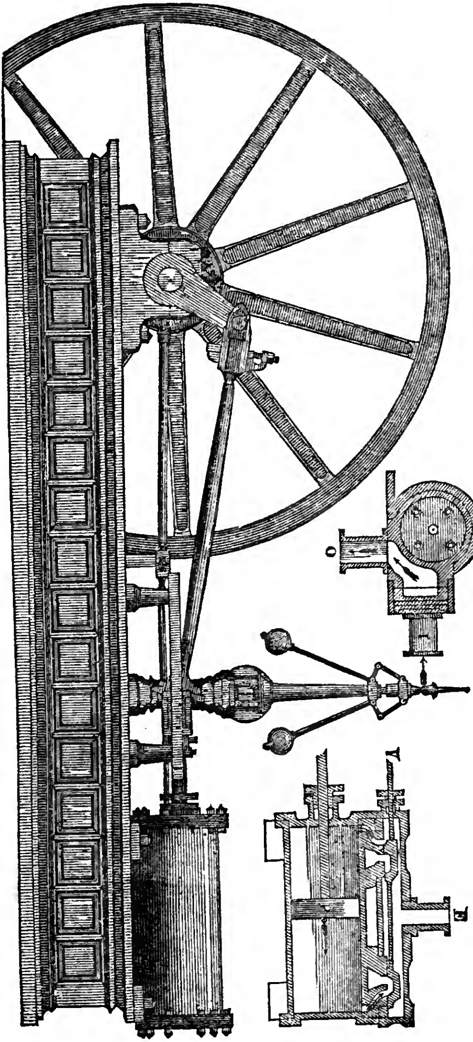
Thus constructed, and placed on a railroad, the locomotive steam-engine is advantageously used as a substitute for horse power, for drawing heavy loads.*

THE STATIONARY STEAM-ENGINE.

This engine is generally a high-pressure, or non-condensing engine, used to propel machinery in workshops and factories. As it is designed for a labor-saving machine, it is desirable to combine simplicity and economy with safety and durability in its construction; and that form of this engine is to be preferred which in the greatest degree unites these qualities. The figure on page 151 represents Tuft's stationary steam-engine,† with sec-

* The apparatus of safety-valves and other appliances for the manage ment of the power produced by the machine, are the same in principle, though differing in form, with those used in other steam-engines; for a particular description of which, the student is referred to practical treatises upon the subject.

† This engine was constructed by Mr. Otis Tufts of East Boston, Massachusetts. It is the engine used to propel the machinery at the late Fair of the Massachusetts Mechanic Association, where it was very highly and justly commended for its beauty and simplicity of construction, and the perfectly "*noiseless tenor of its way.*" The figure which represents it is an *electrotype copy* of a steel plate, designed by Brown & Harbrys, under the direction of Mr. Tufts. The electrotype copy was taken by Mr. A. Wilcox, Washington-street, Boston. The electrotype process will be noticed in a subsequent page of this volume.



TUFTS' STATIONARY STEAM-ENGINE, WITH SECTIONS

tions of the interior. Like the double-acting condensing engine of Mr. Watt, described in Fig. 94, it is furnished with a governor, by which the supply of steam is regulated; and like the locomotive, Fig. 95, the cylinder with its piston has a horizontal position. The steam is admitted into the valve-box through an aperture at E, *in the section*, and from thence passes into the cylinder through a sliding-valve, alternately to each side of the piston P, as is represented by the direction of the arrows, the sliding-valve being moved by the rod V, communicating with an "eccentric" apparatus attached to the axis of the fly-wheel. The direction of the current of steam to the valve-box is represented by the arrow at I, and its passage outward from the cylinder, after it has moved the piston, is seen at O. In this engine there is no working-beam as in Watt's engine, Fig. 94, but the motion is communicated from the piston-rod to a crank connected with the fly-wheel, which, turning the wheel, will move all machinery connected either with the axis or the circumference of that wheel.

CHAPTER X.

OPTICS.

192. Optics is the science which treats of light, of colors, and of vision.

1. The science of optics divides all substances into the following classes; namely, luminous, transparent, and translucent; reflecting, refracting, and opaque.

2. Luminous bodies are those which shine by their own light; such as the sun, the stars, a burning lamp, or a fire.

3. Transparent substances are those which allow light to pass through them freely, so that objects can be distinctly seen through them; as glass, water, air, &c.

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192. Of what does Optics treat? Into what classes does the science of Optics divide all substances? What are luminous bodies? Give an example of a luminous body. What are transparent bodies?

4. Translucent bodies are those which permit a portion of light to pass through them; but render the object behind them indistinct; as horn, oiled paper, colored glass, &c.

5. Reflecting substances are those which do not permit light to pass through them; but throw it off in a direction more or less oblique, according as it falls on the reflecting surface; as polished steel, looking-glasses, polished metal, &c.

6. Refracting substances are those which turn the light from its course, in its passage through them; and opaque substances are those which permit no light to pass through them; as metals, wood, &c.

7. It is not known what light is. Sir Isaac Newton supposed it to consist of exceedingly small particles, moving from luminous bodies; others think that it consists of the undulations of an elastic medium, which fills all space. These undulations (as is supposed) produce the sensation of light to the eye, in the same manner as the vibrations of the air produce the sensation of sound to the ear. The opinions of philosophers at the present day are inclining to the undulatory theory.

193. A ray of light is a single line of light proceeding from a luminous body.

194. Rays of light are said to diverge when they separate more widely, as they proceed from a luminous body.

Fig. 96.

Fig. 96 represents the rays of light diverging as they proceed from the luminous body, from F to D.

195. Rays of light are called converging when they approach each other. The point at which converging rays meet is called the focus.

Fig. 97.

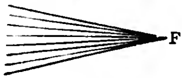

Fig. 97 represents converging rays of light, of which the point F is the focus.

Give an example of a transparent body. What are translucent bodies? Give an example of a translucent body. What are reflecting substances? Give an example of a reflecting body. What are refracting substances? What are opaque substances? What is light? What did Sir Isaac Newton suppose it to be? What other opinions have been formed concerning it?

193. What is a ray of light?

194. When are rays of light said to diverge? What does Fig. 96 represent?

196. A beam of light consists of many rays running in parallel lines.

Fig. 98.

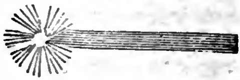

Fig. 98 represents a beam of light.

197. A pencil of rays is a collection of diverging or converging rays.

198. A medium is any substance, solid or fluid, through which light can pass; as water, glass, air, &c.

199. The rays of light which issue from terrestrial bodies, continually diverge, until they meet with a refracting substance; but the rays of the sun diverge so little, on account of the immense distance of that luminary, that they are considered parallel.

200. Light, proceeding from a luminous body, is projected forward in straight lines in every possible direction. It moves with a rapidity but little short of 200,000 miles in a second of time.

201. Every point of a luminous body is a centre, from which light radiates in every direction. Rays of light proceeding from different bodies, cross each other without interfering.

202. A shadow is the darkness produced by the intervention of an opaque body, which prevents the rays of light from reaching an object behind the opaque body.

Shadows are of different degrees of darkness, because the light from other luminous bodies reaches the spot where the

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195. When are rays of light called converging? What is the point, at which converging rays meet, called?

196. What is a beam of light? What does Fig. 98 represent?

197. What is a pencil of light?

198. What is a medium?

199. In what manner do the rays of light proceed from terrestrial bodies In what kind of lines do the rays of light proceed from the sun?

200. In what way is light projected forward from any luminous body? With what rapidity does it move?

201. From what point, in a luminous body, does light radiate?

202. How is a shadow produced? Why are shadows of different degrees of darkness?

shadow is formed. Thus, if a shadow be formed when two candles are burning in a room, that shadow will be both deeper and darker if one of the candles be extinguished. The darkness of a shadow is proportioned to the intensity of the light, when the shadow is produced by the interruption of the rays from a single luminous body.*

203. When a luminous body is larger than an opaque body, the shadow of the opaque body will gradually diminish in size till it terminates in a point. The form of the shadow of a spherical body will be that of a cone.

Fig. 99.

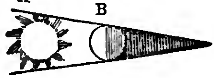
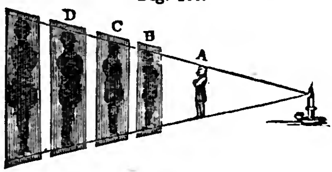


Fig. 99. A represents the sun, and B the moon. The sun, being much larger than the moon, causes it to cast a converging shadow, which terminates at E.

204. When the luminous body is smaller than the opaque body, the shadow of the opaque body gradually increases in size with the distance, without limit.

Fig. 100.



In Fig. 100 the shadow of the object, A, increases in size at the different distances, B, C, D, E, or, in other words, it constantly diverges.

205. When several luminous bodies shine upon the

* As the degree of light and darkness can be estimated only by comparison, the strongest light will appear to produce the deepest shadow Hence, a total eclipse of the sun occasions a more sensible darkness than midnight, because it is immediately contrasted with the strong light of day.

To what is the darkness of a shadow proportioned, when the shadow is produced by the interruption of the rays from a single luminous body?

203. What is said of the shadow of the opaque body when the luminous body is the larger? Explain Fig. 99.

204. What is said of the shadow of the opaque body when the luminous body is the smaller? Explain Fig. 100.

205. How many shadows are produced when several luminous bodies shine upon the same object?

same object, each one will produce a shadow.

Fig. 101.

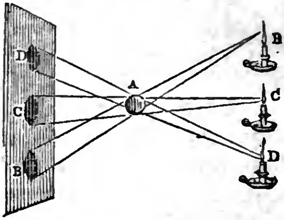


Fig. 101 represents a ball, A, illuminated by the three candles, B, C, and D. The light B produces the shadow *b*, the light C, the shadow *c*, and the light D, the shadow *d*; but as the light from each of the candles shines upon all the shadows, except its own, the shadows will be faint.

206. When rays of light fall upon an opaque body, part of them are absorbed, and part are reflected.

Light is said to be reflected when it is thrown off from the body on which it falls; and it is reflected in the largest quantities from the most highly polished surfaces. Thus, although most substances reflect it in a degree, polished metals, looking-glasses, or mirrors, &c., reflect it in so perfect a manner as to convey to our eyes, when situated in a proper position to receive them, perfect images of whatever objects shine on them, either by their own, or by borrowed light.

207. That part of the science of Optics which relates to reflected light, is called *Catoptrics.*

208. The laws of reflected light are the same as those of reflected motion. Thus, when light falls perpendicularly on an opaque body, it is reflected back in the same line, towards the point whence it proceeded. If it fall obliquely, it will be reflected obliquely in the opposite direction; and in all cases the angle of incidence

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Explain Fig. 101.

206. What is the consequence when rays of light fall upon an opaque body which they cannot pass? What is meant by the reflection of light?

207. What are Catoptrics?

208. By what laws is light governed? How is light reflected when it falls perpendicularly on an opaque body? How is it reflected when it falls obliquely? How do the angles of incidence and reflection compare with each other? By what light are opaque objects seen? By what light are luminous objects seen?

will be equal to the angle of reflection. This is the fundamental law of Catoptrics, or reflected light.*

Opaque objects are seen only by reflected light. Luminous bodies are seen by the rays of light which they send directly to our eyes.

209. All bodies absorb a portion of the light which they receive; therefore the intensity of light is diminished every time that it is reflected.

* The angles of incidence and reflection have already been described under the head of Mechanics; but as all the phenomena of reflected light depend upon the law stated above, and a clear idea of these angles is necessary in order to understand the law, it is deemed expedient to repeat in this connexion the explanation already given.

An incident ray is a ray proceeding *to*, or falling *on* any surface; and a reflected ray is the ray which proceeds *from* any reflecting surface.

Fig 102.

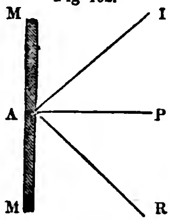

Fig. 102 is designed to show the angles of incidence and of reflection. In this figure M A M is a mirror, or reflecting surface. P is a line perpendicular to the surface. I A represents an incident ray, falling on the mirror in such a manner as to form, with the perpendicular P, the angle I A P. This is called the angle of incidence. The line R A is to be drawn on the other side of P A in such a manner as to have the same inclination with P A as I A has: that is, the angle R A P is equal to I A P. The line R A will then show the course of the reflected ray; and the angle R A P will be the angle of reflection.

From whatever surface a ray of light is reflected, whether it be a plain surface, a convex surface, or a concave surface, this law invariably prevails; so that if we notice the inclination of any incident ray, and the situation of the perpendicular to the surface on which it falls, we can always determine in what manner, or to what point it will be reflected. This law explains the reason why, when we are standing on one side of a mirror, we can see the reflection of objects on the opposite side of the room, but not those on the same side on which we are standing. It also explains the reason why a person can see his whole figure in a mirror not more than half of his height. It also accounts for all the apparent peculiarities of the reflection of the different kinds of mirrors.

Explain the angles of incidence and reflection. Is the same principle applicable to all kinds of surfaces? Explain its application to mirrors.

209. Why is the intensity of light diminished every time it is reflected?

210. Every portion of a reflecting surface reflects an entire image of the luminous body shining upon it.

1. When the sun or the moon shines upon a sheet of water, every portion of the surface reflects an entire image of the luminary; but as the image can be seen only by reflected rays, and as the angle of reflection is always equal to the angle of incidence, the image for any point can be seen only in the reflected ray prolonged.

2. Objects seen by moonlight appear fainter than when seen by daylight, because the light by which they are seen has been twice reflected; for, the moon is not a luminous body, but its light is caused by the sun shining upon it. This light, reflected from the moon and falling upon any object is again reflected by that object. It suffers, therefore, two reflections; and since a portion is absorbed by each surface that reflects it, the light must be proportionally fainter. In traversing the atmosphere, also, the rays, both of the sun and moon, suffer diminution; for, although pure air is a transparent medium, which transmits the rays of light freely, it is generally surcharged with vapors and exhalations, by which some portion of light is absorbed.

211. All objects are seen by means of the rays of light emanating or reflected from them; and therefore when no light falls upon an opaque body it is invisible.

This is the reason why none but luminous bodies can be seen in the dark. For the same reason, objects in the shade, or in a darkened room appear indistinct, while those which are exposed to a strong light can be clearly seen.

212. When rays of light, proceeding from any object, enter a small aperture, they cross one another and form an inverted image of the object.*

* This is a necessary consequence of the law that light always moves in straight lines.

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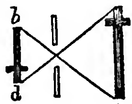
210. Does every portion of a reflecting surface reflect an entire image of the luminous body shining upon it? When the sun or moon shines upon a sheet of water, why do we not see an image reflected from every portion of the surface? Why do objects, seen by moonlight, appear fainter than when seen by daylight? By what light does the moon shine? What absorbs some of the rays of light in traversing the atmosphere?

211. How are all objects seen? Why can none but luminous bodies be seen in the dark?

Fig. 103 represents the rays from an object, *a c*, entering an aperture. The ray from *a* passes down through the aperture to *d*, and the ray from *c* passes up to *b*, and thus these rays, crossing at the aperture, form an inverted image on the wall. The room in which this experiment is made should be darkened, and no light permitted to enter, excepting through the aperture. It then becomes a camera obscura.*

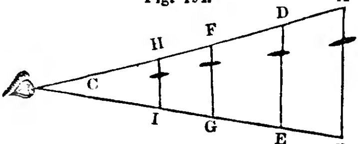
Fig. 103.



213. The angle of vision is the angle formed at the eye by two lines drawn from opposite parts of an object.

1. The angle C, in Fig. 104, represents the angle of vision. The line A C proceeding from one extremity of the object meets the line B C proceeding from the opposite extremity, and forms an angle C at the eye;—this is the angle of vision.

Fig. 104.



2. Fig. 105 represents the different angles, made by the same object, at different distances. From an inspection of the

* These words signify *a darkened chamber*. In the future description which will be given of *the eye*, it will be seen that the camera obscura is constructed on the same principle as the eye. If a convex lens be placed in the aperture, an inverted picture, not only of a single object, but of the entire landscape, will be found on the wall. A portable camera obscura is made by admitting the light, into a box of any size, through a convex lens, which throws the image upon an inclined mirror, from whence it is reflected upwards to a plate of ground glass. In this manner a beautiful but diminished image of the landscape, or of any group of objects, is presented on the plate in an erect position.

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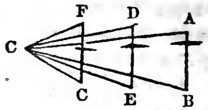
212. What kind of an image is formed when rays of light, proceeding from an object, enter a small aperture? Illustrate this by Fig. 103. What is a camera obscura? How can a portable camera obscura be made?

213. How is the angle of vision formed? Explain Fig. 104. What does Fig. 105 represent?

figure it is evident, that the nearer an object is to the eye, the wider must be the opening of the lines to admit the extremities of the object; and, consequently, the larger the angle under which it is seen; and, on the contrary, that objects at a distance will form small angles of vision. Thus, in this figure, the three crosses, F G, D E, and A B, are all of the same size; but A B, being the most distant, subtends the smallest angle* A C B, while D E and F G, being nearer to the eye, situated at C, form respectively the larger angles, D C E and F C G.

Fig. 105.



214. When an object, at any distance, does not subtend an angle of more than two seconds of a degree, it is invisible.

At the distance of four miles a man of common stature will thus become invisible, because his height at that distance will not subtend an angle of two seconds of a degree. The size of

* The apparent size of an object depends upon the size of the angle of vision. But we are accustomed to correct, by experience, the fallacy of appearances; and, therefore, since we know that real objects do not vary in size, but that the angles under which we see them do vary with the distance, we are not deceived by the variations in the appearance of objects. Thus, a house at a distance appears absolutely smaller than the window through which we look at it; otherwise we could not see it through the window; but our knowledge of the real size of the house prevents our alluding to its apparent magnitude. In Fig. 104 it will be seen that the several crosses, AB, DE, FG, and HI, although very different in size, on account of their different distances, subtend the same angle A C B; they, therefore, all appear to the eye to be of the same size, while, in Fig. 105, the three objects AB, DE, and FG, although of the same absolute size, are seen at a different angle of vision, and they, therefore, will seem of different sizes, appearing larger as they approach the eye.

It is upon a correct observance of the angle of vision that the art of perspective drawing is indebted for its accuracy.

What effect has the nearness of the object to the eye, on the angle? Illustrate this by the figure. Upon what does the apparent size of an object depend? Why do objects appear so large? To what is the art of perspective drawing indebted for its accuracy?

214. How large an angle must a body subtend to be visible?

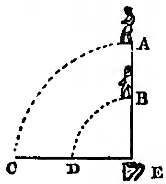
the apparent diameter of the heavenly bodies is generally stated by the angle which they subtend.

215. When the velocity of a moving body does not exceed twenty degrees in an hour, its motion is imperceptible to the eye.

1. It is for this reason that the motion of the heavenly bodies is invisible, notwithstanding their immense velocity.

2. The real velocity of a body in motion ro nd a point, depends on the space comprehended in a degree. The more distant the moving body from the centre, or, in other words, the larger the circle which it has to describe, the larger will be the degree.

Fig. 106.



3. In Fig. 106, if the man at A, and the man at B, both start together, it is manifest that A must move more rapidly than B, to arrive at C at the same time that B reaches D; because the arc A C is the arc of a larger circle than the arc B D. But to the eye at E, the velocity of both appears to be the same, because both are seen under the same angle of vision.

216. There are three kinds of mirrors,* namely, the plain, the concave, and the convex mirror.

Plain mirrors are those which have a flat surface, such as a common looking-glass; and they neither

* A mirror is a smooth and polished surface, that forms images by the reflection of the rays of light. Mirrors (or looking-glasses) are made of glass, with the back covered with an amalgam, or mixture of mercury and tinfoil. It is the smooth and bright surface of the mercury that reflects the rays, the glass acting only as a transparent case, or covering, through which the rays find an easy passage. Some of the rays are absorbed in their passage through the glass, because the purest glass is not free from imperfections. For this reason, the best mirrors are made of fine and highly-polished steel.

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215. When is the motion of a body invisible? Why is the motion of the heavenly bodies invisible? Upon what does the real velocity of a body, in motion round a point, depend? Explain Fig. 106. Why does the velocity of both, to an eye at E, appear to be the same?

216. How many kinds of mirrors are there? What are plain mirrors? Do they magnify or diminish the object?

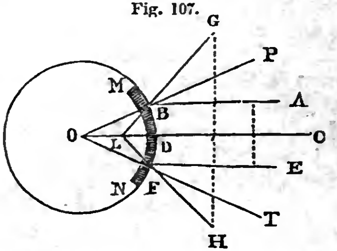
magnify nor diminish the image of objects reflected from them.

A convex mirror is a portion of the external surface of a sphere. Convex mirrors have therefore a convex surface.

A concave mirror is a portion of the inner surface ci a hollow sphere. Concave mirrors have therefore a concave surface.

In Fig. 107, M N represents both a convex and a concave mirror. They are both a portion of a sphere of which O is the centre. The outer part of M N is a convex, and the inner part is a concave mirror. Let AB, CD, EF, represent rays falling on the convex mirror M N. As the three rays are parallel, they would all be perpendicular to a plane or flat mirror; but *no ray can fall perpendicularly on a concave or convex mirror, which is not directed towards the centre of the sphere of which the mirror is a portion.* For this reason the ray C D is perpendicular to the mirror; while the other rays A B and E F fall obliquely upon it. The middle ray therefore falling perpendicularly on the mirror, will be reflected back in the same line, while the two other rays falling obliquely will be reflectea obliquely; namely, the ray A B will be reflected to G, and the ray E F to H, and the angles of incidence A B P and E F T will be equal to the angles of reflection P B G and T F H, and since *we see objects in the direction of the reflected rays,* we shall see the image at L, which is the point at which the reflected rays if continued through the mirror would unite and form the image. This point is equally distant from the surface, and the centre of the sphere, and is called the imaginary focus of the mirror. It is called the *imaginary* focus, because the rays do

Fig. 107.



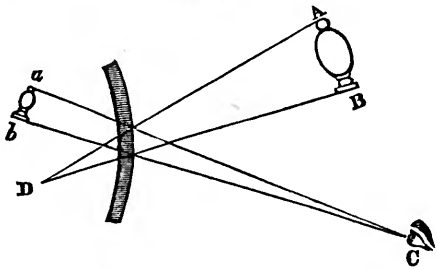
What are convex mirrors? What part of a sphere is a convex mir-.or? What are concave mirrors? What part of a sphere is a concave mirror? In Fig. 107, which part of the sphere represents a convex mirror? Which part a concave mirror? Explain the figure.

not really unite at that point, but only appear to do so; for the rays do not pass through the mirror, since they are reflected by it.

217. The image of an object reflected from a convex mirror is smaller than the object.

This is owing to the divergence of the reflected rays. *A convex mirror converts, by reflection, parallel rays into divergent rays; rays that fall upon the mirror divergent, are rendered still more divergent* by reflection, and convergent rays are reflected either parallel, or less convergent. If, then, an object, A B, be placed before any part of a convex mirror, the two rays A and B proceeding from the extremities, falling convergent on the mirror, will be reflected less convergent, and will not come to a focus until they arrive at C; then an eye placed in the direction of the reflected rays will see the image formed in (or rather behind) the mirror at *a b*; and as the image is seen under a smaller angle than the object, it will appear smaller than the object.

Fig. 108.



218. The true focus of a concave mirror is a point equally distant from the centre and the surface of the sphere, of which the mirror is a portion.

219. When an object is further from the concave mirror than its focus, the image will be inverted; but when the object is between the mirror and its focus,

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217. How does the image of an object reflected from a convex mirror compare with the object? Give the illustration.

218. What is the focus of a concave mirror?

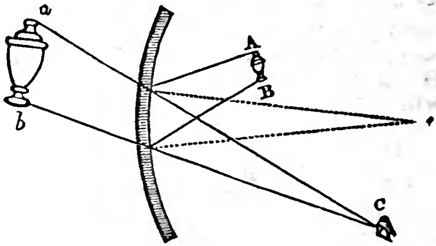
219. When an object is further from the concave mirror than the focus, how will the image appear? When the object is between the mirror and the focus?

the image will be upright, and grow larger in proportion as the object is placed nearer to the mirror.*

220. The image reflected by a concave mirror is larger than the object, when the object is placed between the mirror and its focus.†

1. This is owing to the convergent property of the concave mirror. If the object A B be placed between the concave mirror and its focus *f*, the rays A and B from its extremities will fall divergent on the mirror, and, on being reflected, become less divergent, as if they proceeded from C. To an eye placed in that situation, namely, at

Fig. 109.



* Concave mirrors have the peculiar property of forming images in the air. The mirror and the object being concealed behind a screen, or a wall, and the object being strongly illuminated, the rays from the object fall upon the mirror, and are reflected by it through an opening in the screen or wall, forming an image in the air. Showmen have availed themselves of this property of concave mirrors, in producing the appearance of apparitions, which have terrified the young and the ignorant. These images have been presented with great distiuctness and beauty, by raising a fine transparent cloud of blue smoke, by means of a chafing-dish, around the focus of a large concave mirror.

† 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.

1st. In the first case, the rays of light diverging after reflection, but in a

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How must the object be placed that the image may appear upright? And as the object is removed towards the mirror?

220 If the object be placed between the mirror and the focus how does the image compare with the object?

C, the image will appear magnified behind the mirror, at *a b*, since it is seen under a larger angle than the object.

2. The following facts result from the operation of the law already stated as the fundamental law of Catoptrics, namely, that the angles of incidence and reflection are always equal.

3. In estimating these angles, it must be recollected, that no line is perpendicular to a convex or concave mirror, which will not, when sufficiently prolonged, pass through the centre of the sphere of which the mirror is a portion.

4. The truth of these statements may be illustrated by simple drawings; always recollecting, in drawing the figures, to make the angles of incidence and reflection equal. The whole may also be shown by the simple experiment of placing the flame of a candle in various positions, before both convex and concave mirrors.

FACTS WITH REGARD TO CONVEX MIRRORS.

1. Parallel rays reflected from a CONVEX surface, are made to diverge.

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.

2d. When the object is between the principal focus and the centre of the mirror, the apparent image will be in front of the mirror, and beyond the centre, 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 the retreat of the object, the image will still be inverted, 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 vision, iust as happens when objects are viewed too near with the naked eye.

3d. 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. The more distant the object is from the centre, the less will be its image; but the image and object will coincide when the latter is stationed exactly at the centre.

What peculiar properties have concave mirrors? What facts are stated with regard to convex mirrors, as resulting from the fundamental law of Catoptrics?

2. Diverging rays reflected from a CONVEX surface, are made more diverging.

3. When converging rays tend towards the focus of parallel rays, they will become parallel when reflected from a CONVEX surface.

4. When converging rays tend to a point nearer the surface than the focus, they will converge less when reflected from a CONVEX surface.

5. If converging rays tend to a point between the focus and the centre, they will diverge as from a point on the other side of the centre, farther from it than the point towards which they converged.

6. If converging rays tend to a point beyond the centre, they will diverge as from a point on the contrary side of the centre, nearer to it than the point towards which they converged.

7. If converging rays tend to the centre, when reflected, they will proceed in a direction as far from the centre.

FACTS WITH REGARD TO CONCAVE MIRRORS.

1. Parallel rays, reflected from a CONCAVE surface, are made converging.

2. Converging rays, falling upon a CONCAVE surface, are made to converge more.

3. Diverging rays, falling upon a CONCAVE surface, if they diverge from the focus of parallel rays, become parallel.

4. If from a point nearer to the surface than that focus, they diverge less than before reflection.

5. If from a point between that focus and the centre, they

What is said of parallel rays? What is said of diverging rays? What is said of converging rays, when they tend towards the focus of parallel rays? What is said of converging rays, when they tend to a point nearer the surface than the focus? What is said of converging rays, when they tend to a point between the focus and the centre? What is said of converging rays, when they tend to a point beyond the centre? What is said of converging rays, when they tend to the centre?

What is said with regard to parallel rays, when reflected from a concave surface? What is said of converging rays? What is said of diverging rays, if they diverge from a focus of parallel rays? What, if from a point nearer to the surface than that focus?

converge, after reflection, to some point on the contrary side of the centre, and farther from the centre than the point from which they diverged.

6. If from a point beyond the centre, the reflected rays will converge to a point on the contrary side, but nearer to it than the point from which they diverged.

7. If from the centre, they will be reflected thither again.*

REFRACTION OF LIGHT.

221. That part of the science of Optics which treats of refracted light is called Dioptrics.

222. By the refraction† of light is meant its being turned or bent from its course; and this always takes place when it passes *obliquely* from one medium to another.

223. By a medium,‡ in Optics, is meant any substance through which light can pass. Thus, air, glass, water, and other fluids, are media.

* Concave mirrors, by the property which they possess of causing parallel rays to converge to a focus, are sometimes used as burning-glasses. M. Dufay made a concave mirror of plaster of Paris, gilt and burnished, 20 inches in diameter, with which he set fire to tinder at the distance of 50 feet. But the most remarkable thing of the kind on record, is the compound mirror constructed by Buffon. He arranged 168 small plane mirrors in such a manner as to reflect radiant light and heat to the same focus, like one large concave mirror. With this apparatus, 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.

† The power of being refracted is called *refrangibility*.

‡ The plural number of this word is *media*, although *mediums* is sometimes used. A medium is called dense or rare, in optics, according to its refractive power, and not according to its specific gravity. Thus, alcohol, and many of the essential oils, although of less specific gravity than water,

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What, if from a point between that focus and the centre? If from a point beyond the centre? If from the centre?

221. What is Dioptrics?

222. What is meant by the refraction of light? When does this take place?

223. What is a medium, in Optics? Give some examples of media

Note. In what proportion is a medium dense or rare?

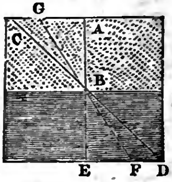
224. There are three fundamental laws of Dioptrics, on which all its phenomena depend, namely:

1st. When light passes from one medium to another, in a direction perpendicular to the surface, it continues on in a straight line without altering its course.

2d. When light passes in an oblique direction, from a *rarer* to a *denser* medium, it will be turned from its course, and proceed through the denser medium *less* obliquely, and in a line nearer to a perpendicular to its surface.

3d. When light passes from a denser to a rarer medium, it passes through the rarer medium in a more oblique direction, and in a line further from a perpendicular to the surface of the denser medium.

Fig. 110.



1. In Fig. 110, the line A B represents a ray of light passing from air into water, in a perpendicular direction. According to the first law, stated above, it will continue on in the same line through the denser medium to E. If the ray were to pass upward through the denser medium, the water, in the same perpendicular direction to the air, by the same law it would also continue on in the same straight line to A.

2. But if the ray proceed from a rarer to a denser medium, in an oblique direction, as from C to B, when it enters the denser medium it will not continue on in the same straight line to D, but, by the second law, stated above, it will be refracted or bent out of its course, and proceed in a less oblique direction to F, which is nearer the perpendicular A B E than D is.

3. Again, if the ray proceed from the denser medium, the

have a greater refracting power, and are, therefore, called denser media than water. In the following list, the various substances are enumerated in the order of their refractive power, or, in other words, in the order of their density, as media; the last-mentioned being the densest, and the first the rarest, namely: air, ether, ice, water, alcohol, alum, olive oil, oil of turpentine, amber, quartz, glass, melted sulphur, diamond.

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224. What are the three fundamental laws of Dioptrics? Illustrate the first law by the line A B, in Fig. 110. Illustrate the second law by the line C B. Illustrate the third law by the line F B.

water, to the rarer medium, the air, namely, from F to B,—instead of pursuing its straight course to G, it will be refracted according to the third law above stated, and proceed in a more oblique direction to C, which is further from the perpendicular E B A than G is.

4. The refraction is more or less in all cases in proportion as the rays fall more or less obliquely on the refracting surface.

5. From what has now been stated, with regard to refraction, it will be seen that many interesting facts may be explained. Thus, an oar or a stick, when partly immersed in water, appears bent, because we see one part in one medium, and the other in another medium: the part which is in the water appears higher than it really is, on account of the refraction of the denser medium.

6. For the same reason, when we look *obliquely* upon a body of water it appears more shallow than it really is. But when we look *perpendicularly* downwards, we are liable to no such deception, because there will be no refraction.

7. Let a piece of money be put into a cup or a bowl, and the cup and the eye be placed in such a position that the side of the cup will just hide the money from the sight; then keeping the eye directed to the same spot, let the cup be filled with water,—the money will become distinctly visible.

225. The refraction of light prevents our seeing the heavenly bodies in their real situation.*

* There is another reason, also, why we do not see the heavenly bodies in their true situation. Light, though it move with great velocity, is about eight and a half minutes in its passage from the sun to the earth, so that when the rays reach us, the sun has quitted the spot he occupied on their departure; yet we see him in the direction of those rays, and, consequently, in a situation which he abandoned eight minutes and a half before. The refraction of light does not affect the appearance of the heavenly bodies when they are vertical, that is, directly over our heads, because the rays then pass vertically, a direction incompatible with refraction.

In what proportion does the refraction increase or diminish? Why does an oar or a stick, when partly immersed in water, appear bent? Why does the part which is in the water appear higher than it really is? Why does a body of water, when viewed obliquely, appear more shallow than it really is? In what direction can we look so as to cause no refraction? What experiment is here related?

225. Why do we not see the heavenly bodies in their real situation?

The light which they send to us is refracted in passing through the atmosphere, and we see the sun, the stars, &c., in the direction of the refracted ray. In consequence of this atmospheric refraction the sun sheds his light upon 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 otherwise 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.

226. When a ray of light passes from one medium to another, and through that into the first again, if the two refractions be equal, and in opposite directions, no sensible effect will be produced.

This explains the reason why the refractive power of flat window-glass produces no effect on objects seen through it. The rays suffer two refractions, which, being in contrary directions, produce the same effect as if no refraction had taken place.

227. A lens is a glass, which, owing to its peculiar form, causes the rays of light to converge to a focus, or disperses them according to the laws of refraction.

It may here also be remarked, that it is entirely owing to the reflection of the atmosphere that the heavens appear bright in the daytime. If the atmosphere had no reflective power, only that part would be luminous in which the sun is placed; and on turning our back to the sun, the whole heavens would appear as dark as in the night; we should have no twilight, but a sudden transition from the brightest sunshine to darkness, immediately upon the setting of the sun.

In what direction do we see them? What causes twilight? Upon what does the duration of twilight depend? What other reason is given, in the note, why we do not see the heavenly bodies in their true situation? When does the refraction of light not affect the appearance of the heavenly bodies? Why do the heavens appear bright in the daytime?

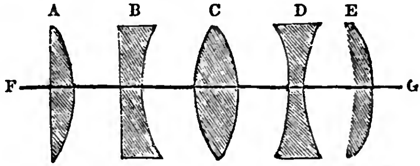
226. What effect is produced when a ray of light passes from one medium to another, and through that into the first again? Why does the refractive power of flat window-glass produce no effect on objects seen through it?

227. What is a lens?

There are various kinds of lenses, named according to their focus; but they are all to be considered as portions of the internal or external surface of a sphere.

1. A single convex lens has one side flat and the other convex; as A in Fig. 111.

Fig. 111.



2. A single concave lens is flat on one side and concave on the other, as B in Fig. 111.

3. A double convex lens is convex on both sides, as C, Fig. 111.

4. A double concave lens is concave on both sides, as D, Fig. 111.

5. A meniscus* is convex on one side and concave on the other, as E, Fig. 111.

6. The axis of a lens is a line passing through the centre; thus, F G, Fig. 111, is the axis of all the five lenses.

228. The peculiar form of the various kinds of lenses causes the light which passes through them to be refracted from its course, according to the laws of Dioptrics.

* The word *meniscus* is derived from the Greek language, and means literally *a little moon.* This term is applied to a *concavo-convex* lens, from its similarity to a moon in its early appearance. To this kind of lens the term *periscopic* has recently been applied, from the Greek language, meaning literally *viewing on all sides.* When the concave and convex sides of periscopic glasses are even or parallel, they act as plane glasses; but when the sides are unequal, or not parallel, they will act as concave or convex lenses, according as the concavity or the convexity is the greater.

How are all lenses to be considered? What is a single convex lens? What part of Fig. 111 represents a single convex lens? What is a single concave lens? What part of Fig. 111 represents a single concave lens? What is a double convex lens? What part of Fig. 111 represents a double convex lens? What is a double concave lens? What part of Fig. 111 represents a double concave lens? What is a meniscus? What part of Fig. 111 represents a meniscus? What is the axis of a lens? What line in Fig. 111, represents the axis of all the five lenses?

228. What is stated with regard to the form of the lenses?

It will be remembered that, according to these laws, light, in passing from a rarer to a denser medium is *refracted* towards the perpendicular; and, on the contrary, that in passing from a denser to a rarer medium, it is refracted further from the perpendicular. In order to estimate the effect of a lens, we must consider the situation of the perpendicular, with respect to the surface of the lens. Now, a perpendicular, to any convex or concave surface, must always, when prolonged, pass through the centre of sphericity; that is, in a lens, the centre of the sphere of which the lens is a portion. By an attentive observation, therefore, of the laws above stated, and of the situation of the perpendicular on *each* side of the lens, it will be found *in general*,—

1. *That convex lenses collect the rays into a focus, and magnify objects at a certain distance.*
2. *That concave lenses disperse the rays, and diminish objects seen through them.*

229. The focal distance of a lens is the distance from the middle of the glass to the focus. This, in a single convex lens, is equal to the diameter of the sphere of which the lens is a portion; and in a double convex lens is equal to the radius of a sphere of which the lens is a portion.

230. When parallel rays* fall on a convex lens, those only which fall in the direction of the axis of the lens are perpendicular to its surface, and those only will continue on in a straight line through the lens. The other rays, falling obliquely, are refracted towards the axis and will meet in a focus.

* The rays of the sun are considered parallel at the surface of the earth.

How is light refracted in passing from a rarer to a denser medium? How, in passing from a denser to a rarer? What must be considered in estimating the effect of lenses? Through what must a perpendicular, to any convex or concave surface, always, when prolonged, pass? What is stated with regard to convex lenses? What, with regard to concave lenses?

229. What is the focal distance of a lens? To what is this equal in a single convex lens? To what is it equal in a double convex lens?

230. When parallel rays fall on a convex lens, which one is perpendicular to its surface? How are the other rays, falling obliquely, refracted?

It is this property of a convex lens which gives it its power as a burning-glass. All the parallel rays of the sun which pass through the glass, are collected together in the focus; and, consequently, *the heat at the focus is to the common heat of the sun, as the area of the glass is to the area of the focus.* Thus, if a lens, four inches in diameter, collect the sun's rays into a focus, at the distance of twelve inches, the image will not be more than one-tenth of an inch in diameter; the surface of this little circle is 1600 times less than the surface of the lens, and consequently, the heat will be 1600 times greater at the focus than at the lens.*

231. The following effects result from the laws of refraction.

FACTS WITH REGARD TO CONVEX SURFACES.

1. Parallel rays passing out of a rarer into a denser medium, through a CONVEX surface, will become converging.

2. Diverging rays will be made to diverge less, to become parallel, or to converge, according to the degree of divergency before refraction, or the convexity of the surface.

3. Converging rays, towards the centre of convexity, will suffer no refraction.

4. Rays converging to a point beyond the centre of convexity, will be made more converging.

* The following effects were produced by a large lens, or burning-glass, two feet in diameter, made at Leipsic in 1691. Pieces of lead and tin were instantly melted; a plate of iron was soon rendered red-hot, and afterwards fused, or melted; and a burnt brick was converted into yellow glass. A double convex lens, three feet in diameter, and weighing 212 pounds, made by Mr. Parker, in England, melted the most refractory substances. Cornelian was fused in 75 seconds, a crystal pebble in 6 seconds, and a piece of white agate in 30 seconds. This lens was presented by the king of England to the emperor of China.

What property of a convex lens gives it its power as a burning-glass? Where are all the parallel rays of the sun, which pass through the glass, collected? How does the heat at the focus compare with the common heat of the sun? What is related in the note with regard to the effects of lenses produced by burning-glasses?

231. What is the first effect related as resulting from the laws of refraction with regard to convex surfaces? What is said of diverging rays? What is said of rays converging towards the centre of convexity? What of rays converging to a point beyond the centre of convexity?

5. Converging rays towards a point nearer the surface than the centre of convexity, will be made less converging by refraction.

[When the rays proceed out of a *denser* into a *rarer* medium, the reverse occurs in each case.]

FACTS WITH REGARD TO CONCAVE SURFACES.

1. Parallel rays, proceeding out of a rarer into a denser medium, through a CONCAVE surface, are made to diverge.

2. Diverging rays are made to diverge more,—to suffer no refraction,—or to diverge less. according as they proceed from a point beyond the centre, from the centre, or between the centre and the surface.

3. Converging rays are made less converging, parallel, or diverging, according to their degree of convergency before refraction.*

[When the rays proceed out of a denser into a rarer medium, the reverse takes place in each case.]

232. Double convex, and double concave glasses, or lenses, are used in spectacles, to remedy the defects of the eye; the former, when by age it becomes too flat, or loses a portion of its roundness; the latter, when by

* The above eight principles are all the necessary consequence of the operation of the three laws mentioned as the fundamental laws of Dioptrics. The reason that so many different principles are produced by the operation of those laws, is, that the perpendiculars to a convex or concave surface are constantly varying, so that no two are parallel. But in flat surfaces the perpendiculars are parallel; and one invariable result is produced by the rays when passing from a rarer to a denser, or from a denser to a rarer medium, having a flat surface.

What of rays converging to a point nearer the surface than the centre of convexity? When the rays proceed out of a denser into a rarer medium, what occurs?

What is stated of parallel rays, proceeding from a rarer into a denser medium, through a concave surface? What is said of diverging rays? What is said of converging rays? Of what are the above eight principles the necessary consequence? What is the reason that so many different principles are produced by the operation of these laws?

232. For what are double convex and concave glasses, or lenses, used in spectacles?

any other cause it assumes too round a form, as in the case of short-sighted (or, as they are sometimes called, near-sighted) persons. Convex glasses are used when the eye is too flat, and concave glasses when it is too round.*

THE EYE.

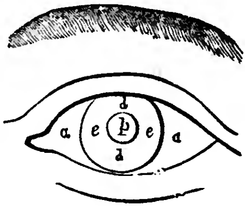
233. The eye is composed of a number of coats, or coverings, within which are enclosed a lens, and certain humors, in the shape, and performing the office of con vex lenses.

1. The different parts of the eye, are:

1. The Cornea.	6. The Vitreous Humor.
2. The Iris.	7. The Retina.
3. The Pupil.	8. The Choroid.
4. The Aqueous Humor.	9. The Sclerotica.
5. The Crystalline Lens.	10. The Optic Nerve.

2. Fig. 112 represents a front view of the eye, in which *a a* represents the Cornea, or, as it is commonly called, the white of the eye; *e e* is the Iris,† having a circular opening in the centre, called the pupil, *p*, which contracts in a strong light, and expands in a faint light, and thus regulates the quantity which is admitted to the tender parts in the interior of the eye.

Fig. 112.



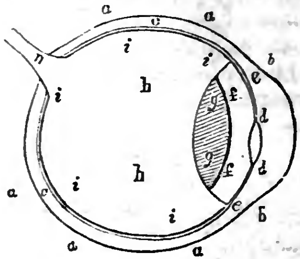
* These lenses or glasses are generally numbered, by opticians, according to their degree of convexity or concavity; so that by knowing the number that fits the eye, the purchaser can generally be accommodated, without the trouble of trying many glasses.

† It is the iris which gives the peculiar color to the eye.

What glasses are used when the eye is too flat? What are used when the eye is too round?

233. Of what is the eye composed? What are the different parts of the eye? First? Second? Third? Fourth? Fifth? Sixth? Seventh? Eighth? Ninth? Tenth? What does Fig. 112 represent? Explain the figure.

Fig. 113.



3. Fig. 113 represents a side view of the eye, laid open, in which *b b* represents the cornea, *e e* the iris, *d d* the pupil, *f f* the aqueous humor, *g g* the crystalline lens, *h h* the vitreous humor, *i i i i i* the retina, *c c* the choroid, *a a a a a* the sclerotica, and *n* the optic nerve.

4. The cornea forms the anterior portion of the eye. It is set in the sclerotica in the same manner as the crystal of a watch is set in the case. Its degree of convexity varies in different individuals and in different periods of life. As it covers the pupil and the iris, it protects them from injury. Its principal office is to cause the light which reaches the eye to converge to the axis. Part of the light, however, is reflected by its finely polished surface, and causes the brilliancy of the eye.

5. The iris is so named from its being of different colors. It is a kind of circular curtain, placed in the front of the eye to regulate the quantity of light passing to the back part of the eye. It has a circular opening in the centre, which it involuntarily enlarges or diminishes.

6. The pupil is merely the opening in the iris, through which the light passes to the lens behind. It is always circular in the human eye, but in quadrupeds it is of different shape. When the pupil is expanded to its utmost extent, it is capable of admitting ten times the quantity of light that it does when most contracted.* In cats and other animals, which are said

* When we come from a dark place into a strong light, our eyes suffer pain, because the pupil being expanded, admits a larger quantity of light to rush in, before it has had time to contract. And when we go from a strong light into a faint one, we at first imagine ourselves in darkness, because the pupil is then contracted, and does not *instantly* expand.

What does Fig. 113 represent? Explain the figure. What part of the eye does the cornea form? Is its degree of convexity the same in all persons and all periods of life? What is its principal office? From what does the iris take its name? What is the use of the iris? What is the pupil? What is its form in the human eye? How much more light is the pupil capable of admitting, when expanded to its utmost extent, than when most contracted?

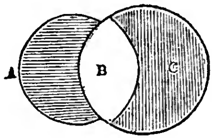
to see in the dark, the power of dilatation and contraction is much greater; it is computed, that their pupils may receive one hundred times more light at one time than at another. That light only, which passes the pupil, can be of use in vision; that which falls on the iris being reflected, returns through the cornea, and exhibits the color of the iris.

7. The aqueous humor is a fluid, as clear as the purest water. In shape it resembles a meniscus, and, being situated between the cornea and the crystalline lens, it assists in collecting and transmitting the rays of light from external objects to that lens.

8. The crystalline lens is a transparent body, in the form of a double convex lens, placed between the aqueous and vitreous humors. Its office is not only to collect the rays to a focus, on the retina, but also to increase the intensity of the light which is directed to the back part of the eye.

9. The vitreous humor (so called from its resemblance to melted glass) is a perfectly transparent mass, occupying the globe of the eye. Its shape is like a meniscus, the convexity of which greatly exceeds the concavity.

Fig. 114.



10. In Fig. 114 the shape of the aqueous and vitreous humors and the crystalline lens is presented. *a* is the aqueous humor, which is a meniscus, *b* the crystalline lens, which is a double convex lens, and *c* the vitreous humor, which is, also, a meniscus, whose concavity has a smaller radius than its convexity.

11. The retina is the seat of vision. The rays of light being refracted in their passage by the other parts of the eye, are brought to a focus in the retina, where an inverted image of the object is represented.

12. The choroid is the inner coat or covering of the eye. Its outer and inner surface is covered with a substance called the

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What is said of those animals which are said to see in the dark? What light, only, is of use in vision? What becomes of the light which falls on the iris? What is the aqueous humor? What is its form? Of what use is it? What is the crystalline lens? What is its office? What is the vitreous humor? Why do persons sometimes experience pain when passing from a dark place into strong light? What is the shape of the vitreous humor? Explain Fig 114. What is the retina? What is the choroid *pigmentum nigrum,* (or black paint.) Its office is, apparently, to absorb the rays of light immediately after they have fallen on the retina. It is the opinion of some philosophers, that it is the choroid and not the retina, which conveys the sensation produced by rays of light to the brain.

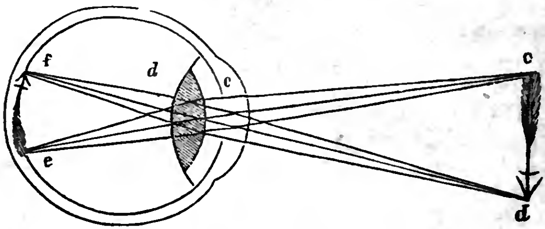
13. The sclerotica is the outer coat of the eye. It derives its name from its hardness. Its office is to preserve the globular figure of the eye, and defend its more delicate internal structure. To the sclerotica are attached the muscles which move the eye. It receives the cornea, which is inserted in it somewhat like a watch-glass in its case. It is pierced by the optic nerve, which, passing through it, expands over the inner surface of the choroid, and thus forms the retina.

14. The optic nerve is the organ which carries the impressions made by the rays of light, (whether by the medium of the retina, or the choroid,) to the brain, and thus produces the sensation of sight.*

234. The eye is a natural *camera obscura*,† and the images of all objects seen by the eye are represented on the retina, in the same manner as the forms of external objects are delineated in that instrument.

1. Fig. 115 represents only those parts of the eye which are most essential for the explanation of the phenomena of

Fig. 115.



* For the above description of the eye and its parts, the author is mainly indebted to Paxton's Introduction to the Study of Anatomy, edited by Dr. Lewis of this city.

† The camera obscura is explained in a note on page 157.

By what is its outer and inner surface covered? What is its office? What is the opinion of some philosophers with regard to the choroid? What is the sclerotica? From what does it derive its name? What is its office? What are attached to the sclerotica? What is the optic nerve?

vision. The image is formed thus. The rays from the object *c d*, diverging towards the eye, enter the cornea *c*, and cross one another in their passage through the crystalline lens *d*, by which they are made to converge on the retina, where they form the inverted* image, *f e*.

2. The convexity of the crystalline humor is increased or

* Although the image is inverted on the retina, we see objects *erect*, because all the images formed on the retina have the same relative position which the objects themselves have; and as the rays all cross each other, the eye is directed upwards, to receive the rays which proceed from the upper part of an object, and downwards, to receive those which proceed from the lower part.

A distinct image is also formed on the retina of each eye; but as the optic nerves of the two eyes unite, or cross each other before they reach the brain, the impressions received by the two nerves are united, so that only one idea is excited, and objects are seen single. Although an object may be distinctly seen with only one eye, it has been calculated that the use of *both* eyes makes a difference of about one-twelfth. From the description now given of the eye, it may be seen what are the defects which are remedied by the use of concave and convex lenses, and how the use of these lenses remedies them. When the crystalline humor of the eye is too round, the rays of light which enter the eye converge to a focus *before* they reach the retina, and, therefore, the image will not be distinct; and when the crystalline humor is too *flat*, (as is often the case with old persons,) the rays will not converge on the retina, but tend to a point beyond it. A convex glass, by assisting the convergency of the crystalline lens, brings the rays to a focus on the retina, and produces distinct vision.

The eye is also subject to imperfection by reason of the humors losing their transparency, either by age or disease. For these imperfections no glasses offer a remedy without the aid of surgical skill. The operation of couching and removing cataracts from the eye, consists in making a puncture or incision through which the diseased part may escape. Its office is then supplied by a lens. If, however, the operator, by accident or want of skill, permit the vitreous humor to escape, the globe of the eye immediately diminishes in size, and total blindness is the inevitable result.

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234. What philosophical instrument does the eye resemble in its construction? Explain Fig. 115. *Note.* Why do the objects appear erect when the images are inverted? Why do we see only one image when an image is formed on both eyes? What are the defects which are remedied by the use of concave and convex lenses? In what other way is the eye subject to imperfection? Is there any remedy for this?

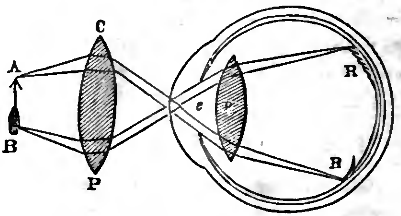
diminished by means of two muscles, to which it is attached. By this means the focus of the rays which pass through it, constantly falls on the retina; and an equally distinct image is formed, both of distant objects and those which are near.

235. A single microscope consists simply of a convex lens, commonly called a magnifying-glass; in the focus of which the object is placed, and through which it is viewed.

1. By means of a microscope the rays of light from an object are caused to diverge less; so that when they enter the pupil of the eye, they fall parallel on the crystalline lens, by which they are refracted to a focus on the retina.

2. Fig. 116 represents a convex lens, or single microscope, C P. The diverging rays from the object A B are refracted in their passage through the lens C P, and made to fall parallel on the crystalline lens, by which they are refracted to a focus on the retina R R; and the image is thus magnified, because the divergent rays are collected by the lens and carried to the retina.

Fig. 116.



3. Those lenses or microscopes which have the shortest focus, have the greatest magnifying power; and those which are the most bulging or convex, have the shortest focus. Lenses are made small because a reduction in size is necessary to an increase of curvature.

236. A double microscope consists of two convex lenses, by one of which a magnified image is formed,

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By what is the convexity of the crystalline humor increased or diminished? What is effected by this means?

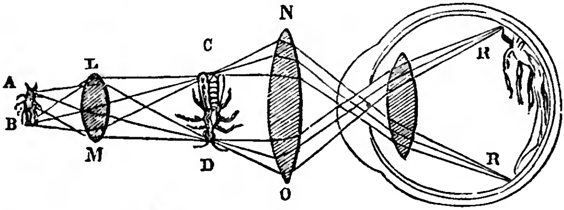
235. What is a single microscope? What is the use of this microscope? What figure represents a microscope? Explain the figure. What lenses have the greatest magnifying power? What lenses have the shortest focus?

236. Of what does a double microscope consist?

and by the other this image is carried to the retina of the eye.

Fig. 117 represents the effect produced by the lenses of a double microscope. The rays which diverge from the object A B are collected by the lens L M, (called the object-glass, because it is nearest to the object,) and form an inverted magni-

Fig. 117.



fied image at C D. The rays which diverge from this image are collected by the lens N O, (called the eye-glass, because it is nearest to the eye,) which acts on the principle of the single microscope, and forms a still more magnified image on the retina R R.

237. The solar microscope, is a microscope with a mirror attached to it, upon a moveable joint, which can be so adjusted as to receive the sun's rays and reflect them upon the object. It consists of a tube, a mirror or looking-glass, and two convex lenses. The sun's rays are reflected by the mirror through the tube upon the object; the image of which is thrown upon a white screen, placed at a distance to receive it.

1. The microscope, as above described, is used for viewing transparent objects only. When opaque objects are to be viewed, a mirror is used to reflect the light on the side of the

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What is the use of these two lenses? What does Fig. 117 represent? Explain the figure.

237. What is the solar microscope? Of what does it consist? By what, in this microscope, are the sun's rays reflected, and upon what? For viewing what objects, only, is the microscope, above described, used? How do those microscopes, used for viewing opaque objects, differ from these?

object; the image is then formed by light reflected *from* the object, instead of being transmitted through it.

2. The magnifying power of a single microscope is ascertained by dividing the least distance at which an object can be distinctly seen by the naked eye, by the focal distance of the lens. This, in common eyes, is about 7 inches. Thus, if the focal distance of a lens be only $\frac{1}{4}$ of an inch, then the *diameter* of an object will be magnified 28 times, (because 7, divided by $\frac{1}{4}$, is the same as multiplying 7 by 4,) and the *surface* will be magnified 784 times.

3. The magnifying power of the compound microscope is found in a similar manner, by ascertaining the magnifying power, first of one lens, and then of the other.

4. The magnifying power of the solar microscope is in proportion as the distance of the image, from the object-glass, is greater than that of the object itself from it. Thus, if the distance of the object from the object-glass be $\frac{1}{4}$ of an inch, and the distance of the image, or picture, on the screen, be ten feet, or 120 inches, the object will be magnified in length 480 times, or, in surface, 230,000 times.*

238. The magic lantern is an instrument constructed on the principle of the solar microscope, but the light is supplied by a lamp instead of the sun.

1. The objects to be viewed by the magic lantern are generally painted with transparent colors, on glass slides, which are received into an opening in the front of the lantern. The light from the lamp, in the lantern, passes through them, and carries the pictures, painted on the slides, through the lenses, by means of which a magnified image is thrown upon the wall, on a white surface prepared to receive it.

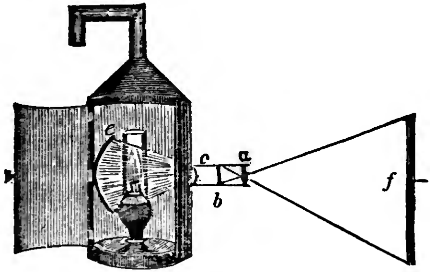
* A lens may be caused to magnify or to diminish an object. If the object be placed at a distance from the focus of a lens, and the image be formed in or near the focus, the image will be diminished; but if the object be placed near the focus, the image will be magnified.

How is the image then formed? How is the magnifying power of a single microscope ascertained? Illustrate this. How is the magnifying of the compound microscope ascertained? In what proportion is the magnifying power of the solar microscope? Illustrate this. *Note.* How may a lens be made to magnify or diminish an object?

238. What is the magic lantern? How are objects, viewed by the magic lantern, generally represented?

2. Fig. 118 represents the magic lantern. The rays of light from the lamp are received upon the concave mirror *e*, and re-

Fig. 118.



flected to the convex lens *c*, which is called the condensing lens, because it concentrates a large quantity of light upon the object painted on the slide, inserted at *b*. The rays from the illuminated object at *b*, are carried divergent through the lens *a*, forming an image on the screen at *f*. The image will increase or diminish in size, in proportion to the distance of the screen from the lens *a*.

239. A telescope is an instrument for viewing distant objects.

There are two kinds of telescopes, namely, the refracting telescope and the reflecting telescope.

A refracting telescope is one in which the object itself is viewed, through the medium of a number of lenses.

A reflecting telescope is one in which the image of the object is reflected from a concave mirror, within the tube of the telescope, and viewed through a number of lenses.*

* The image of the object seen through a refracting telescope is never so clear and perfect as that obtained by the reflecting telescope ; because

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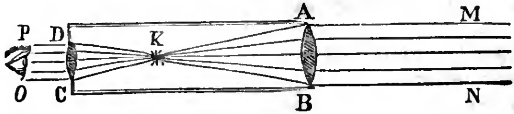
What figure represents a magic lantern? Explain the figure. In what proportion will the size of the image increase or diminish?

239. What is a telescope? How many kinds of telescopes are there? What are they? What is a refracting telescope? What is a reflecting telescope? *Note.* Why is the image of an object, seen through a refracting telescope, less clear and perfect than when seen through a reflecting telescope?

1. There are two kinds of refracting telescopes, called the astronomical telescope, or night-glass, and the terrestrial telescope, or day-glass.* In the former, or night-glass, there are but two lenses or glasses, but the object is viewed in an inverted position. As the glass is used principally for viewing the heavenly bodies, the inversion of the image produces no inconvenience. In the latter, or day-glass, two additional lenses are introduced to give the image its natural position.

2. Fig. 119 represents a night-glass, or astronomical telescope. It consists of a tube, A B C D, containing two glasses, or lenses. The lens, A B, having a longer focus, forms the object-glass; the other lens, D C, is the eye-glass. The rays

Fig. 119.



from a very distant body, as a star, and which may be considered parallel to each other, are refracted by the object-glass A B to a focus at K. The image is then seen through the eye-glass D C, magnified as many times as the focal length of the eye-glass is contained in the focal length of the object-glass. Thus, if the focal length of the eye-glass D C, be contained 100 times in that of the object-glass A B, the star will be seen magnified 100 times. It will be seen by the figure, that the image is inverted; for the ray M A, after refraction, will be seen in the direction C O, and the ray N B, in the direction D P.

3. Fig. 120 represents a day-glass or terrestrial telescope, commonly called a spy-glass. This, likewise, consists of a tube, A B H G, containing four lenses, or glasses, namely,

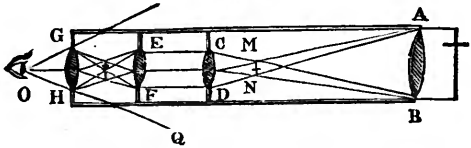
the dispersion of colors which every lens produces, in a greater or less degree, renders the image dull and indistinct, in proportion to the number of lenses employed.

* Some glasses or telescopes are marked "Night and Day." These have four glasses, two of which may be removed when the heavenly bodies are viewed.

How many kinds of refracting telescopes are there? What are they? How do they differ the one from the other? What does Fig. 119 represent? Explain the figure.

A B, C D, E F, and G H. The lens A B is the object-glass, and G H the eye-glass. The two additional eye-glasses, E F and C D, are of the same size and shape, and placed

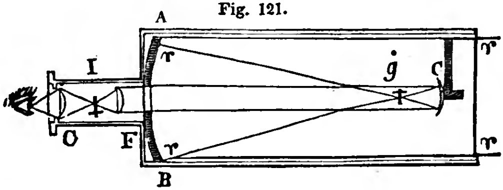
Fig. 120.



at equal distances from each other, in such a manner that the focus of the one meets that of the next lens. These two eye-glasses, E F and C D, are introduced for the purpose of collecting the rays proceeding from the inverted image M N, into a new upright image, between G H and E F, and the image is then seen through the last eye-glass G H, under the angle of vision, P O Q.

4. Fig. 121 represents a reflecting telescope. This consists also of a large tube, containing two concave metallic mirrors, A B and C, with two plano-convex eye-glasses. The mirrors

Fig. 121.



are placed at a little more than the sum of their focal distance from each other. The parallel rays *r r*, coming from a distant object, are reflected to a focus *g*, by the concave mirror A B, and thus form an inverted image at *g*; the diverging rays proceeding from this image are again reflected by the small mirror C, and received by the eye-glass F, through an aperture in the middle of the mirror A B. The eye-glass F collects these reflected rays into a new image at I, and this image is seen magnified through the second eye-glass, G.

What does Fig. 120 represent? Explain the figure. What does Fig. 121 represent? Explain the figure.

5. In reflecting telescopes, mirrors are used to bring the image near the eye; and a lens, or eye-glass, is employed to magnify the image.

6. The advantage of reflecting telescopes is, that they possess greater magnifying power, and do not decompose the light.*

240. That part of the science of Optics which relates to colors is called Chromatics.

Colors do not exist in the bodies themselves, but are caused by the peculiar manner in which the light is reflected from their surfaces.

241. Light is composed of rays of different colors, which may be separated by a prism.†

242. A prism is a solid triangular, or three-sided piece of highly-polished glass, generally six or eight inches long.‡

243. The colors which enter into the composition of light are seven, namely, red, orange, yellow, green,

* Common telescopes have a defect arising from the convexity of the object-glass, which, as it is increased, has a tendency to tinge the edges of the images. To remedy this defect, *achromatic* lenses were formed by the union of a convex lens of crown glass with a concave lens of flint glass. Owing to the difference of the refracting power of these two kinds of glass, the images become *free from color* and more distinct, and hence the glasses which produce them were called *achromatic*, that is, *free from color*.

† This discovery was made by Sir Isaac Newton.

‡ A prism may be made of three pieces of plate glass, about six or eight inches long, and two or three broad, joined together at their edges, and made water-tight by putty. The ends may be fitted to a triangular piece of wood, in one of which an aperture is made by which to fill it with water, and thus to give it the appearance and the refractive power of a solid prism.

Why are mirrors used in reflecting telescopes? What is the use of the lens? What is the advantage of the reflecting telescope?

240. What is Chromatics? What causes color?

241. Of what is light composed? How can these rays be separated? *Note.* By whom was this discovery made?

242. What is a prism? *Note.* How may a prism be made?

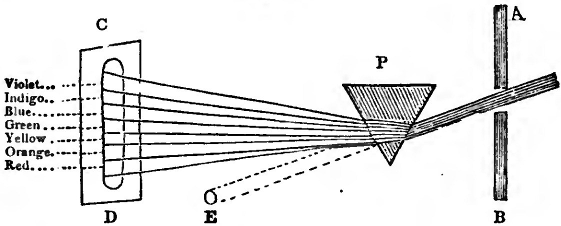
243. How many colors enter into the composition of light? What are they?

blue, indigo, and violet. Each of these has a different degree of refrangibility.

244. When light is made to pass through a prism, the different colored rays are separated, and form an image on a screen or wall, in which the colors will be arranged in the order just mentioned.

1. Fig. 122 represents rays of light passing from the aperture, in a window-shutter, A B, through the prism P. Instead

Fig. 122.



of continuing in a straight course to E, and there forming an image, they will be refracted, in their passage through the prism, and form an image on the screen, C D. But as the different colored rays have different degrees of refrangibility, those which are refracted the least will fall upon the lowest part of the screen, and those which are refracted the most will fall upon the highest part. The red rays, therefore, suffering the smallest degree of refraction, fall on the lowest part of the screen, and the remaining colors are arranged in the order of their refraction.*

* It is supposed that the red rays are refracted the least, on account of their greater momentum, and that the blue, indigo, and violet are refracted the most, because they have the least momentum. The same reason, it is supposed, will account for the red appearance of the sun, through a fog, or at rising and setting. The increased quantity of the atmosphere, which

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Do these rays all have the same degree of refrangibility?

244. What takes place when light is made to pass through a prism? Explain Fig. 122. Why do the red rays fall on the lowest part of the screen? What is supposed with regard to the red rays? What with regard to the blue, indigo, and violet rays? Why does the sun appear red through a fog?

2. If the colored rays, which have been separated by a prism, fall upon a convex lens, they will converge to a focus, and appear white. Hence, it appears, that white is not a simple color, but is produced by the union of several colors.

3. The spectrum, formed by a glass prism, being divided into 360 parts, it is found that the red occupies 45 of those parts, the orange 27, the yellow 48, the green 60, the blue 60, the indigo 40, and the violet 80.* By mixing the seven primitive colors in these proportions, a white is obtained; but, on account of the impurity of all colors, it will be of a dingy hue. If the colors were more clearly and accurately defined, the white, thus obtained, would appear more pure also. An experiment to prove what has just been said may be thus performed. Take a circular piece of board, or card, and divide it into parts, by lines drawn from the centre to the circumference. Then, having painted the seven colors in the proportions above named, cause the board to revolve rapidly around a pin or wire at the centre. The board will then appear of a white color. From this, it is inferred, that the whiteness of the sun's light arises from a due mixture of all the primary colors.

4. The colors of all bodies are either the simple colors, as

the oblique rays must traverse, and its being loaded with mists and vapors, which are usually formed at those times, prevents the other rays from reaching us.

A similar reason will account for the blue appearance of the sky. As these rays have less momentum, they cannot traverse the atmosphere so readily as the other rays, and they are, therefore, reflected back to our eyes by the atmosphere. If the atmosphere did not reflect any rays, the skies would appear perfectly black.

* Light is found to possess both heat and chemical action. The prismatic spectrum presents some remarkable phenomena with regard to these qualities; for while the red rays appear to be the seat of the maximum of heat, the violet, on the contrary, are the apparent seat of the maximum of chemical action.

Why does the sky appear of a blue color? What would be the appearance of the sky if the atmosphere did not reflect any rays? Is white a simple color? How is it produced? The spectrum formed by a prism, being divided into 360 parts, how many of these parts does the red occupy? The orange? The yellow? The green? The blue? The indigo? The violet? What are the colors of all bodies?

refracted by the prism, or such compound colors as arise from a mixture of two or more of them.*

245. The rainbow is produced by the refraction of the sun's rays in their passage through a shower of rain; each drop of which acts as a prism in separating the colored rays, as they pass through it.

This is proved by the following considerations. *First*, A rainbow is never seen except when rain is falling, and the sun shining at the same time; and that the sun and the bow are always in opposite parts of the heavens; and, *secondly*, that the same appearance may be produced artificially, by means of water thrown into the air, when the spectator is placed in a proper position, with his back to the sun; and, *thirdly*, that a similar bow is generally produced by the spray which arises from large cataracts, or waterfalls.†

246. The color of all bodies depends upon the rays which they reflect.

1. Some bodies absorb all the rays which they receive except the red rays. These bodies, therefore, appear of a red color; some reflect the green, and absorb all the others,—these will appear of a green color; and, in general, bodies appear of the color of those rays which they reflect, while they absorb all the other rays. Sometimes a body reflects a portion of the rays of several colors. The body will then appear of a compound color, composed of the various colors which it reflects. When a body reflects *all* the rays, it appears *white*,—when it absorbs all the rays, it appears black. White, then,

* From the experiments of Dr. Wollaston, it appears that the seven colors formed by the prism may be reduced to four, namely, red, green, blue, and violet; and that the other colors are produced by combinations of these.

† The Falls of Niagara afford a beautiful exemplification of the truth of this observation.

Note. What appears from the experiments of Dr. Wollaston?

245. How is the rainbow produced? How is this proved? First? Second? Third?

246. Upon what does the color of all bodies depend? Of what color do bodies generally appear? When will a body appear of a compound color? Of what color will a body appear that reflects all the rays? When will a body appear black?

is a mixture of all the primitive colors, and black is the deprivation of all color.

2. From what has now been said, it appears, that no body has a permanent or intrinsic color of its own,—but that color, as well as weight, are *accidental,* and not essential properties. All substances appear of the same color, or rather, more properly speaking, are deprived of all color, in the dark.

3. Light, from whatever source it proceeds, is of the same nature, composed of the various colored rays; and although some substances appear differently by candlelight, from what they appear by day, this result may be supposed to arise from the weakness or want of purity in artificial light.

4. *There can be no light without colors, and there can be no colors without light.*

5. That the above remarks, in relation to the colors of bodies, are true, may be proved by the following simple experiment. Place a colored body in a dark room, in a ray of light that has been refracted by a prism; the body, of whatever color it naturally is, will appear of the color of the ray in which it is placed; for, since it receives no other colored rays, it can reflect no others.*

* Although bodies, from the arrangement of their particles, have a tendency to absorb some rays, and reflect others, they are not so uniform in their arrangement as to reflect only pure rays of one color, and perfectly absorb all others; it is found, on the contrary, that a body reflects in great abundance the rays which determine its color, and the others in a greater or less degree, in proportion as they are nearer or further from its color, in the order of refrangibility. Thus, the green leaves of a rose will reflect a few of the red rays, which will give them a brown tinge. Deepness of color proceeds from a deficiency rather than from an abundance of reflected rays. Thus, if a body reflect only a few of the green rays, it will appear of a dark green. The brightness and intensity of a color shows that a great quantity of rays are reflected. That bodies sometimes change their color, is owing to some chemical change, which takes place in the

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Is color an essential property of a body? Of what color do bodies appear in the dark? Why do some bodies appear differently by candlelight? What is necessary to produce color? What experiments are related to prove the truth of the above? *Note.* What rays does a body reflect in the greatest abundance? In what proportion does it reflect the other rays? Why do the green leaves of a rose appear to have a brown tinge? What does the brightness and intensity of a color show? Why do some bodies change their color?

247. A multiplying-glass is a convex lens, one side of which is ground down into several flat surfaces.

When an object is viewed through a multiplying-glass, it will be multiplied as many times as there are flat surfaces on the lens. Thus, if one lighted candle be viewed through a lens, having twelve flat surfaces, twelve candles will be seen through the lens. The principle of the multiplying-glass is the same with that of a convex or concave lens.

248. The Kaleidoscope* consists of two reflecting surfaces, or pieces of looking-glass, inclined to each other at an angle of 60 degrees, and placed between the eye and the objects intended to form the picture.

The two plates are enclosed in a tin or paper tube, and the objects, consisting of pieces of colored glass, beads, or other highly-colored fragments, are loosely confined between two circular pieces of common glass, the outer one of which is slightly ground, to make the light uniform. On looking down the tube through a small aperture, and where the ends of the glass plates nearly meet, a beautiful figure will be seen, having six angles, the reflectors being inclined the sixth part of a circle. If inclined the twelfth part, or twentieth part of a circle, twelve or twenty angles will be seen. By turning the tube so as to alter the position of the colored fragments within, these beautiful forms will be changed; and in this manner an almost infinite variety of patterns may be produced.

OF THE THERMAL, CHEMICAL, AND OTHER NON-OPTICAL EFFECTS OF LIGHT.

1. The science of Optics treats particularly of light as the medium of vision. But there are other effects of this agent,

internal arrangement of their parts, whereby they lose their tendency to reflect certain colors, and acquire the power of reflecting others.

* The word Kaleidoscope is derived from the Greek language, and means, "the sight of a beautiful form." The instrument was invented by Dr. Brewster, of Edinburgh, a few years ago.

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247. What is a multiplying-glass? How many times will an object, viewed through a multiplying-glass, be multiplied? What is the principle of the multiplying-glass?

248. Of what does the kaleidoscope consist? *Note.* From what is the word kaloidescope derived, and what does it mean? By whom was the instrument invented? What is here said with regard to the kaleidoscope?

which, although more immediately connected with the science of Chemistry, deserve to be noticed in this connexion.

2. The thermal effects of light, that is, its agency in the excitation of heat, when it proceeds directly from the sun, are well known. But it is not generally known that these effects are extremely unequal in the differently colored rays, as they are refracted by the prism. It has already been stated in a note on page 186, that the red rays appear to possess the thermal properties in the greatest degree, and that in the other rays in the spectrum there is a decrease of thermal power towards the violet, where it ceases altogether. But, on the contrary, that the chemical agency is the most powerful in the violet, from which it constantly decreases towards the red, where it ceases altogether. Whether these thermal and chemical powers exist in all light, from whatever source it is derived, remains yet to be ascertained. The chromatic intensity of the colored spectrum is greatest in the yellow, from whence it decreases both ways, terminating almost abruptly in the red, and decreasing by almost imperceptible shades towards the violet, where it becomes faint, and then wholly indistinct. Thus it appears that the greatest heating power resides where the chemical power is feeblest, and the greatest chemical power where the heating power is feeblest, and that the optical power is the strongest between the other two.

3. The chemical properties of light are shown in this, that the light of the sun, and in an inferior degree that of day when the sun is hidden from view, is a means of accelerating chemical combinations and decompositions. The following experiment exhibits the chemical effects of light:

Place a mixture of equal parts (by measure) of chlorine and hydrogen gas in a glass vessel, and no change will happen so long as the vessel be kept in the dark and at an ordinary temperature; but on exposing it to the daylight, the elements will slowly combine and form hydrochloric acid; if the glass be set

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In what way does Optics treat of light? What is the thermal property of light? Are the thermal properties of the rays the same, or different in each color of the prism? How do they differ? How do the chemical agencies differ? Do these powers exist in all light, or in solar light only? Where is the greatest heating power found? Where the greatest chemical power? Where the greatest optical power?

In what are the chemical powers of light shown? Name the experiments and explain them.

in the sun's rays, the union will be accompanied with an instantaneous detonation. The report may also be produced by transmitting ordinary daylight through violet or blue glass to the mixture, but by interposing a red glass between the vessel and the light, all combination of the elements is prevented.

4. The chemical effects of light have recently been employed to render permanent the images obtained by means of convex lenses. The art of thus fixing them is termed Photography or Heliography.* The mode in which the process is performed is essentially as follows:—The picture, formed by a camera obscura, is received on a plate, the surface of which has been previously prepared, so as to make it as susceptible as possible of the chemical influence of light. After the lapse of a longer or shorter time, the light will have so acted on the plate that the various objects, the images of which were projected upon it, will appear, with all their gradations of light and shade, most exactly depicted in black and white, no color being present. This is the process commonly known by the name of Daguerreotype, from M. Daguerre, the author of the discovery. Since his original discovery he has ascertained that by isolating and electrifying the plate, it acquired such a sensibility to the chemical influence of light, that one-tenth of a second is a sufficient time to obtain the requisite luminous impression for the formation of the picture.

5. The chemical effects of light are seen in the varied colors of the vegetable world. Vegetables grown in dark places are either white or of a palish yellow. The sunny side of fruits is of a richer tinge than that which grows in the shade. Persons whose daily employment keeps them much within doors, are pale, and more or less sickly in consequence of such confinement.

From what has now been detailed with regard to the nature, the effects, and the importance of light, we may see with what reason the great epic poet of our language has apostrophized it in the words:

> "Hail, holy Light! offspring of Heaven, first-born,
> Bright effluence of bright essence increate,"

* These words are Greek derivatives; the former meaning "*writing or drawing by means of light*," the latter, "*writing or drawing by the aid of the sun*."

Explain the art of Photography, or Heliography. By what name is it now known? How else are the chemical effects of light seen?

and why the author of the Seasons has in a similar manner addressed it in the terms:

"Prime cheerer, Light!
Of all material beings first and best!
Efflux divine! Nature's resplendent robe!
Without whose vesting beauty all were wrapt
In unessential gloom; and thou, O Sun!
Soul of surrounding worlds, in whom best seen
Shines out thy Maker! may I sing of thee?"

CHAPTER XI.

ELECTRICITY.

249. The word Electricity* is a term used by philosophers to signify the operations of a very subtle and elastic fluid, which pervades the material world. Electricity can be seen only in its effects; which are exhibited in the form of attraction and repulsion.

If a piece of amber, sealing-wax, or smooth glass, perfectly clean and dry, be briskly rubbed with a dry woollen cloth, and immediately afterwards held over small and light bodies, such as pieces of paper, thread, cork, straw, feathers, or fragments of gold leaf, strewed upon a table, these bodies will be attracted, and fly towards the surface that has been rubbed, and adhere to it for a certain time. The surfaces that have acquired this power of attraction are said to be *excited;* and the substances thus susceptible of being excited are called *electrics,* while those which cannot be excited in a similar manner are called *non-electrics.*

* This word is derived from a Greek word, which signifies amber, because this substance was supposed to possess, in a remarkable degree, the property of producing the fluid, when excited or rubbed. The property itself was first discovered by Thales of Miletus, one of the seven wise men

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249. What is electricity? How can electricity be seen? How are these effects exhibited? What illustration of this is given? What is said of the surfaces which have acquired the power of attraction? What are electrics? What are non-electrics? *Note.* What is stated with regard to the word electricity? By whom was this property first discovered?

250. The science of electricity, therefore, divides all substances into two kinds; namely, *Electrics*, or those substances which can be excited, and *Non-electrics*, or those substances which cannot be excited.

of Greece. The word is now used to express both the fluid itself, and the cience which treats of it.

The nature of electricity is entirely unknown. Some philosophers consider it a fluid; others consider it as two fluids of opposite qualities; and others again deny its materiality, and deem it, like attraction, a mere property of matter. In this volume the opinion of Dr. Franklin is adopted, who supposed it to be a *single* fluid, disposed to diffuse itself equally among all substances, and exhibiting its peculiar effects only when a body by any means becomes possessed of more or less than its proper share. That when any substance has more than its natural share, it is said to be *positively* electrified, and that when it has less than its natural share, it is said to be *negatively* electrified; that *positive* electricity implies a redundancy, and *negative* electricity a deficiency of the fluid. The adoption of this opinion of Franklin is a matter of mere verbal preference; for whether the effects described under the name of electricity be the effects of one fluid moving in a particular direction, or of two fluids moving in opposite directions, or no motion of a fluid at all, the facts remain the same whatever the theory may be, and they may be explained as well under one set of terms as another. Professor Faraday has proposed a nomenclature of electricity, which has been adopted in some scientific treatises. From the Greek words ἤλεκτρον, (electricity, or *amber*, from which it was first produced,) and ὁδός, (a way or path,) he formed the word *electrodes*, that is, ways or paths of electricity. The course of positive electricity he called *the anode*, (from the Greek ἄνοδος, an ascending or entering way,) and the course of the negative electricity *the cathode*, (from the Greek καθοδος, a descending way, or path of exit.) The terms positive and negative are, however, more frequently employed to designate the extremities of the channels through which electricity passes. Positive electricity is sometimes expressed by the term *plus*, or its character +, and negative electricity by the term *minus*, or its character —.

Electricity may be excited by several modes—as 1st, *by friction*, whence

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What is stated with regard to the nature of electricity? Whose and what opinion is adopted in this volume? When is a substance said to be positively electrified? When is it said to be negatively electrified? What does positive electricity imply? What does negative electricity imply? In how many ways may electricity be excited? What are the different kinds of electricity called?

250. Into how many kinds does the science of electricity divide all substances? What are they?

251. The electric fluid is readily communicated from one substance to another. Some substances, however, will not allow it to pass through or over them, while others give it a free passage. Those substances through which it passes without obstruction are called *conductors;* while those through which it cannot readily pass are called *non-conductors;* and it is found, by experiment, that all *electrics* are *non-conductors*, and all *non-electrics* are good *conductors* of electricity.

1. The following substances are *electrics*, or non-conductors of electricity; namely,

Atmospheric air, (when dry,)	Feathers,
Glass,	Amber,
Diamond,	Sulphur,
All precious stones,	Silk,
All gums and resins,	Wool,
The oxides of all metals,	Hair,
Beeswax,	Paper,
Sealing-wax,	Cotton.

All these substances must be dry, or they will become more or less conductors.

2. The following substances are non-electrics, or conductors of electricity; namely,

All metals,	Living animals,
Charcoal,	Vapor, or steam.

it is called *Frictional Electricity;* 2dly, *by chemical action,* called, from its discoverers, *Galvanic* or *Voltaic Electricity;* 3dly, *by the action of heat,* whence it is called *Thermo-Electricity;* 4thly, *by Magnetism.* Frictional Electricity forms the subject of that branch of Electricity usually treated under the head of Natural Philosophy. *Electricity,* excited by chemical action, forms the subject of *Galvanism;* and Electricity produced by the agency of heat, or by Magnetism, is usually considered in connexion with the subject of Electro-Magnetism. The intimate connexion between these several subjects shows how close are the links of the chain by which all the departments of physical science are united

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251. What is said with regard to the communication of the electric fluid from one substance to another? Will all substances allow it to pass through them? What bodies are called conductors? What bodies are called non conductors? What has been found, by experiment, with regard to elec trics and non-electrics? What substances are electrics or non-conductors? Why must these substances be dry? What substances are non-electrics or conductors?

3. The following are imperfect conductors, (that is, they conduct the electric fluid, but not so readily as the substances above mentioned,) namely,

Water,	Common wood,
Green vegetables,	Dead animals,
Damp air,	Bone,
Wet wood,	Horn, &c.
All substances containing moisture,	

252. When a conductor is surrounded on all sides by non-conducting substances, it is said to be *insulated.*

1. As glass is a non-conducting substance, any conducting substance surrounded with glass, or standing on a table or stool, with glass legs, will be *insulated.*

2. As the air is a non-conductor, when dry, a substance which rests on any non-conducting substance will be insulated, unless it communicate with the ground, the floor, a table, &c.

253. When a communication is made between a conductor and an excited surface, the electricity from the excited surface is immediately conveyed by the conductor to the ground ;* but if the conductor be insulated, its whole surface will become electrified, and it is said to be charged.

* The earth may be considered as the principal reservoir of electricity ; and when a communication exists, by means of any conducting substance, between a body containing more than its natural share of the fluid, and the earth, the body will immediately lose its redundant quantity, and the fluid will escape to the earth. Thus, when a person holds a metallic tube to an excited surface, the electricity escapes from the surface to the tube, and passes from the tube through the person to the floor; and the floor being connected with the earth by conducting substances, such as the timbers, &c., which support the building, the electricity will finally pass off by a regular succession of conducting substances, from the excited surface to the earth. But if the chain of conducting substances be interrupted,

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What substances are mentioned as imperfect conductors?

252. When is a substance said to be insulated? Give the examples.

253. When a communication is made between a conductor and an excited surface, where is the electricity from the excited substance conveyed? When is it said to be charged? *Note.* When a communication exists by means of any conducting substance, between a body containing more than its natural share of the fluid and the earth, what will become of the redundant quantity which the body possesses?

254. The simplest mode of exciting electricity is by friction.

Thus, if a thick cylinder of sealing-wax, or sulphur, or a glass tube,* be rubbed with a silk handkerchief, a piece of clean flannel, or the fur of a quadruped, the electric fluid will be excited, and may be communicated to other substances from the electric thus excited.

255. The electricity excited in glass is called the *vitreous* or *positive* electricity; and that obtained from sealing-wax, or other resinous substances, is called *resinous* or *negative* electricity.

256. The vitreous and resinous, or, in other words, the positive and negative electricities, always accompany each other; for if any surface become positive, the surface with which it is rubbed will become negative; and if any surface be made positive, the *nearest* conducting surface will become negative. And if positive electricity be communicated to one side of an *electric*, (as a pane of glass, or a glass vial,) the opposite side will become negatively electrified, and the plate or the glass is then said to be charged.

1. When one side of a metallic, or other conductor, receives

that is, if any non-conducting substance occur between the excited surface and the course which the fluid takes in its progress to the earth, the conducting substances will be insulated, and become charged with electricity. Thus, if an excited surface be connected by a long chain to a metallic tube, and the metallic tube be held by a person who is standing on a stool with glass legs, or on a cake of sealing-wax, resin, or any other non-conducting substance, the electricity cannot pass to the ground, and the person, the chain, and the tube will all become electrified.

* Whatever substance is used, it must be perfectly dry. If, therefore, a glass tube be used, it should previously be held to the fire, and gently warmed, in order to remove all moisture from its surface.

What illustration of this is given? What follows if this chain of conducting substances be interrupted?

254. What is the simplest mode of exciting electricity? What illustration of this is given?

255. What is the electricity excited in glass called? What is that obtained from resinous substances called?

256 What is stated with regard to positive and negative electricity?

the electric fluid, its whole surface is instantly pervaded; but when an electric is presented to an electrified body, it becomes electrified in a small spot only.

2. When two surfaces oppositely electrified are united, their powers are destroyed; and if their union be made through the human body, it produces an affection of the nerves, called an electric shock.

257. Similar states of electricity repel each other; and dissimilar states attract each other.

Thus, if two pith-balls suspended by a silk thread, are both positively or both negatively electrified, they will repel each other; but if one be positively and the other negatively electrified, they will attract each other.

258. The Leyden jar is a glass vessel used for the purpose of accumulating the electric fluid, procured from excited surfaces.

1. Fig. 123 represents a Leyden jar. It is a glass jar, coated both on the inside and the outside with tinfoil, with a cork or wooden stopper through which a metallic rod passes, terminating upwards in a brass knob, and connected by means of a wire, at the other end, with the inside coating of the jar. The coating extends both on the inside and outside only to within two or three inches of the top of the jar. Thus prepared, when an excited surface is applied to the brass knob, or connected with it by any conducting surface, it parts with its electricity, the fluid enters the jar, and the jar is said to be charged.

Fig. 123

When the Leyden jar is charged, the fluid is contained in the inside coating of the vial; and as this coating is insulated, the fluid will remain in the jar until a communication be made, by

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What follows when one side of a metallic, or other conductor, receives the electric fluid? What follows when an electric is presented to an electrified body? What follows when two surfaces, oppositely electrified, are united?

257. How do similar states of electricity act on each other? How do dissimilar states act on each other? Give the examples.

258. For what is the Leyden jar used? What does Fig. 123 represent? What is a Leyden jar? When is the Leyden jar said to be charged?

means of some conducting substance, between the inside and the outside of the jar. If then a person apply one hand or finger to the brass knob, and the other to the outside coating of the jar, a communication will be formed by means of the brass knob with the inside and outside of the jar, and the jar will be discharged. *A vial or jar that is insulated cannot be charged.*

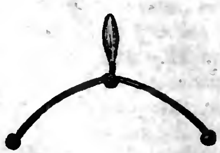
259. An electrical battery is composed of a number of Leyden jars connected together.

The inner coatings of the jars are connected together by chains or metallic bars attached to the brass knobs of each jar; and the outer coatings have a similar connexion established by placing the vials on a sheet of tinfoil. The whole battery may then be charged like a single jar. For the sake of convenience in discharging the battery, a knob, connected with the tinfoil on which the jars stand, projects from the bottom of the box which contains the jars.

260. The *jointed* discharger is an instrument used to discharge a jar, or battery.

Fig. 124 represents the jointed discharger. It consists of two rods, generally of brass, terminating at one end in brass balls, and connected together at the other end by a joint, like that of a pair of tongs, allowing them to be opened or closed. It is furnished with a glass handle, to secure the person who holds it from the effects of a shock. When opened, one of the balls is made to touch the outside coating of the jar, or the knob connected with the bottom of the battery, and the other is applied to the knob of the jar, or jars. A communication being thus formed between the inside and the outside of the jar, a discharge of the fluid will be produced.

Fig. 124.



How can the jar be discharged? Can an insulated jar be charged?

259. Of what is an electrical battery composed? How are the inner coatings of the jars connected together? How are the outer coatings connected? In what way is the battery charged?

260. What is the jointed discharger? What does Fig. 124 represent? Of what does it consist?

261. When a charge of electricity is to be sent through any particular substance, the substance must form a part of the *circuit of the electricity;* that is, it must be placed in such a manner that the fluid cannot pass from the inside to the outside surface of the jar, or battery, without passing through the substance in its passage.

262. Metallic rods, with sharp points, silently attract the electric fluid.

1. If the balls be removed from the jointed discharger, and the two rods terminate in sharp points, the electricity will pass off silently and produce but little effect.

2. A Leyden jar, or a battery, may be silently discharged by presenting a metallic point, even that of the finest needle, to the knob. It is on this principle that lightning-rods are constructed. The electric fluid is silently drawn from the cloud by the sharp points on the rods, and is thus prevented from suddenly exploding on high buildings.

3. 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.*

4. A body, on approaching another body powerfully electrified, will be thrown into a contrary state of electricity. Thus, a feather, brought near to a *glass tube* excited by friction, will be attracted by it; and, therefore, previously to its touching the tube, negative electricity must have been induced in it. On the contrary, if a feather be brought near to excited *sealing-wax,* it will be attracted, and, consequently, positive electricity must have been induced in it before contact.

263. When electricity is communicated from one body to another *in contact* with it, it is called electricity *by transfer.*

264. The electrical machine is a machine constructed

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261. What is necessary when a charge of electricity is to be sent through any particular substance?

262. In what way do metallic rods, with sharp points, attract the electric fluid? How can the electricity be made to pass off silently? Upon what principle are lightning-rods constructed? When is electricity said to be communicated by induction?

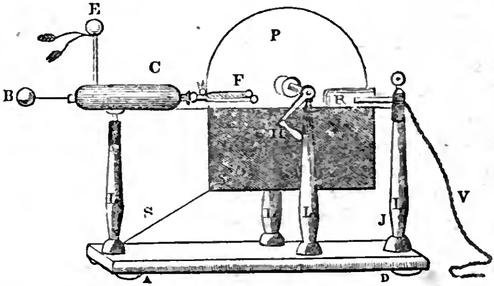
263. When is electricity produced by transfer?

for the purpose of accumulating or collecting electricity, and transferring it to other substances.

1. Electrical machines are made in various forms, but all on the same principle, namely, the attraction of metallic points. The electricity is excited by the friction of silk on a glass surface, assisted by a mixture or preparation called an amalgam.* The glass surface is made either in the form of a cylinder or a circular plate, and the machine is called a cylinder or a plate machine, according as it is made with a cylinder or with a plate.

2. Fig. 125 represents a plate electrical machine. A D is the stand of the machine. L L L L are the four glass legs, or

Fig. 125.



posts which support and insulate the parts of the machine. P is the glass plate, (which in some machines is a hollow cylinder,) from which the electricity is excited, and H is the handle by which the plate (or cylinder) is turned. R is a leather cushion, or rubber, held closely to both sides of the glass plate

* The amalgam is composed of mercury, tin, and zinc. That recommended by Singer, is made by melting together one ounce of tin and two ounces of zinc, which are to be mixed, while fluid, with six ounces of mercury, and agitated in an iron, or thick wooden box, until cold. It is then to be reduced to a very fine powder in a mortar, and mixed with a sufficient quantity of lard to form it into a paste.

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264. For what purpose is the electrical machine constructed? Upon what principle are all electrical machines constructed? How is the electricity excited? Of what is the amalgam composed? In what form is the glass surface made? When is the machine called a plate machine? When is it called a cylinder machine? What does Fig. 125 represent? Explain the figure.

by a brass clasp, supported by the post G L, which is called the rubber-post. S is a silk bag,* embraced by the same clasp that holds the leather cushion or rubber; and it is connected by strings S S S attached to its three other corners, and to the legs L L and the fork F of the prime conductor. C is the prime conductor, terminating at one end with a moveable brass ball, B, and at the other by the fork F, which has one prong on each side of the glass plate. On each prong of the fork there are several sharp points projecting towards the plate, to collect the electricity as it is generated by the friction of the plate against the rubber. V is a chain, or wire, attached to the brass ball on the rubber-post, and resting on the table or the floor, designed to convey the fluid from the ground to the plate. When negative electricity is to be obtained, this chain is removed from the rubber-post, and attached to the prime conductor, and the electricity is to be gathered from the ball on the rubber-post.

Operation of the Machine.—By turning the handle H, the glass plate is pressed by the rubber. The friction of the rubber against the glass plate (or cylinder) produces a transfer of the electric fluid from the rubber to the plate; that is, the cushion becomes negatively and the glass positively electrified. The fluid which thus adheres to the glass, is carried round by the revolution of the cylinder; and its escape being prevented by the silk bag, or flap, which covers the plate, (or cylinder,) until it comes to the immediate vicinity of the metallic points on the fork F, it is attracted by the points, and carried by them to the prime conductor. Positive electricity is thus accumulated on the prime conductor, while the conductor on the rubber-post, being deprived of this electricity, is negatively electrified. The fluid may then be collected by a Leyden jar from the prime conductor, or conveyed, by means of a chain attached to the prime conductor, to any substance which is to be electrified. If both of the conductors be insulated, but a small portion of the electric fluid can be excited; for this reason, *the chain must in all cases be attached to the rubber-post, when positive electricity is required, and to the prime conductor, when negative electricity is wanted.*

* In cylindrical machines this silk bag is called "*the flap.*"

Explain the operation of the machine. To what must the chain be attached when positive electricity is required? To what must it be attached when negative electricity is wanted?

EXPERIMENTS WITH THE ELECTRICAL MACHINE

1. On the prime conductor of the electrical machine is placed the electrometer,* E. It consists of a wooden ball mounted on a metallic stick, or wire, having two pith balls, suspended by silk, hair, or linen threads. When the machine is worked, the pith balls, being both similarly electrified, repel each other; and this causes them to fly apart, as is represented in the figure; and they will continue elevated until the electricity is drawn off. But if an uninsulated conducting substance touch the prime conductor, the pith balls will fall. The height to which the balls rise, and the quickness with which they are elevated, afford some test of the power of the machine. This simple apparatus may be attached to any body, the electricity of which we wish to measure.

2. The balls of the electrometer, when elevated, are attracted by any resinous substance, and repelled by any vitreous substance that has been previously excited by friction.

3. If an electric, or a non-conductor, be presented to the prime conductor, when charged, it will produce no effect on the balls; but if a non-electric, or any conducting substance be presented to the conductor, the balls of the electrometer will fall. This shows that the conductor has parted with its electricity, and that the fluid has passed off to the earth through the substance, and the hand of the person presenting it.

* The word "*electrometer*" means "*a measurer of electricity.*" It is made in a variety of forms, on the principle that similar states of electricity repel each other. It sometimes consists of a single pith-ball, attached to a light rod, in the manner of a pendulum, before a graduated arc or circle.

An *electroscope* is an instrument of more delicate construction, to detect the presence of electricity. The most sensitive of this kind of apparatus, is that called Bennett's Goldleaf Electroscope, improved by Singer It consists of two strips of goldleaf suspended under a glass covering which completely insulates them. Strips of tinfoil are attached to the sides of the glass, opposite the goldleaf, and when the strips of goldleaf diverge, they will touch the tinfoil, and be discharged. A pointed wire surmounts the instrument, by which the electricity of the atmosphere may be observed.

What is the first experiment mentioned with the electrical machine? What does the word electrometer mean? Of what does it sometimes consist? What is an electroscope? What is the second experiment?

4. When the machine is turned, if a person touch the prime conductor, the fluid passes off through the person to the floor without his feeling it. But if he present his finger, his knuckle, or any part of the body, *near* to the conductor, without touching it, a spark will pass from the conductor to the knuckle, which will produce a sensation similar to the pricking of a pin, or needle.

5. If a person stand on a stool with glass legs, or any other non-conductor, he will be *insulated*. If in this situation he touch the prime conductor, or a chain connected with it, when the machine is worked, sparks may be drawn from any part of the body in the same manner as from the prime conductor. While the person remains insulated, he experiences no sensation from being filled with electricity; or, if a metallic point be presented to any part of his body, the fluid may be drawn off silently, without being perceived. But if he touch a blunt piece of metal, or any other conducting substance, or if he step from the stool to the floor, he will feel the electric shock; and the shock will vary in force according to the quantity of fluid with which he is charged.

6. THE TISSUE FIGURE. Fig. 126 is a figure with a dress of fancy paper cut into narrow strips. When placed on the prime conductor, or being insulated, is connected with it, the strips being all electrified will recede and form a sphere around the head. On presenting a metallic point to the electrified strips, very singular combinations will take place. If the electrometer be removed from the prime conductor, and a tuft of feathers, or hair, fastened to a stick or wire, be put in its place, on turning the machine the feathers or hair will become electrified, and the separate hairs will rise and repel each other. A toy is in this way constructed, representing a person under excessive fright. On touching the head with the hand, or any conducting substance, not insulated, the hair will fall.

Fig. 126.

7. The Leyden jar may be charged by presenting it to the

What is the third? What does this show? What is the fourth? What is the fifth? What is the sixth?

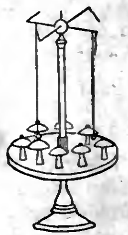
prime conductor, when the machine is worked. If the ball of the jar touch the prime conductor, it will receive the fluid silently; but if the ball of the jar be held at a small distance from the prime conductor, the sparks will be seen darting from the prime conductor to the jar with considerable noise.

8. The jar may in like manner be filled with negative electricity, by applying it to the ball on the rubber-post, and connecting the chain with the prime conductor.

9. If the Leyden jar be charged from the prime conductor, (that is, with positive electricity,) and presented to the pith balls of the electrometer, they will be repelled; but if the jar be charged from the brass ball of the rubber-post, (that is, with negative electricity,) they will be attracted.

10. If the electrometer be removed from the prime conductor, and a pointed wire be substituted for it, a wire with sharp points bent in the form of an S, balanced on it, will be made to revolve rapidly. In a similar manner the motion of the sun and the earth around their common centre of gravity, together with the motion of the earth and the moon, may be represented.*

Fig. 127.



11. A chime of small bells, on a stand, Fig. 127, may also be rung by means of brass balls suspended from the revolving wires. The principle of this revolution is similar to that mentioned in connexion with the revolving jet, Fig. 85, which is founded on the law, that action and reaction are equal and in opposite directions.

12. If powdered resin be scattered over dry cotton-wool, loosely wrapped on one end of the jointed discharger, it may be inflamed by the discharge of the battery or a Leyden jar. Gunpowder may be substituted for the resin.

265. The *universal discharger*, is an instrument for directing a charge of electricity through any substance, with certainty and precision.

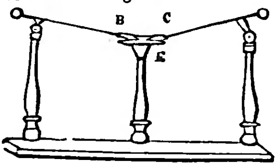
* Such an apparatus is sometimes called an *Electrical Tellurium.* It may rest on the prime conductor, or upon an insulated stand.

What is the seventh? How may the jar be filled with negative electricity? What is the eighth? What is the ninth? What is the tenth? What is the eleventh? What is the twelfth?

265 What is the universal discharger? What is its use?

1. It consists of two sliding rods, A B and C D, terminating at the extremities, A and D, with brass balls, and at the other ends, which rest upon the ivory table or stand E, having a fork, to which any small substance may be attached. The whole is insulated by glass legs or pillars. The rods slide through collars, by which means their distance from one another may be adjusted.

Fig. 128.



2. In using the universal discharger, one of the rods or slides must be connected by a chain, or, otherwise, with the outside, and the other with the inside coating of the jar or battery. By this means the substance through which the charge is to be sent is placed within the electric circuit.

3. By means of the universal discharger, any small metallic substance may be burnt. The substance must be placed in the forks of the slides, and the slides placed within the electric circuit, in the manner described in the last paragraph. In the same manner, by bringing the forks of the slides into contact with a substance placed upon the ivory stand of the discharger, such as an egg, a piece of a potato, water, &c., it may be illuminated.

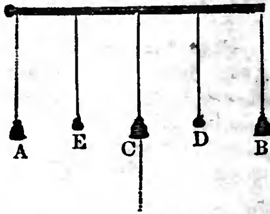
4. Ether, or alcohol, may be inflamed by a spark communicated from a person, in the following manner. The person standing on the insulating stool, receives the electric fluid from the prime conductor, by touching the conductor or any conducting substance in contact with it; he then inserts the knuckles of his hand in a small quantity of sulphuric ether, or alcohol, held in a shallow metallic cup, by another person, who is not insulated, and the ether or alcohol immediately inflames. In this case the fluid passes from the conductor to the person who is insulated, and he becomes charged with electricity. As soon as he touches the liquid in the cup, the electric fluid, passing from him to the spirit, sets it on fire.

What figure represents it? Of what does it consist? What is necessary in using the universal discharger? What is effected by this means? What experiments are shown by means of the universal discharger? How must the substance be placed? How may ether or alcohol be inflamed?

266. The electrical bells are designed to show the effects of electrical attraction and repulsion.

1. They are thus to be applied.* The ball B of the prime conductor, with its rod, is to be unscrewed, and the rod on which the bells are suspended is to be screwed in its place. The middle bell is to be connected by a chain with the table or the floor. When the machine is turned, the balls suspended between the bells will be alternately attracted and repelled by the bells, and cause a constant ringing. If the battery be charged and connected with the prime conductor, the bells will continue to ring until all the fluid from the battery has escaped.

Fig. 129.



It may be observed, that the fluid from the prime conductor passes readily from the two outer bells, which are suspended by chains; they, therefore, attract the two balls towards them. The balls becoming electrified by contact with the outer bells, are repelled by them and driven to the middle bell, to which they communicate their electricity; having parted with their electricity they are repelled by the middle bell, and again attracted by the outer ones, and thus the constant ringing is maintained. The fluid which is communicated to the middle bell, is conducted to the earth by the chain attached to it.

2. Spiral Tube. The passage of the electric fluid from one

Fig. 130.

conducting substance to another, is beautifully exhibited by means of a glass tube having a brass ball at each end, and

* In some sets of instruments, the bells are insulated on a separate stand; but the mode described above is a convenient mode of connecting them with the prime conductor

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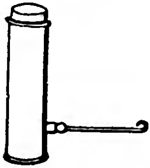
266. What are the electrical bells? What figure represents them? What are they designed to show? How are they to be applied? Explain the spiral tube

coated in the inside with small pieces of tinfoil, placed at small distances from each other in a spiral direction, as represented in Fig. 130.

In the same manner various figures, letters, and words may be represented, by arranging similar pieces of tinfoil between two pieces of flat glass. These experiments appear more brilliant in a darkened room.

Fig. 131



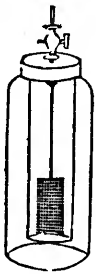
3. Hydrogen Pistol. Fig. 131 represents a hydrogen pistol.* When filled with hydrogen gas,† if the insulated knob K be presented to the prime conductor, it will immediately explode.

4. Electrical Sportsman. Fig. 133 represents the electrical sportsman. From the larger ball of a Leyden-jar two birds

* This apparatus is made in a variety of forms, sometimes in the exact form of a pistol, and sometimes in the form of a piece of ordnance. The form in the figure is a simple and cheap contrivance, and is sufficient to explain the manner in which the instrument is to be used in any of its forms.

† A very convenient and economical way of procuring hydrogen gas for this and other experiments, is by means of *the hydrogen gas generator*, as represented in Fig. 132. It consists of a glass vessel, with a brass cover, in the centre of which is a stop-cock; from the inside of the cover, another glass vessel is suspended, with its open end downwards. Within this, a piece of zinc is suspended by a wire. The outer vessel contains a mixture of sulphuric acid and water, about nine parts of water to one of acid. When the cover, to which the inner glass is firmly fixed, is placed upon the vessel, the acid acting upon the zinc, causes the metal to absorb the oxygen of the water, and the hydrogen, the other constituent part of the water, being thus disengaged, rises in the inner glass, from which it expels the water; and when the stop-cock is turned the hydrogen gas may be collected in the hydrogen pistol, or any other vessel. In the use of hydrogen gas for explosion, it will be necessary to dilute the gas with an equal portion of atmospheric air.

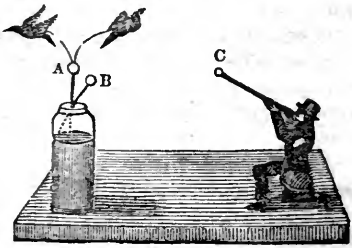
Fig. 132



Explain the hydrogen pistol.

made of pith,* are suspended by a linen thread, silk, or hair. When the jar is charged the birds will rise, as represented in the figure, on account of the repulsion of the fluid in the jar.

Fig. 133

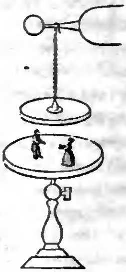


If the jar be then placed on the tinfoil of the stand, and the smaller ball placed within a half inch of the end of the gun, a discharge will be produced, and the birds will fall.

FURTHER EXPERIMENTS.

1. If images, made of pith, or small pieces of paper, are placed under the insulated stool, and a connexion be made between the prime conductor and the top of the stool, the images will be alternately attracted and repelled; or, in other words, they will first rise to the electrified top of the stool, and thus becoming themselves electrified, will be repelled, and fall to the ground, the floor, or the table; where, parting with their electricity, they will again be attracted by the stool, thus rising and falling with considerable rapidity. In order to conduct this experiment successfully, the images, &c., must be placed within a short distance of the bottom of the stool.

Fig. 134.



2. On the same principle light figures may be made to dance when placed between two discs, the lower one being placed upon a sliding stand with a screw to adjust the distance, and the upper one being suspended from the prime conductor, as in Fig. 134.

3. A hole may be perforated through a quire of paper, by charging the battery, resting the paper up-

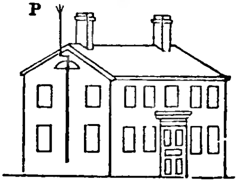
* This substance is obtained in large quantities from the cornstalk, the whole of which, with the exception of the outside, is composed of *pith.*

Explain experiment one. Explain the second experiment.

on the brass ball of the battery, and making a communication, by means of the jointed discharger, between the ball of one of the jars and the brass ball of the box. The paper, in this case, will be between the ball of the battery and the end of the discharger.

4. The thunder-house, Fig. 135, is designed to show the security afforded by lightning-rods, when lightning strikes a building. This is done by placing a highly combustible material in the inside of the house, and passing a charge of electricity through it. On the floor of the house is a surface of tinfoil. The hydrogen pistol being filled with hydrogen gas from the gasometer, must be placed on the floor of the thunder-house, and connected with the wire on the opposite side. The house being then put together, a chain must be connected with the wire on the side opposite to the lightning-rod, and the other end placed in contact either with a single Leyden jar or with the battery. When the jar, thus situated, is charged, if a connexion be formed between the jar and the points of the lightning-rod, the fluid will pass off silently, and produce no effect. But if a small brass ball be placed on the points of the rod, and a charge of electricity be sent to it, from the jar or the battery, the gas in the pistol will explode, and throw the parts of the house asunder with a loud noise.*

Fig. 135.



* The success of this experiment depends upon the proper connexion of the jar with the lightning-rod, and the electrical pistol. On the side of the house opposite to the lightning-rod there is a wire, passing through the side, and terminating on the outside in a hook. When the house is put together, this wire, in the inside, must touch the tinfoil on the floor of the house. The hydrogen pistol must stand on the tinfoil, and its insulated knob or wire, projecting from its side, must be connected with the lower end of the lightning-rod, extending into the inside of the house. A communication must then be made between the hook on the outside of the house, and the outside of the jar or battery. This is conveniently done by attaching one end of a chain to the hook, and holding the other end in the hand against the side of a charged jar. By presenting the knob of the jar to the points of the lightning-rod no effect is produced, but if a brass ball be placed on the points at P, and the knob of the jar be presented to

Explain the third experiment. The fourth

5. If the ball of the prime conductor be removed and a pointed wire be put in its place, the current of electricity flowing from the point, when the machine is turned, may be perceived by placing a lighted lamp before it; the flame will be blown *from* the point; and this will be the case in what part soever of the machine the point is placed, whether on the prime conductor or the rubber; or if the point be held in the hand and the flame placed between it and the machine, thus showing that in all cases the fluid is blown *from* the point. Delicate apparatus may be put in motion by the electric fluid when issuing from a point. In this way electrical orreries, mills, &c., are constructed.

6. Goldleaf may be forced into the pores of glass by placing it between two slips of window-glass, pressing the slips of glass firmly together, and sending a shock from a battery through them.

7. If goldleaf be placed between two cards, and a strong charge be passed through them, it will be completely fused.

8. When electricity enters at a point, it appears in the form of a star; but when it goes out from a point, it puts on the appearance of a brush.

GENERAL REMARKS.

1. Lightning is the rapid motion of vast quantities of electric matter. Thunder is the noise produced by the rapid motion of lightning through the air.

2. The *aurora borealis* (or northern lights) is supposed to be caused by the electric fluid passing through highly-rarefied air; and most of the great convulsions of nature, such as earthquakes, whirlwinds, hurricanes, water-spouts, &c., are generally accompanied by electricity, and often depend upon it.

3. The electricity which a body manifests by being brought near to an excited body, without receiving a spark from it, is

the ball, the explosion will take place. If the charged jar be *very suddenly* presented to the points, the explosion *may* take place; and the jar *may* be silently discharged if it be brought very slowly to the ball. The thunder-house is sometimes put together with magnets.

Explain the fifth experiment. The sixth. The seventh.

What is lightning? What is thunder? How is the aurora boreali supposed to be caused?

said to be acquired by *induction*. When an insulated but unelectrified conductor is brought near an insulated charged conductor, the end near to the excited conductor assumes a state of opposite electricity, while the farther end assumes the same kind of electricity,—that is, if the conductor be electrified positively, the unelectrified conductor will be negative at the nearer end and positive at the further end, while the middle point evinces neither positive nor negative electricity.

4. The experiments which have now been described exemplify all the elementary principles of the science of electricity. These experiments may be varied, multiplied, and extended in innumerable forms, by an ingenious practical electrician. Among other things with which the subject may be made interesting, may be mentioned the following facts, &c.

5. A number of feathers, suspended by strings from an insulated conducting substance, will rise and present the appearance of a flight of birds. As soon as the substance is discharged the feathers will fall. The experiment may be varied by placing the sportsman on the prime conductor, without the use of the Leyden jar, to which the birds are attached.

6. Instead of the Leyden jar a plate of common glass (a pane of window-glass, for instance) may be coated on both sides with tinfoil, leaving the edges bare. A bent wire balanced on the edge of the glass, to the ends of which balls may be attached, with an image at each end, may be made to represent two persons tilting, on the same principle by which the electrical bells are made to ring.

7. A beautiful little sawmill was lately exhibited at a lecture at the Odeon, in Boston, by Mr. Quimby, its ingenious contriver. The moving power was a wheel, with balls at the ends of the spokes, situated within the attractive influence of two larger balls, differently electrified. As the balls on the spokes were attracted by one of the larger balls, they changed their electrical state and were attracted by the other, which, in its return, repelled them, and thus the motion being given to the wheel was communicated by cranks at the end of the axle to the saws above.

• How is the electricity which a body manifests by being brought near to an excited body, without receiving a spark from it, said to be acquired? When an insulated, but unelectrified conductor, is brought near an insulated charged conductor, what is said with regard to the end near the excited conductor? What example is given to illustrate this?

8. When the hand is presented to the prime conductor, a spark is communicated, attended with a slightly painful sensation. But if a pin or a needle be held in the hand with the point towards the conductor, neither spark nor pain will be perceived, owing to the attracting (or perhaps, more properly speaking, the *receiving*) *power* of the point.

9. That square rods are better than round ones to conduct electricity silently to the ground, and thus to protect buildings, may be proved by causing each kind of rod to approach the prime conductor when charged. It will thus be perceived, that while little effect is produced on the pith-balls of the electrometer by the near approach of the round rod, on the approach of the square one the balls will immediately fall. The round rod also, will produce an explosion and a spark, from the ball of the prime conductor, while the square one will draw off the fluid silently.

10. The effects of pointed conductors upon clouds charged with electricity may be familiarly exemplified by suspending a small fleece of cotton-wool from the prime conductor, and other smaller fleeces from the upper one, by small filaments. On presenting a point to them they will be repelled and all drawn together; but if a blunt conductor approach them they will be attracted.

11. From a great variety of facts, it has been ascertained, that lightning-rods afford but little security to any part of a building beyond twenty feet from them; and that when a rod is *painted* it loses its conducting power. The lightning-rods of the most approved construction, and in strictest accordance with philosophical principles, are composed of *small* square rods, (similar to nail-rods.) They run over the building, and down each of the corners, presenting many elevated points in their course. At each of the corners, and on the chimneys, the rods should be elevated several feet above the building. Rods of this description have been placed on all the public school-houses and other public buildings of Boston, by order of the city authorities. They were constructed by Dr. King, who has introduced an improvement, by twisting the square rods,

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Why are square rods better than round ones to conduct electricity silently to the ground, and thus protect buildings from lightning? How far beyond the rod do lightning-rods afford protection? In what way are the most approved lightning-rods constructed?

and thus multiplying the sharp surfaces presented to collect the fluid.

12. The removal of silk and woollen garments, worn during the day in cold weather, is often accompanied by a slight noise, resembling that of sparks issuing from a fire. A similar effect is produced on passing the hand softly over the back of a cat. These effects are produced by electricity.

13. It may here be remarked, that the terms positive and negative, are merely relative terms, as applied to the subject of electricity. Thus, a body which is possessed of its natural share of electricity, is positive in respect to one that has less, and negative in respect to one that has more than its natural share of the fluid. So, also, one that has more than its natural share is positive with regard to one that has only its natural share, or less than its natural share,—and negative in respect to one having a larger share than itself.

14. The experiments with the spiral tube connected with Fig. 130 may be beautifully varied by having a collection of such tubes placed on a stand; and a jar coated with small strips resembling a brick wall, presents, when it is charged, a beautiful appearance in the dark.

15. The electric fluid occupies no perceptible space of time in its passage through its circuit. It always seems to prefer the shortest passage, when the conductors are equally good. Thus, if two, ten, a hundred, or a thousand or more persons, join hands and be made part of the circuit of the fluid in passing from the inside to the outside of a Leyden jar, they will all feel the shock at the same moment of time. But, in its passage, the fluid always prefers the best conductors. Thus, if two clouds, differently electrified, approach one another, the fluid, in its passage from one cloud to the other, will sometimes take the earth in its course, because the air is a bad conductor.

16. In thunder-storms, the electric fluid sometimes passes from the clouds to the earth, and sometimes from the earth to the clouds; and sometimes, as has just been stated, from one cloud to the earth, and from the earth to another cloud.

What is remarked with regard to the terms negative and positive? How can this be illustrated? What is said with regard to the time the electric fluid occupies in its passage through its circuit? What example is given to show that the fluid prefers the best conductors? In what different ways does the electric fluid sometimes pass in thunder-storms?

17. It is not safe, during a thunder-storm, to take shelter under a tree, because the tree attracts the fluid, and the human body being a better conductor than the tree, the fluid will leave the tree and pass into the body.

18. It is also unsafe to hold in the hand edge-tools, or any sharp point which will attract the fluid.

19. The safest position that can be chosen during a thunder-storm, is a recumbent posture on a feather bed; and in all situations a recumbent is safer than an erect position. No danger is to be apprehended from lightning when the interval between the flash and the noise of the explosion is as much as three or four seconds. This space of time may be conveniently measured by the beatings of the pulse, if no time-piece be at hand.

20. Lightning-rods were first proposed by Dr. Franklin, to whom is also ascribed the honor of the discovery that thunder and lightning are the effects of electricity. He raised a kite, constructed of a silk handkerchief, adjusted to two light strips of cedar, with a pointed wire fixed to it; and fastening the end of the twine to a key, and the key, by means of a piece of silk lace, to a post, (the silk lace serving to insulate the whole apparatus,) on the approach of a thunder-cloud, he was able to collect sparks from the key, to charge Leyden jars, and to set fire to spirits. This experiment established the identity of lightning and electricity. The experiment was a dangerous one, as was proved in the case of Professor Richman, of St. Petersburgh, who fell a sacrifice to his zeal for electrical science, by a stroke of lightning from his apparatus.

21. Among the most remarkable facts, connected with the science of Electricity, may be mentioned the power possessed by certain species of fishes, of giving shocks, similar to those produced by the Leyden jar. There are three animals possessed of this power, namely, the Torpedo, the Gymnotus Electricus, (or Surinam Eel,) and the Silurus Electricus. But although it has been ascertained that the Torpedo is capable of giving shocks to the animal system, similar to those of the Leyden jar, yet he has never been made to afford a spark, nor

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Why is it unsafe, during a thunder-storm, to take shelter under a tree, or to hold in the hand any edge-tools? What position is the safest in a thunder-storm? When is there no danger to be apprehended from the lightning? By whom were lightning-rods first proposed? Who first discovered that thunder and lightning are the effects of electricity?

to produce the least effect upon the most delicate electrometer. The Gymnotus gives a small but perceptible spark. The electrical powers of the Silurus are inferior to those of the Torpedo or the Gymnotus, but still sufficient to give a distinct shock to the human system. This power seems to have been bestowed upon these animals to enable them to secure their prey; and to resist the attacks of their enemies. Small fishes, when put into the water where the Gymnotus is kept, are generally killed or stunned by the shock and swallowed by the animal, when he is hungry. The Gymnotus seems to be possessed of a new kind of sense, by which he perceives whether the bodies presented to him be conductors or not.*

22. It will be recollected that the phenomena which have now been described, with the exception of what has just been stated as belonging to animal electricity, belong to the subject of *frictional electricity.* But there are other forms in which this subtle agent presents itself, which are yet to be described, which show that its operations are not confined to beautiful experiments such as have already been presented, nor to the terrific and tremendous effects that we witness in the storm and the thunder-gust. Its powerful agency works unseen on the intimate relations of the parts and properties of bodies of every description, effecting changes in their constitution and character, so wonderfully minute, thorough, and universal, that it may almost be considered as the chief agent of nature, the prime minister of omnipotence, the vicegerent of creative power.

* The consideration of the electricity developed by the organs of these animals of the aquatic order, belongs to that department called ***Animal Electricity.***

CHAPTER XII.

GALVANISM, OR VOLTAIC ELECTRICITY.

267. Galvanism, a branch of Electricity, derives its name from Galvani,* who first discovered the principles which form its basis.

1. Electricity is produced by the mechanical action of bodies on one another; but Galvanism, or Galvanic Electricity, is produced by their chemical action.

2. The motion of the electric fluid excited by galvanic power, differs from that explained under the head of frictional electricity, in its duration; for while the latter exhibits itself in sudden and intermitted shocks and explosions, the former continues in constant and uninterrupted action.

3. The nerves and muscles of animals are most easily

* Dr. Aloysius Galvani was a Professor of Anatomy in Bologna, and made his discoveries about the year 1790. His wife, being consumptive, was advised to take, as a nutritive article of diet, some soup made of the flesh of frogs. Several of these animals, recently skinned for that purpose, were lying on a table in his laboratory, near an electrical machine, with which a pupil of the professor was amusing himself in trying experiments. While the machine was in action, he chanced to touch the bare nerve of the leg of one of the frogs with the blade of a knife that he held in his hand, when suddenly the whole limb was thrown into violent convulsions. Galvani being informed of the fact, repeated the experiment, and examined minutely all the circumstances connected with it. In this way he was led to the discovery of the principles which form the basis of this science. The science was subsequently extended by the discoveries of Professor Volta, of Pavia, who first constructed the Galvanic or Voltaic pile, in the beginning of the present century.

To produce electricity mechanically, (as has been stated under the head of frictional electricity,) it is necessary to excite an electric or non-conducting substance by friction. But galvanic action is produced by the *contact* of different conducting substances with each other.

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267. What is Galvanism? By whom and when was galvanism discovered? What led to the discovery? How is electricity generally produced? How is galvanic electricity produced? How does the motion of the galvanic fluid, excited by galvanic power, differ from that explained in the science of Electricity? What bodies are most easily affected by the galvanic fluid?

affected by the galvanic fluid; and the voltaic or galvanic battery possesses the most surprising powers of chemical decomposition.

268. The galvanic fluid or influence is excited by the contact of pieces of different metal, and sometimes by different pieces of the same metal.

1. If a living frog, or a fish, having a slip of tinfoil on its back, be placed upon a piece of zinc, spasms of the muscles will be excited whenever a communication is made between the zinc and the tinfoil.

2. If a person place a piece of one metal, as a half-dollar, above his tongue, and a piece of some other metal, (as zinc,) below the tongue, he will perceive a peculiar taste; and, in the dark, will see a flash of light, whenever the outer edges of the metals are in contact.

3. A faint flash may be made to appear before the eyes by putting a slip of tinfoil upon the bulb of one of the eyes, a piece of silver in the mouth, and making a communication between them. In these experiments, no effect is produced so long as the metals are kept apart; but on bringing them into contact, the effects above described are produced.

269. The conductors of the galvanic fluid, like those of frictional electricity, are divided into the *perfect* and the *imperfect*. Metallic substances, plumbago and charcoal, the mineral acids and saline solutions, are *perfect* conductors. Water, oxydated fluids, as the acids, and all the substances that contain these fluids, alcohol, ether, sulphur, oils, resins, and metallic oxydes, are *imperfect* conductors.

270. To produce any galvanic action it is necessary to form what is called a galvanic circle; that is, a certain order or succession of substances capable of exciting electricity.

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268. How is the galvanic fluid or influence excited? What illustrations of this are given?

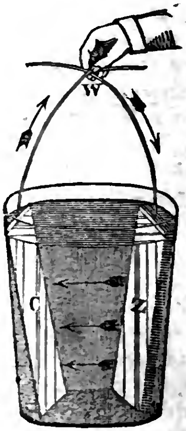
269. Into what are the conductors of the galvanic fluid divided? What substances are perfect conductors? What substances are imperfect conductors?

270. What is necessary in order to produce galvanic action?

271. The simplest galvanic circle is composed of three conductors, one of which must be solid, and one fluid; the third may be either solid or fluid.

1. The process usually adopted for obtaining galvanic electricity is to place between two plates, of different kinds of metal, a fluid capable of exerting some chemical action on one of the plates, while it has no action, or a different action, on the other. A communication is then formed between the two plates.

Fig. 136.



2. Fig. 136 represents a simple galvanic circle. It consists of a vessel containing a portion of diluted sulphuric acid,* with a plate of zinc Z and of copper C immersed in it. The plates are separated at the bottom, and the circle is completed by connecting the two plates on the outside of the vessel by means of wires. The same effect will be produced, if, instead of using the wires the metallic plates come into direct contact.

3. In the above arrangement, there are three elements or essential parts;† namely, the zinc, the copper, and the acid. The acid, acting chemically‡ upon the zinc, produces an alteration in the electrical state of the metal. The zinc com-

* The acid employed in the galvanic circuit must always be one that has a strong affinity for one of the metals in the circuit. When zinc is employed, sulphuric acid may form one of the three elements, because that acid has a strong affinity for zinc.

† It is essential in all cases to have three elements to produce galvanic action. In the experiments which have already been mentioned, in the case of the frogs, the fish, the mouth, and the eye, the *moisture* of the animal, or of the mouth, supplies the place of the acid, so that the *three* constituent parts of the circle are completed.

‡ *A certain quantity of electricity is always developed whenever*

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271. Of what is the simplest galvanic circle composed? What process is usually adopted for obtaining galvanic electricity? Illustrate this by Fig. 136.

municating its natural share of the electrical fluid to the acid, becomes *negatively** electrified. The copper, attracting the same fluid from the acid, becomes *positively* electrified. Any conducting substance, therefore, placed within the line of communication between the positive and negative points, will receive the charge thus to be obtained. The arrows in Fig. 136 show the direction of the current of positive electricity, namely, from the zinc to the fluid,—from the fluid to the copper,—from the copper back through the wires to the zinc, passing from zinc to copper *in* the acid, and from copper to zinc *out* of the acid. The substance submitted to the action of the electric current must be placed in the line of communication between the copper and the zinc. The wire connected with the copper is called the *positive pole,* and that connected with the zinc the *negative pole,* and in all cases *the substance submitted to galvanic action must be placed between the positive and negative poles.*

4. The electrical effects of a simple galvanic circle, such as has now been described, are, in general, too feeble to be perceived, except by very delicate tests. The muscles of animals,

chemical action takes place between a fluid and a solid body. This is a general law of chemical action; and, indeed, it has been ascertained, that there is so intimate a connexion between electrical and chemical changes, that the chemical action can proceed only to a certain extent, unless the electrical equilibrium, which has been disturbed, be again restored. Hence, we find that in the simple, as well as in the compound galvanic circle, the oxydation of the zinc proceeds with activity whenever the galvanic circle is completed; and that it ceases, or, at least, takes place very slowly, whenever the circuit is interrupted.

* It appears at first view to be a singular fact, that in a simple galvanic circle, composed of zinc, acid, and copper, the zinc end will always be negative and the copper end positive; while in all *compound* galvanic circles, composed of the same elements, the zinc will be positive, and the copper *negative.* This apparent difference arises from the compound circle being usually terminated by two superfluous plates.

What effect will be produced if, instead of allowing the metallic plates to come into direct contact, the communication between them be effected by wires? How many parts are there in the above arrangement? What are they? What effect does the acid produce? What is the electrical state of the zinc? Of the copper? What are the arrows in Fig. 136 designed to show? Where must the substance, to be submitted to the action of the fluid, be placed? What is said of the electrical effects of a simple galvanic circle?

especially those of cold-blooded animals, such as frogs, &c., the tongue, the eye, and other sensitive parts of the body, being very easily affected, afford examples of the operation of simple galvanic circles. In these, although the quantity of electricity set in motion is exceedingly small, it is yet sufficient to produce very considerable effects; but it produces little or no effect on the most delicate electrometer.

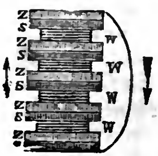
272. The galvanic effects of a simple circle may be increased to any degree, by a repetition of the same simple combination.

Such repetitions constitute compound galvanic circles, and are called galvanic piles or galvanic batteries, according to the mode in which they are constructed.

273. The voltaic pile consists of alternate plates of two different kinds of metal, separated by woollen cloth, card, or some similar substance.

1. Fig. 137 represents a voltaic pile. A voltaic pile may be constructed in the following manner: take a number of plates of silver, and the same number of zinc, and also of woollen cloth, the cloth having been soaked in a solution of sal ammoniac in water; with these a pile is to be formed in the following order: namely, a piece of silver, a piece of zinc, a piece of cloth, and thus repeated. These are to be supported by three glass rods, placed perpendicularly with pieces of wood at the top and bottom, and the pile will then be complete; and will afford a constant current of electric fluid through any conducting substance. Thus, if one hand be applied to the lower plate, and the other to the upper one, a shock will be felt, which will be repeated as often as the contact is renewed.

Fig. 137.



Instead of silver, copper plates, or plates of other metal,

What examples are given illustrating the operation of simple galvanic circles?

272. How may the galvanic effects of the simple circle be increased? What are compound galvanic circles?

273. Of what does the voltaic pile consist? What does Fig. 137 represent? How may a voltaic pile be constructed? Can any other metal be used? What are the arrows in the figure designed to show?

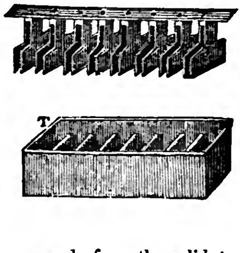
may be used in the above arrangement The arrows in the figure, show the course of the current of electricity in the arrangement of silver, zinc, &c.

2. Voltaic piles have been constructed of layers of gold and silver paper. The effect of such piles remains undisturbed for years. With the assistance of two such piles, a kind of *perpetual motion*, or self-moving clock, has been invented by an Italian philosopher. The motion is produced by the attraction and repulsion of the piles exerted on a pith ball, on the principle of the electrical bells. The top of one of the piles was positive, and the bottom negative. The other pile was in an opposite state; namely, the top negative, and the bottom positive.

274. The voltaic or galvanic battery is a combination of metallic plates, immersed by pairs in a fluid which exerts a chemical action on one of each pair of the plates, and no action, or, at least, a different action on the other.*

1. Fig. 138 represents a voltaic battery. It consists of a trough made of baked wood, wedgewood-ware, or some other non-conducting substance. It is divided into grooves or partitions, for the reception of the acid, or a saline solution, and the plates of zinc or copper (or other metals) are immersed by pairs in the grooves. These pairs of plates are united by a slip of metal passing from the one and soldered to the other; each pair being placed so as to enclose a partition between them, and each cell or groove in the trough containing

Fig. 138.



* The electricity excited by the battery, proceeds *from* the solid *to* the fluid which acts upon it chemically. Thus, in a battery composed of zinc, diluted sulphuric acid, and copper, the acid acts upon the zinc, and not on the copper. The galvanic fluid proceed, therefore, from the zinc to the acid, from the acid to the copper, &c. Instead of using two different metals to form the galvanic circuit, one metal, in different states, may be

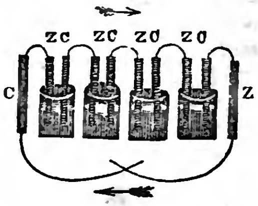
274. What is the voltaic battery? What is said in the note with regard to the electricity excited by the battery? What does Fig. 138 represent? Of what does the voltaic battery consist?

a plate of zinc, connected with the copper plate of the succeeding cell, and a copper plate joined with the zinc plate of the preceding cell. These pairs must commence with copper and terminate with zinc, or commence with zinc and terminate with copper. The communication between the first and last plates is made by wires, which thus complete the galvanic circuit. The substance to be submitted to galvanic action is placed between the points of the two wires.

2. A compound battery of great power is obtained by uniting a number of these troughs. In a similar manner a battery may be produced by uniting several piles, making a metallic communication between the last plate of the one and the first plate of the next, and so on, taking care that the order of succession of the plates in the circuit be preserved inviolate.

3. The *Couronne des tasses*, represented in Fig. 139, is another form of the galvanic battery. It consists of a number of cups, bowls, or glasses, with the zinc and copper plates immersed in them, in the order represented in the figure; Z indicating the zinc, and C the copper plates; the arrows denoting the course of the electric fluid.

Fig. 139.



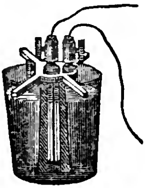
4. The electric shock from the voltaic battery may be received by any number of persons, by joining hands, having previously wetted them.

employed; the essential principle being, that one of the elements shall be more powerfully affected by some chemical agent than the other. Thus, if a galvanic pair be made of the same metal, one part must be softer than the other, (as is the case with cast and rolled zinc;) or a greater amount of surface must be exposed to corrosion on one side than on the other; or a more powerful chemical agent be used on one side, so that a current will be sent from the part most corroded, through the liquid, to the part least corroded, whenever the poles are united and the circuit thereby completed.

How is the communication between the first and last plates made? Where must the substance, which is to be submitted to galvanic action, be placed? How can a compound battery of great power be obtained? What does Fig. 139 represent? Of what does this battery consist? How can the electric shock, from the voltaic battery, be received by any number of persons?

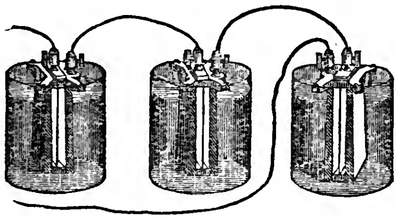
5. SMEE'S GALVANIC BATTERY is represented in Fig. 140, and affords an instance of a battery in its simplest form. It consists of a glass vessel, (as a tumbler,) on which rests the frame that supports the apparatus within. Two screw-cups rise from the frame, to which wires may be attached for the conveyance of the electric current in any direction. One of the screw-cups communicates with a thin strip of platinum, or platinum foil, which is suspended within the glass vessel between two plates of zinc, thus presenting each surface of the platinum to a surface of zinc; and the galvanic action is in proportion to the extent of the opposite surfaces of the two metals, and their nearness to each other. The other screw-cup is connected with the two zinc plates. The screw-cup connected with the platinum is insulated from the metallic frame which supports it, by rosewood, and a thumb-screw confines the zinc plates, so that they can be renewed when necessary. The liquid employed for this battery is sulphuric acid, or oil of vitriol, diluted with ten parts of water by measure. To prevent the action of the acid upon the zinc plates, their surfaces are commonly amalgamated, or combined with mercury, which prevents any chemical action of the acid with the zinc until the galvanic circuit is established, when the zinc is immediately attacked by the acid.

Fig. 140.



6. Fig. 141 represents a series of three pairs of this battery,

Fig. 141.



in which it will be observed that the platinum of one is connected with the zinc of the next, and that the terminal wires proceed,

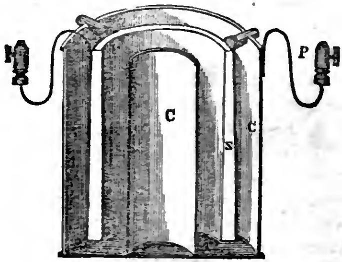
What figure represents Smee's galvanic battery? Describe it. What liquid is employed for this battery? Describe Fig. 141.

consequently, one from a platinum plate, and the other from a zinc plate, as in a single pair.

7. Sulphate of Copper Battery. Fig. 142 represents a sulphate of copper battery, and Fig. 143 a vertical section of the same battery. It consists of a double cylinder of copper, C C, Fig. 143, with a bottom of the same metal, which serves the double purpose of a galvanic plate, and a vessel to contain the exciting solution. The solution is contained in the space between the two copper cylinders. A moveable cylinder of zinc, Z, is let down into the solution whenever the battery is to be used. It rests on three arms of wood or ivory at the top, by means of which it is insulated. Thus suspended in the solution, the surfaces of zinc and copper respectively, face each other. A screw-cup, N, is attached to the zinc, and another, P, to the copper cylinder, to receive the wires. When a communication is made between the two cups, electricity is excited. The liquid employed in this battery is a solution of sulphate of copper (common blue vitriol) in water. A saturated solution is first made, and to this solution as much more water is added.*

Fig 142.

Fig. 143.

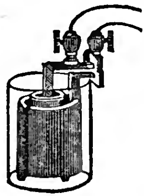


* A pint of water will dissolve about a quarter of a pound of blue vitriol. The solution described above will therefore contain about two ounces of the salt to the pint. The addition of alcohol, in small quantities, increases

Describe the sulphate of copper battery.

8. Grove's Battery. This is the most energetic battery yet known, and is the one most generally used for the magnetic telegraph. The metals employed are platinum and zinc, and the solutions are strong nitric acid, in contact with the platinum, and sulphuric acid diluted with ten or twelve parts of water in contact with the zinc. This battery must be used with great care on account of the strength of the acids used for the solutions, which send out injurious fumes, and which are destructive to organic substances. Fig. 144 represents Grove's battery. The containing vessel is glass; within this is a thick cylinder of amalgamated zinc, standing on short legs, and divided by a longitudinal opening on one side, in order to allow the acid to circulate freely. Inside of this is a porous cell of unglazed porcelain, containing the nitric acid, and strip of platinum. The platinum is supported by a strip of brass fixed by a thumb-screw and an insulating piece of ivory to the arm proceeding from the zinc cylinder. The amalgamated zinc is not acted upon by the diluted sulphuric acid, until the circuit of the battery is completed. But as the nitric acid will filter through the porous

Fig. 144.



the permanency of the action of the solution The zinc cylinder should always be taken out of the solution when the battery is not in use; but the solution may remain in the battery. The battery will keep in good action for twenty or thirty minutes at a time.

The sulphate of copper battery, although not so energetic as Smee's, is found very convenient in a large class of experiments, and is particularly recommended to those who are inexpert in the use of acids; because the sulphate of copper being entirely neutral, will not injure the color nor the texture of organic substances.

There is another form of the sulphate of copper battery, called the *Protected Sulphate of Copper Battery*, which differs from the one described in having a porous cell of earthenware, or leather, interposed between the zinc and the copper, thus forming two cells, in the outer of which sulphate of copper may be used, and in the inner one a solution of sulphate of soda, (Glauber salt,) or chloride of sodium, (common salt,) or even dilute sulphuric acid. This battery will continue in use for several days, and it is therefore of great use in the electrotype process.

Describe Grove's battery. Which is the most powerful battery? For what is it used?

cell, and act upon the zinc, it is advisable to remove the zinc from the acid when the battery is to remain inactive. The action of Grove's battery may be considered as three times greater than that of the sulphate of copper battery.

275. The spark from a powerful voltaic battery acts upon and inflames gunpowder, charcoal, cotton, and other inflammable bodies, fuses all metals, burns up or disperses diamonds and other substances on which heat in other forms produces little or no effect.*

The wires, by which the circuit of the battery is completed, are generally covered with glass tubes, in order that they may be held, or directed to any substance.

276. There are three principal circumstances in which the electricity produced by the galvanic or voltaic battery, differs from that obtained by the ordinary electrical machine, namely,—

1st. The very low degree of *intensity*† of that pro-

* The most striking effects of Galvanism on the human frame, after death, were exhibited at Glasgow, a few years ago. The subject on which the experiments were made, was the body of the murderer Clydesdale, who was hanged at that city. He had been suspended an hour, and the first experiment was made in about ten minutes after he was cut down. The galvanic battery employed consisted of 270 pairs of four-inch plates. On the application of the battery to different parts of the body, every muscle was thrown into violent agitation; the leg was thrown out with great violence, breathing commenced, the face exhibited extraordinary grimaces, and the finger seemed to point out the spectators. Many persons were obliged to leave the room from terror or sickness; one gentleman fainted, and some thought that the body had really come to life.

† By *intensity* is here meant the same that is implied by density, as applied to matter. The *quantity* of electricity obtained by galvanic action is much greater than can be obtained by the machine; but it flows, as it were, in narrow streams. The action of the electrical machine may be

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275 What effects may be produced by a spark from a voltaic battery? What precaution is taken in regard to the lines of the circuit?

276. In how many ways does the electricity produced by the galvanic or voltaic battery differ from that obtained by the ordinary electrical machine? What is the first? What is here meant by intensity? How does the quantity of electricity obtained by galvanic action, compare with that obtained by the machine?

duced by the galvanic battery, compared with that obtained by the machine.

2d. The very large quantity of electricity which is set in motion by the voltaic battery; and,

3d. The continuity of the current of voltaic electricity, and its perpetual reproduction, even while this current is tending to restore the equilibrium.*

A common electrical battery may be charged from a voltaic battery of sufficient size; but a battery constructed of a small number of pairs, even though the plates are large, furnishes no indication of attraction or repulsion equal to that which is given

compared to a mighty torrent, dashing and *exhausting itself* in one leap from a precipitous height. The galvanic action may be compared to a steady stream, supplied by an inexhaustible fountain. In other words, the *momentum* of the electricity excited by galvanism is less than that from the electrical machine; but the *quantity*, as has been stated, is greater.

* Whenever an electrical battery is charged, how great soever may be the quantity that it contains, the whole of the power is *at once* expended, as soon as the circuit is completed. Its action may be sufficiently energetic while it lasts, but it is exerted only for an instant, and like the destructive operation of lightning, can effect, during its momentary passage, only sudden and violent changes, which it is beyond human power to regulate or control. On the contrary, the voltaic battery continues, for an indefinite time, to develop and supply vast quantities of electricity, which, far from being lost by returning to their source, circulate in a perpetual stream, and with undiminished force. The effects of this continued current on the bodies subjected to its action, will, therefore, be more definite, and will be constantly accumulating; and their amount, in process of time, will be incomparably greater than even those of the ordinary electrical explosion. It is therefore found that changes in the composition of bodies are effected by galvanism, which can be accomplished by no other means. The science of Galvanism, therefore, has extended the field, and multiplied the means of investigation in the kindred sciences, especially that of Chemistry.

To what may the action of the electrical machine be compared? To what may the galvanic action be compared? What is the second way in which they differ? What is the third? What is said in the note with regard to the third circumstance in which the electricity obtained by the ordinary electrical machine differs from that produced by the galvanic battery? What is said of the effects of this continued current on the bodies subjected to its action?

by the feeblest degree of excitation to a piece of sealing-wax. A galvanic battery, consisting of fifty pairs of plates, will affect a delicate goldleaf electrometer; and, with a series of one thousand pairs, even pith balls are made to diverge.

277. The effect of the voltaic pile on the animal body depends chiefly on the *number* of plates that are employed; but the intensity of the spark and its chemical agencies increase more with the *size* of the plates, than with their number. Galvanism explains many facts in common life.

1. Porter, ale, or strong beer, is said to have a peculiar taste when drunk from a pewter vessel. The peculiarity of taste is caused by the galvanic circle formed by the pewter, the beer, &c., and the moisture of the under lip.

Works of metals, the parts of which are soldered together, soon tarnish in the places where the metals are joined.

Ancient coins, composed of a mixture of metal, have crumbled to pieces, while those composed of pure metal have been uninjured.

The nails and the copper in sheathing of ships are soon corroded about the place of contact. These are all the effects of galvanism.

There are persons who profess to be able to find out seams in brass and copper vessels by the tongue, which the eye cannot discover; and, by the same means, to distinguish the base mixtures which abound in gold and silver trinkets.

2. From what has now been stated, it will be seen that the effects of galvanic action depend on two circumstances, namely; 1st, the size of the plates employed in the circuit; and, 2dly, the number of the pairs constituting a battery. But there is a remarkable circumstance to be noticed in this connexion; namely, that there is one class of facts dependent on the extension of the size of the plates, and another on the increase of their number. *The power to develop heat and magnetism is dependent on the size of the plates,* that is, on the extent of the surfaces acted upon by the chemical agent; while the power to decompose chemical compounds, and to affect the animal system, is affected in a greater ratio by the increase of the number

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277. On what does the effect of the voltaic pile on the body depend? What facts in common life does galvanism explain? On what does the effects of galvanic action depend?

of the pairs. Batteries constructed of large plates are sometimes called *Calorimotors*,* from their great power of producing heat. They usually consist of from one to eight pairs of plates. They are made in various forms; sometimes the sheets of copper and zinc are coiled in concentric spirals, sometimes placed side by side; and they may be divided into a great number of small plates, *provided that all the zinc plates are connected together, and all the copper plates together, and then that the experiments are performed in a channel of communication, opened between the* SETS OF PLATES, *and not between* PAIRS *as in the common battery*, for it is immaterial whether one large surface be used, or many small ones electrically connected together. The effect of all these arrangements, by which the metallic surface of a single pair is augmented, is to increase the quantity produced.

3. The galvanic or voltaic battery is one of the most valuable acquisitions of modern science. It has proved in many instances the key by which science has entered into the innermost recesses of nature, and discovered the secret of many of her operations. It has, in great measure, lifted the hitherto impenetrable veil that has concealed the mysterious workings in the material world, and has opened a field for investigation and discovery as inviting as it is boundless. It has strengthened the sight, and enlarged the view of the philosopher and the man of science, and given a degree of certainty to scientific inquiry hitherto known to be unreached, and supposed to be unattainable; and if it has not yet satisfied the hopes of the Alchymist, nor emulated the gold-converting touch of Midas, it has shown, almost to demonstration, that science may yet achieve wonders beyond the stories of Mythology, and realize the familiar adage that "*truth is stranger than fiction.*"

* The name *Calorimotor* (that is, *the mover of heat*) was applied by Dr. Hare of Philadelphia to a very powerful apparatus which he constructed, and which he found possessed of a very remarkable power in producing heat.

What are batteries constructed of large plates sometimes called? Why? Describe them. Upon what principle is the calorimotor constructed? Are galvanic batteries of value?

CHAPTER XIII.

MAGNETISM AND ELECTRO-MAGNETISM.

278. Magnetism treats of the properties and effects of the magnet, or loadstone.*

There are two kinds of magnets, namely, the native or natural magnet, and the artificial.

The native magnet, or loadstone,† is an ore of iron, found in iron mines, and has the property of attracting iron and other substances which contain it.

A permanent artificial magnet is a piece of iron to which permanent magnetic properties have been communicated.

For all purposes of accurate experiment, the artificial is to be preferred to the native magnet.

If a straight bar of soft iron be held in a vertical position, (or, still better, in a position slightly inclined to the perpendicular, the lower end deviating to the north,) and struck several smart blows with a hammer, it will be found to have

* That part of science which relates to the development of magnetism by means of a current of electricity, will be noticed under the head of Electro-Magnetism, in which connexion will also be mentioned the development of electricity by magnetism, to which the term Magneto-Electricity has been applied.

† Certain ores of iron are found to be naturally possessed of magnetic properties, and are therefore called natural or native magnets, or loadstones. Besides iron and some of its compounds, *nickel* and perhaps *cobalt* also possess magnetic properties. But all conductors of electricity are capable of exerting the magnetic properties of attraction and repulsion while conveying a current of electricity, as will be shown under the head of Electro-Magnetism.

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278. Of what does Magnetism treat? How many kinds of magnets are there? What are they? What is the native magnet? What property does it possess? What is an artificial magnet? What magnet is preferred, for all purposes of accurate experiment? How can an artificial magnet be made?

acquired, by this process, all the properties of a magnet; or, in other words, it will become an artificial magnet.

279. The properties of a magnet are four; namely,
1. Polarity.
2. Attraction of unmagnetic iron.
3. Attraction *and repulsion* of *magnetic* iron.
4. The power of communicating magnetism to other iron.

Besides these properties the magnet has recently been discovered to be possessed of electrical properties. These will be considered in another connexion.

280. By the *polarity* of a magnet is meant the property of pointing, or turning to the north and south poles. The end which points to the north, is called the north pole of the magnet, and the other the south pole. The attractive power of a magnet is strongest at the poles.*

When a magnet is supported in such a manner as to move freely, it will spontaneously assume a position directed *nearly* north and south.†

There are several ways of supporting a magnet, so as to enable it to manifest its polarity. *First,* by suspending it, accurately balanced, from a string. *Secondly,* by poising it on a sharp point. *Thirdly,* by attaching it to some buoyant substance and allowing it to float freely on water.

* The attractive power of a magnet is generally stated to be greatest *at the poles;* but the actual poles, or points of greatest magnetic intensity in a steel magnet, are not exactly at the ends, but a little within them.

† The points to which the poles of a magnet turn are the *magnetic poles.* These do not exactly coincide with the astronomical poles of the earth; but although the value of the magnetic needle has been predicated on the supposition that its polarity is a tendency to point exactly to the north and south poles of the earth, the recent discovery of the magnetic poles, as the points of attraction, has not depreciated the value of the compass, because the variation is known and can be corrected.

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279. What is the first property of the magnet? Second? Third? Fourth?

280. What is meant by the polarity of a magnet? Where is the attractive power of a magnet the strongest? When will a magnet assume a position directed nearly north or south? What is the north pole of the magnet? What is the south pole? In what ways can a magnet be supported so as to enable it to manifest its polarity?

281. Different poles of magnets attract, and similar poles repel each other.*

1. A magnet, whether native or artificial, attracts iron or steel which has no magnetic properties; but it both *attracts* and *repels* those substances, when they are magnetic; that is, the north pole of one magnet will attract the south pole of another, and the south pole of one will attract the north of another; but the north pole of the one *repels* the north pole of the other, and the south pole of one repels the south pole of another.

2. If either pole of a magnet be brought near any small piece of soft iron, it will attract it. Iron filings will also adhere in clusters to either pole.

282. A magnet may communicate its properties to other unmagnetized bodies. But these properties can be conveyed to no other substances than iron, nickel, or cobalt, without the aid of electricity.†

All permanent natural and artificial magnets, as well as the bodies on which they act, are either iron in its pure state, or such compounds as contain it.

The powers of a magnet are increased by action, and are impaired and even lost by long disuse.

* There is here a close analogy between the attractive and repulsive powers of the positive and the negative forms of electricity, and the northern and southern polarities of the magnet. The same law obtains with regard to both, namely—*between like powers there is repulsion; between unlike, there is attraction.*

† The accuracy of the above statement may, perhaps, be questioned, since Coulomb has discovered, that "*all solid bodies are susceptible of magnetic influence.*" But the "*influence*" is perceptible only by the nicest tests, and under peculiar circumstances. [See Electro-Magnetism.]

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281. How do the same and different poles of a magnet affect each other? What is said with regard to the attraction of magnets, whether native or artificial? What analogy is there between the attractive and repulsive powers of the different kinds of electricity, and the northern and southern polarities of the magnet?

282. Can a magnet communicate its properties to other bodies? To what substances, only, can these properties be conveyed? Of what substances are all natural and artificial magnets, as well as the bodies on which they act, composed? How can the powers of a magnet be increased?

1. When the two poles of a magnet are brought together, so that the magnet resembles in shape a horse-shoe, or the capital letter U, it is called a horse-shoe magnet, or a U magnet, and it may be made to sustain a considerable weight by suspending substances from a small iron bar, extending from one pole to the other. This bar is called the keeper. A small addition may be made to the weight every day.

2. Soft iron acquires the magnetic power very readily, and also loses it as readily,—hardened iron or steel acquires the property with difficulty, but retains it permanently.

283. When a magnet is broken or divided, each part becomes a perfect magnet, having both a north and south pole.

This is a remarkable circumstance, since the central part of a magnet appears to possess but little of the magnetic power, —but when a magnet is divided *in the centre*, this very part assumes the magnetic power, and becomes possessed, in the one part, of the north, and in the other, of the south polarity.

284. The magnetic power of iron or steel resides wholly on the surface, and is independent of its mass.*

* In this respect there is a strong resemblance between magnetism and electricity. Electricity, as has already been stated, is wholly confined to the surface of bodies. In a few words, magnetism and electricity may be said to resemble each other in the following particulars:

1. Each consists of two species, namely, the vitreous and the resinous (or, the positive and negative) electricities; and the northern and southern (sometimes called the *Boreal* and the *Astral*) polarity.

2. In both magnetism and electricity, those of the same name repel, and those of different names attract each other.

3. The laws of induction in both are similar.

4. The influence, in both cases, (as has just been stated,) resides at the *surface*, and is wholly independent of their *mass*.

What is a horse-shoe magnet? How can it be made to sustain a considerable weight? What is this bar called? How does soft iron differ from hardened iron, with respect to its acquiring and losing the magnetic power?

283. What effect is produced when a magnet is broken or divided? Why is this a remarkable circumstance?

284. Where does the magnetic power of iron or steel wholly reside? *Note.* In what particulars do magnetism and electricity resemble each other? What is the first? What is the second? What is the third? What is the fourth?

285. Heat weakens, and a great degree of heat destroys the power of a magnet; but the magnetic attraction is undiminished by the interposition of any bodies, except iron, steel, &c.

Electricity frequently changes the poles of a magnet; and the explosion of a small quantity of gunpowder, on one of the poles, produces the same effect.

Electricity, also, sometimes renders iron and steel magnetic, which were not so before the charge was received.

286. The effect produced by two magnets, used together, are much more than double that of either one used alone.

When a magnet is suspended freely from its centre, the two poles will not lie in the same horizontal direction. This is called the inclination or *the dipping* of the magnet.*

287. The magnet, when suspended, does not invariably point *exactly* to the north and south points, but varies a little towards the east or the west. This variation differs at different places, at different seasons, and at different times in the day.†

* The tendency of a magnetic needle to dip is corrected in the mariner's and surveyor's compasses, by making the south ends of the needles intended for use in northern latitudes somewhat heavier than the north ends. Compass-needles, intended to be employed on long voyages where great variations of latitude may be expected, are furnished with a small sliding weight, by the adjusting of which the tendency *to dip* may be counteracted. The cause of the dipping of the needle is the superior attraction caused by the closer proximity of the pole of the magnet to the magnetic pole of the earth. In north latitude, the north pole of the needle dips; in south latitude, the south pole.

† The variation of the magnetic needle from what has been supposed its true polarity, was a phenomenon that for centuries had baffled the

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285. What effect has heat on the power of the magnet? By what is the magnetic attraction diminished? What effect has electricity on the poles of a magnet? What effect has electricity sometimes on iron and steel?

286. What proportion do the effects produced by two magnets, used together, bear to that of either, used alone? What is meant by the inclination or dipping of the magnet?

287. Does the magnet, when suspended, invariably point to the north and south points?

1. The science of magnetism has rendered immense advantages to commerce and navigation, by means of the mariner's compass.* The mariner's compass consists of a magnetized bar of steel, called a *needle;* having at its centre a cap fitted to it,

science of the philosopher to explain. Recent discoveries have given a satisfactory explanation of this apparent anomaly. The earth has, in fact, four magnetic poles, two of which are strong and two are weak. The strongest north pole is in America, the weakest in Asia. The earth itself is considered as a magnet, or rather, as composed in part of magnetic substances, so that its action at the surface is irregular. The variation of the needle from the true geographical meridian is therefore subject to changes more or less irregular.

This subject is very ably treated in "Davis' Manual of Magnetism," (edition of 1847,) to which the student is referred, as probably the best treatise on the subject that has ever been published. Mr. Davis is one of those scientific and skilful mechanics, (of whom there are not a few among us,) who have, as it were, forced their way into the temple of science amid discouragements and difficulties, but have deposited richer gifts on the altar than most of those whose contributions were expected. He has originated many improvements in this department of science; and his devotion to the subject has probably rendered him as familiar with all the peculiar phenomena relating to it, as any one in or out of the country His address is, Daniel Davis, Jr., Magnetical Instrument Maker, 428 Washington-street, Boston.

* The invention of the mariner's compass is usually ascribed to Flavio de Melfi, or Flavio Gioia, a Neapolitan, about the year 1302. Some authorities, however, assert that it was brought from China by Marco Paolo, a Venetian, in 1260. The invention is also claimed both by the French and English.

The value of this discovery may be estimated from the consideration, that, before the use of the compass, mariners seldom trusted themselves out of sight of land; they were unable to make long or distant voyages, as they had no means to find their way back. This discovery enabled them to find a way where all is trackless; to conduct their vessels through the mighty ocean, out of the sight of land; and to prosecute those discoveries, and perform those gallant deeds, which have immortalized the names of Cook, of La Perouse, Vancouver, Sir Francis Drake, Nelson, Parry, Franklin, and others.

What advantage has the science of magnetism rendered to commerce and navigation? Of what does the mariner's compass consist? *Note.* To whom is the invention of the mariner's compass usually ascribed? How may the value of this discovery be estimated?

which is supported on a sharp-pointed pivot fixed in the base of the instrument. A circular plate, or card, the circumference of which is divided into degrees, is attached to the needle, and turns with it. On an inner circle of the card the thirty-two points of the mariner's compass are inscribed.*

2. The needle is generally placed *under* the card of a mariner's compass, so that it is out of sight; but small needles, used on land, are placed above the card, not attached to it, and the card is permanently fixed to the box.

288. The north pole of a magnet is more powerful in the northern hemisphere, or north of the equator, and the south pole in the southern parts of the world.

1. When a piece of iron is brought sufficiently near to a magnet, it becomes itself a magnet; and bars of iron, that have stood long in a perpendicular situation, are generally found to be magnetical.

2. Artificial magnets are made by applying one or more powerful magnets to pieces of soft iron.† The end which is touched by the north pole becomes the south pole of the new magnet, and that touched by the south pole becomes the north pole. The magnet which is employed in magnetizing a steel bar loses none of its power by being thus employed; and as the effect is increased when two or more magnets are used, with one magnet a number of bars may be magnetized, and then combined together; by which means their power may be

* The compass is generally fitted by two sets of axes to an outer box, so that it always retains a horizontal position, even when the vessel rolls. When the artificial magnet or *needle* is kept thus freely suspended, so that it may turn north or south, the pilot, by looking at its position, can ascertain in what direction his vessel is proceeding; and, although the needle varies a little from a correct polarity, yet this variation is neither so great, nor so irregular, as seriously to impair its use as a guide to the vessel in its course over the pathless deep.

† This mode of making artificial magnets is likely to be wholly superseded by the new mode by electrical aid, which will be noticed in connexion with Electro-Magnetism.

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288. Where are the north and south poles of a magnet the most powerful? What effect has a magnet on a piece of iron, when it is brought sufficiently near to it? How are artificial magnets made? Does the magnet which is employed in magnetizing a steel bar lose any of its power by being thus employed?

indefinitely increased. Such an apparatus is called a *magnetic magazine.**

3. A magnetic needle is made by fastening the steel on a piece of board, and drawing magnets over it from the centre outwards.

4. A horse-shoe magnet should be kept *armed*, by a small piece of iron or steel, connecting the two poles.

5. Interesting experiments may be made by a magnet, even of no great power, with steel or iron filings, small needles, pieces of ferruginous substances, and black sand, which contains iron. Such substances may be made to assume a variety of amusing forms and positions, by moving the magnet *under* the card, paper, or table, on which they are placed. Toys, representing fishes, frogs, &c., which are made to appear to bite at a hook, birds floating on the water, &c., are constructed on magnetic principles, and sold in the shops.

* There are many methods of making artificial magnets. One of the most simple and effectual consists in passing a strong horse-shoe magnet over bars of soft iron.

In making bar (or straight) magnets, the bars must be laid lengthwise, on a flat table, with the marked end of one bar against the unmarked end of the next; and in making horse-shoe magnets, 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 two capital U's, with their tops joined together, thus ⊂⊃, observing that the marked ends come opposite to those which are not marked; and then, in either case, a strong horse-shoe 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 then to proceed to an unmarked end, and enter the next bar at its marked end, and so proceed.

After having thus 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 be moved *even once* over the bars in a contrary direction, or if its south pole should be permitted to precede, after the north pole has been first used, all the previously excited magnetism will disappear, and the bars will be found in their original state.

What is a magnetic magazine? How is a magnetic needle made? What is said with regard to a horse-shoe magnet? How should a horse-shoe magnet be kept?

ELECTRO-MAGNETISM.

289. Electro-Magnetism relates to magnetism which is induced by the agency of electricity.*

* The passage of the two kinds of electricity (namely, the positive and the negative) through their circuit, is called the electric currents; and the science of Electro-Magnetism explains the phenomena attending those currents. It has already been stated, that, from the connecting wires of the galvanic circle, or battery, there is a constant current of electricity passing from the zinc to the copper, and from the copper to the zinc plates. In the single circle these currents will be negative from the zinc, and positive from the copper; but in the compound circles, or the battery, the current of positive electricity will flow from the zinc to the copper, and the current of negative electricity from the copper to the zinc. From the effect produced by electricity on the magnetic needle, it had been conjectured, by a number of eminent philosophers, that magnetism, or magnetic attraction is in some manner caused by electricity. In the year 1819, Professor Œrsted of Copenhagen, made the grand discovery of the power of the electric current to induce magnetism; thus proving the connexion between magnetism and electricity. In a short time after the discovery of Professor Œrsted, Mr. Faraday discovered that an electrical spark could be taken from a magnet; and thus the common source of magnetism and electricity was fully proved. In a paper published a few years ago, this distinguished philosopher has very ably maintained the identity of common electricity, voltaic electricity, magnetic electricity, (or electro-magnetism,) thermo-electricity, and animal electricity. The phenomena exhibited in all these five kinds of electricity differ merely in degree and the state of intensity in the action of the fluid. The discovery of Professor Œrsted has been followed out by Ampère, who, by his mathematical and experimental researches, has presented a theory of the science less obnoxious to objections than that proposed by the Professor. The discovery of Œrsted was limited to the action of the electric current on needles *previously magnetized;* it was afterwards ascertained by Sir Humphrey Davy, and M. Arago, that magnetism may be developed in steel not pre-

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289. Of what does Electro-Magnetism treat? *Note.* What is the electric current? What does the science of electro-magnetism explain? What is the difference between the currents in the single and the compound circles? What is it thought causes magnetic attraction? What discovery was made in the year 1819? By whom? What further discovery was made soon after, and by whom? What does this philosopher maintain? How many kinds of electricity are there? How do the phenomena exhibited in these five kinds of electricity differ?

290. The principal facts in connexion with the science of electro-magnetism are,—

1. That the electrical current, passing *uninterruptedly** through a wire, connecting the two ends of a galvanic battery, produces an effect upon the magnetic needle.
2. That electricity will induce magnetism.
3. That a magnet, or a magnetic magazine, will induce electricity.†
4. That the combined action of electricity and magnetism, as described in this science, produces a rotatory motion of certain kinds of bodies, in a direction pointed out by certain laws.
5. That the periodical variation of the magnetic needle from the true meridian, or, in other words, the variation of the compass, is caused by the influence of the electric currents.
6. That the magnetic influence is not confined to iron, steel, &c., but that most metals, and many other substances, may be converted into temporary magnets by electrical action.
7. That the magnetic attraction of iron, steel, &c. may be prodigiously increased by electrical agency.

viously possessing it, if the steel be placed in the electric current. Both of these philosophers, independently of each other, ascertained that the uniting wire, becoming a magnet, attracts iron filings, and collects sufficient to acquire the diameter of a common quill but the moment the connexion is broken, all the filings drop off, and the attraction diminishes with the decaying energy of the pile. Filings of brass or copper, or wood shavings, are not attracted at all.

* All the effects of electricity and galvanism that have hitherto been described, have been produced on bodies *interposed* between the extremities of conductors, proceeding from the positive and negative poles. It was not known, until the discoveries of Professor Œrsted were made, that any effect could be produced when the electric circuit is *uninterrupted.*

† The consideration of the subject of electricity, induced by magnetism, properly belongs to the subject of Magneto-Electricity, in which connexion it will be particularly noticed.

Note. Can magnetism be developed in steel not previously possessing it Where must the steel be placed? What property has the uniting wire?

290. What are the principal facts in connexion with the science of electro-magnetism? What is the first? What is the second? What is the third? What is the fourth? What is the fifth? What is the sixth? What is the seventh?

8. That the *direction* of the electric current may, in all cases, be ascertained.*

9. That magnetism is produced whenever concentrated electricity is passed through space.

10. That while in common electrical and magnetic attractions and repulsions, those of the same name are mutually repulsive, and those of different names attract each other; in the attractions and repulsions of *electric currents*, it is precisely the reverse, the repulsion taking place only when the wires are so situated that the currents are in *opposite direction*.

291. A magnet freely suspended tends to assume a position at right angles to the direction of a current of electricity passing near it.

1. If a wire, which connects 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, whether the wire be on one side of the needle or the other, provided only, that it be parallel with it.

Again, 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 attraction of the earth, and the manner in which it is suspended. When the wire is to the east of the needle, the pole

* This is done by means of the magnetic needle. If a sheet of paper be placed over a horse-shoe magnet, and fine black sand, or steel filings, be dropped loosely on the paper, the particles will be disposed to arrange themselves in a regular order, and in the direction of curve lines. This is, undoubtedly, the effect of some influence, whether that of electricity, or of magnetism alone, cannot at present be determined.

Where have the bodies been supposed to be placed, in all the effects of electricity and galvanism that have hitherto been described? What is the eighth fact in connexion with the science of electro-magnetism? What is the ninth? What is the tenth? How can the direction of the electric current be ascertained?

291. If a magnet be freely suspended, and a current of electricity be passed near it, what direction will it assume? What illustration of this is given? What second illustration is given?

nearest to the negative extremity of the battery will be elevated; and when it is on the west side, that pole will be depressed.

2. 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 the reverse of those observed in the former case.*

292. The two sides of an unmagnetized steel needle will become endued with the north and south polarity, if the needle be placed parallel with the connecting wire of a voltaic battery, and nearly or quite in contact with it. But if the needle be placed at right angles with 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 freely suspended and suffered to vibrate undisturbed.

293. Magnetism may be communicated to iron and steel by means of electricity from an electrical machine; but the effect can be more conveniently produced by means of the voltaic battery. This phenomenon is called *electro-magnetic induction.*

* The action of the conducting-wire in these cases exhibits a remarkable peculiarity. All other known forces exerted between two points, act in the direction of a straight line connecting these points; and such is the case with electric and magnetic actions, separately considered; but the electric current exerts its magnetic influence laterally, at right angles to its own course. Nor does the magnetic pole move either directly towards or directly from the conducting-wire, but tends to revolve around it without changing its distance. Hence the force must be considered as acting in the direction of a *tangent* to the circle in which the magnetic pole would move.

In what direction will the pole of the needle next to the negative end of the wire move, if the connecting wire be placed below the plane in which the needle moves, and parallel with it? What is said with regard to the attractions and repulsions?

292. How may the two sides of an unmagnetized steel needle become endued with the north and south polarity? Under what circumstances will it become permanently magnetic?

293. How can magnetism be communicated to iron and steel? How can the effect be more conveniently produced?

1. If a *helix** be formed of wire, and a bar of steel be enclosed within the helix, the bar will immediately become magnetic by applying the conducting wires of the battery to the extremities of the helix. The electricity from the common electrical machine, when passed through the helix, will produce the same effect.

2. 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.

294. If a magnetic needle be surrounded by coiled wire, covered with silk, a very minute portion of electricity through the wire will cause the needle to deviate from its proper direction.

A needle thus prepared, is called an electro-magnetic multiplier. It is, in fact, a very delicate electroscope, or rather *galvanometer*,—capable of pointing out the direction of the electric current in all cases.

295. Among the most remarkable of the facts connected with the science of electro-magnetism, is what is called the electro-magnetic rotation. Any wire, through which a current of electricity is passing, has a tendency to revolve around a magnetic pole, in a plane perpendicular to the current; and that without reference to the axis of the magnet, the pole of which is used. In like manner a magnetic pole has a tendency to revolve around such a wire.

1. Suppose the wire perpendicular, its upper end positive, or attached to the positive pole of the voltaic battery, and its

* The *helix* is a spiral line, or a line in the form of a corkscrew. The wire which forms the helix should be coated with some non-conducting substance, such as silk wound around 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.

What illustration of this is given? *Note.* What is the helix? Why should the wire, which forms the helix, be coated with some non-conducting substance? What is said of a helix, if it be placed so that it may move freely?

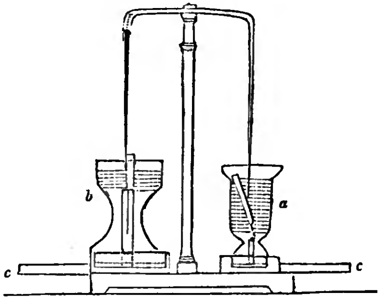
294. How can the magnetic needle be made to deviate from its proper direction? What is a needle thus prepared called?

295. What is the electro-magnetic rotation? What illustration is given?

lower end negative; and let the centre of a watch-dial represent the magnetic pole: if it be a north pole, the wire will rotate round it in the direction that the hands move; if it be a south pole, the motion will be in the opposite direction. From these two, the motions which would take place if the wire were inverted, or the pole changed, or made to move, may be readily ascertained, since the relation now pointed out remains constant.

2. Fig. 145 represents the ingenious apparatus, invented by Mr. Faraday, to illustrate the electro-magnetic rotation. The central pillar supports a piece of thick copper wire, which, on the one side, dips into the mercury contained in a small glass cup *a*. To a pin at the bottom of this cup, a small cylindrical magnet is attached by a piece of thread, so that one pole shall rise a little above the surface of the mercury, and be at liberty to move around the wire. The bottom of the cup is perforated, and has a copper pin passing through it, which, touching the mercury on the inside, is also in contact with the wire that proceeds outwards, on that side of the instrument. On the other side of the instrument, *b*, the thick copper wire, soon after turning down, terminates, but a thinner piece of wire forms a communication between it and the mercury on the cup beneath. As freedom of motion is regarded in the wire, it is made to communicate with the former by a ball and socket-joint, the ball being held in the socket by a piece of thread; or else the ends are bent into hooks, and the one is then hooked to the other. As good metallic contact is required, the parts should be amalgamated, and a small drop of mercury placed between them; the lower ends of the wire

Fig. 145.



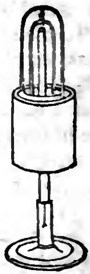
What does Fig. 145 represent? Explain the figure. How is the freedom of motion, which is required on the wire, obtained? How can the metallic contact which is required be obtained?

should also be amalgamated. Beneath the hanging wire, a small circular magnet is fixed in the socket of the cup *b*, so that one of its poles is a little above the mercury. As in the former cup, a metallic connexion is made through the bottom, from the mercury to the external wire.

If now the poles of a battery be connected with the horizontal external wires, *c c*, the current of electricity will be through the mercury and the horizontal wire, on the pillar which connects them, and it will now be found, that the moveable part of the wire will rotate around the magnetic pole in the cup *b*, and the magnetic pole round the fixed wire in the other cup *a*, in the direction before mentioned.

By using a very delicate apparatus, the magnetic pole of the earth may be made to put the wire in motion.

Fig. 146.



3. Fig. 146 represents another ingenious contrivance, invented by M. Ampère, for illustrating the electro-magnetic rotation; and it has the advantage of comprising within itself the voltaic combination which is employed. It consists of a cylinder of copper about two inches high, and a little less than two inches internal diameter, within which is a small cylinder, about one inch in diameter. The two cylinders are connected together by a bottom, having an aperture in its centre the size of the smaller cylinder, leaving a circular cell, which may be filled with acid. A piece of strong copper wire is fastened across the top of the inner cylinder, and from the middle of it rises, at a right angle, a piece of copper wire, supporting a very small metal cup, containing a few globules of mercury. A cylinder of zinc, open at each end, and about an inch and a quarter in diameter, completes the voltaic combination. To the latter cylinder a wire, bent like an inverted U, is soldered at opposite sides; and in the bend of this wire a metallic point is fixed, which, when inserted in the little cup of mercury, suspends the zinc cylinder in the cell, and allows it a free circular motion. An additional point is directed down-

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If the poles of a battery be connected with the horizontal external wires, *c c*, throughout, what direction will the current of electricity take? Round what pole will the moveable part of the wire rotate? Round what will the magnetic pole rotate? What does Fig. 146 represent? Of what does it consist?

wards from the central part of the stronger wire, which point is adapted to a small hole at the top of a powerful bar magnet. When the apparatus with one point only is charged with diluted acid, and set on the magnet placed vertically, the zinc cylinder revolves in a direction determined by the magnetic pole which is uppermost. With two points, the copper revolves in one direction, and the zinc in a contrary direction.

4. If, instead of a bar magnet, a horse-shoe magnet be employed, with an apparatus on each pole similar to that which has now been described, the cylinders in each will revolve in opposite directions. The small cups of mercury mentioned in the preceding description are sometimes omitted, and the points are inserted in an indentation on the inverted U.*

296. The magnetizing power of the conducting wires of a battery is very greatly increased by coiling it into a helix, into which the body to be magnetized may be inserted. A single circular turn is more efficient than a straight wire, and each turn adds to the power within a certain limit, whether the whole forms a single layer, or whether each successive turn encloses the previous one.

1. When a helix of great power is required, it is composed of several layers of wire. The wire forming the coil must be insulated by being wound with cotton, to prevent any lateral passage of the current.

2. Fig. 147 represents a helix on a stand. A bar of soft iron, N S, being placed within the helix, is connected with the

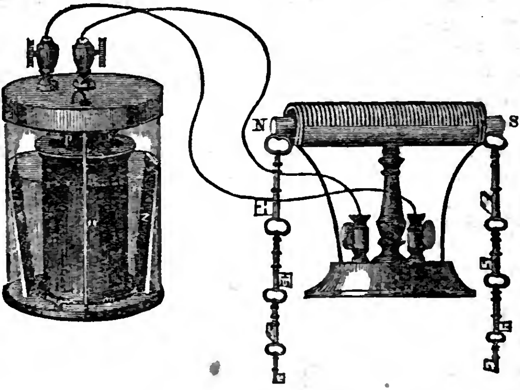
* The phenomenon of electro-magnetic rotation is beautifully illustrated by Mr. Davis, in his treatise on Magnetism, to which reference has already been made. He has invented and prepared a great variety of ingenious contrivances for the illustration of this subject, and his book should be in the hands of all who desire a thorough acquaintance with all that has been discovered in the new department of science in which magnetism and electricity are combined. The author has been indebted to Mr. Davis' volume for a number of explanations which are incorporated in this work.

How will the cylinders in each revolve, if, instead of a bar-magnet, a horse-shoe magnet be employed, with an apparatus on each pole similar to that which has now been described?

296. How may the magnetizing power of the connecting wires be increased? Is a single circuit preferable to a straight wire? Explain Fig. 147.

battery by means of the screw-cups on the base of the stand. The two extremities of the bar instantly become strongly

Fig. 147.



magnetic, and keys, or pieces of iron, iron filings, nails, &c. will be held up so long as the connexion with the battery is sustained. But so soon as the connexion is broken, the bar loses its magnetic power, and the suspended articles will fall. The bar can be made alternately to take up and drop such magnetizable articles as are brought near it, as the connexion with the battery is made or broken.

3. A steel bar placed within the helix acquires the polarity less readily, but retains it after the connexion is broken. Small rods or bars of steel, needles, &c. may be made permanent magnets in this way.

297. A bar temporarily magnetized by the electric current is called an electro-magnet.

To ascertain the poles of an electro-magnet it must be observed that *the north pole will be at the farthest end of the helix when the current circulates in the direction of the hands of a watch.*

298. Magnets of prodigious power have been formed by means of voltaic electricity.

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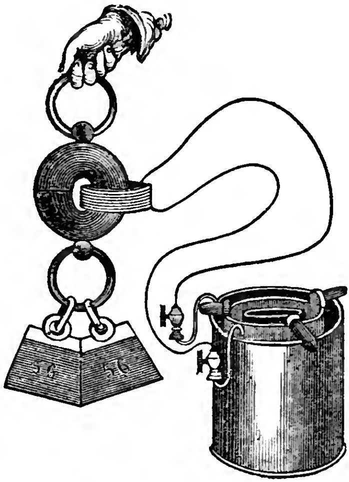
297. What is a bar called that is temporarily magnetized? How do you ascertain the poles of an electro-magnet?

298. How have magnets of great power been formed?

1. An electro-magnet was constructed by Professor Henry and Dr. Ten Eyck, which was capable of supporting a weight of 750 pounds. They have subsequently constructed another, which will sustain 2063 pounds. It consists of a bar of soft iron, bent into the form of a horse-shoe, 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 horse-shoe it forms three thicknesses of wire; and on the ends, or near the poles, it is wound so as to form six thicknesses. Being connected with a battery consisting of plates, containing a little less than forty-eight square feet of surface, the magnet supported the prodigious weight stated above, namely, 2063 pounds.

2. HELIACAL RING. Fig. 148 represents a heliacal ring, or ring of wire bent in the form of a helix, with the ends of the wire left free to be inserted in the screw-cups of a battery. Two semicircular pieces of soft unmagnetized iron, furnished with rings—the upper one for the hand, the lower one for weights—are prepared to be inserted into the helix, in the manner of the links of a chain. As soon as the ends of the helix are inserted into the screw-cups of the battery, the rings will be held together with great force, by magnetic attraction.*

Fig. 148.



* That the attraction is caused, or that the magnetism is induced by

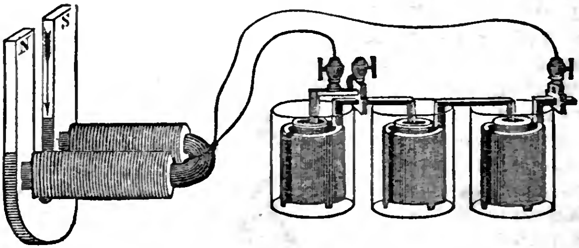
What weight was the magnet constructed by Professor Henry and Dr Ten Eyck capable of supporting? Explain the heliacal ring and Fig. 148

COMMUNICATION OF MAGNETISM TO STEEL BY THE ELECTRO-MAGNET.

299. Bars of the U form are most readily magnetized by drawing them from the bend to the extremities, across the poles of the U electro-magnet, in such a way that both halves of the bar may pass at the same time over the poles to which they are applied. This should be repeated several times, recollecting always to draw the bar in the same direction.

Fig. 149 represents the U electro-magnet, with the bar to be magnetized. When the bar is thick both surfaces should

Fig. 149



be drawn across the electro-magnet, keeping each half applied to the same pole. To remove the magnetism it is only necessary to reverse the process by which it was magnetized, that is, to draw the bar across the electro-magnet in a contrary direction.

the circulation of electricity *around* the coils, may be proved by the following interesting experiment. Hold the heliacal ring *horizontally* over a plate of small nails, and suspend an unmagnetized bar *perpendicularly* on the *outside* of the ring, over the nails, and there will be no attraction. Suspend the bar *perpendicularly through* the helix, and the nails will all attach themselves to it in the form of tangents to the circles formed by the coils of the heliacal ring.

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299 How are bars of the U form most readily magnetized? Explain Fig. 149

THE ELECTRO-MAGNETIC TELEGRAPH.

300. From the description which has now been given of the electro-magnetic power, it will readily be perceived that a great force can be made to act, simply by bringing a wire into contact with another conductor, and that the force can be instantly arrested in its operation by removing the wire from the contact; in other words, that by connecting and disconnecting a helix with a battery a prodigious power can be made successively to act and cease to act. Advantage has been taken of this principle in the construction of the American electro-magnetic telegraph, which was matured by Professor Morse, and first put into operation between the cities of Baltimore and Washington, in 1844.* It comes not within the province of this work to enter into a minute description of this great invention, but the principles of its construction may be briefly stated as follows:

1. An electro-magnet is so arranged with its armature, that when the armature is attracted it communicates its motion to a lever, to which a blunt point is attached, which marks a narrow strip of paper, drawn under it by machinery resembling clock-work, whenever the electro-magnet is in action. When the electro-magnet ceases to act, the armature falls, and communicating its motion to the lever, the blunt point is removed from its contact with the paper. By this means, if one of the wires from the battery is attached to the screw-cup, whenever the other wire is attached to the remaining cup, the armature is powerfully attracted by the magnet, and the

* For a particular description of this wonderful invention, the student is referred to Davis' treatise on Magnetism, in which the parts are all described with a minuteness which leaves little more to be desired. The history, also, of the successive steps by which it was brought to its present degree of perfection, is also to be found in the same connexion. It will be sufficient here to state, that it was not until Professor Henry of Princeton, N. J., had discovered the mode of constructing the powerful electro-magnets which have been described, that this form of telegraph became possible.

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300. Explain the electro-magnetic telegraph.

point on the lever presses the paper into the groove of a roller, thereby making an indentation on the paper corresponding in length to the time during which the contact with the battery is maintained, the paper being drawn slowly under the roller.

An alphabet of signs or symbols, is formed by indentations of the paper varying in length, which is easily read by those connected with the telegraph. Thus, the letter *e* is represented by one short mark thus -; the letter *o*, by two marks thus - -; the letter *a*, by a short and a long one thus - —; the letter *f* by a short, a long, and a short one, thus - — -; the figure 1 by a short, two long, and a short one, thus - — — -. By such an arrangement all the letters and the numerals are represented by the telegraph.* A simple contrivance connected with the machinery causes a bell to strike when the telegraph commences its operations, and thus gives warning to the attendant.

2. It has already been stated that the motion of electricity exceeds in velocity even that of light, and that its velocity is equal to 288,000 miles in a second of time. The invention that thus enables man to communicate with his brother man, with a rapidity that sets time and space at defiance, deservedly ranks as one of the greatest ever achieved by human ingenuity.

* The following table presents a view of *Morse's Telegraphic Alphabet:*

A -—	B —---	C -- -	D —--	E -
F -—-	G ——-	H ----	I --	J —-—
K —-—	L ——	M ——	N —-	O - -
P -----	Q --—-	R - --	S ---	T —
U —--	V ---—	W -——	X -—--	Y -- -
	Z --- -	& - ---	&c. - --- -- -	

Numerals.

1 -——-	2 --—--	3 ---—-	4 ----—	5 ———
6 ------	7 ——--	8 —----	9 —--—	0 ———

An improvement on this mode of communication has very recently been made by Mr. House; by which, instead of an alphabet of signs, the letters themselves are actually printed on paper, or presented to the eye, to be read by the operator. This wonderfully ingenious piece of mechanism is constructed with a key board, precisely like that of a Piano-forte. The keys regulate the revolutions of a wheel, on which the letters or types are placed, and when pressed down by the finger of the operator, they present, each its own letter, to the eye of the operator at the remote station, or at his pleasure, (by the aid of compressed air, and subject to his own control,) print it in capital letters on paper before him. The precision with which a message or communication can thus be sent by this invisible power, to any distance however great, leaves little to be desired for the perfection of the instrument.

3. Electro-Magnetism as a Motive Power.—The first application of electro-magnetism as a motive power was made by Professor Henry, but he made no attempt to apply it to practical purposes. Dr. Page has gone further, and suggested improvements which have overcome some of the obstacles to the employment of this power. But thus far it has been found that the smallest machines present the strongest probability of this power becoming available.

MAGNETO-ELECTRICITY.

301. Magneto-Electricity treats of the development of electricity by magnetism.

Electric currents are excited in a conductor of electricity by magnetic changes taking place in its vicinity. Thus, the movement of a magnet near a metallic wire, or near an iron bar enclosed in a wire coil, occasions currents in the wire.

1. When an armature, or any piece of soft iron, is brought into contact with one or both of the poles of a magnet, it becomes itself magnetic by induction, and by its reaction adds to the power of the magnet: on the contrary, when removed from the contact, it diminishes the power of the magnet, and these alternate changes in its magnetic state induce a current of electricity.

2. The most powerful effects are obtained by causing a bar of soft iron, enclosed in a helix, to revolve *by mechanical means* near the poles of a steel magnet. As the iron approaches the poles, in its revolution, it becomes magnetic; as it recedes

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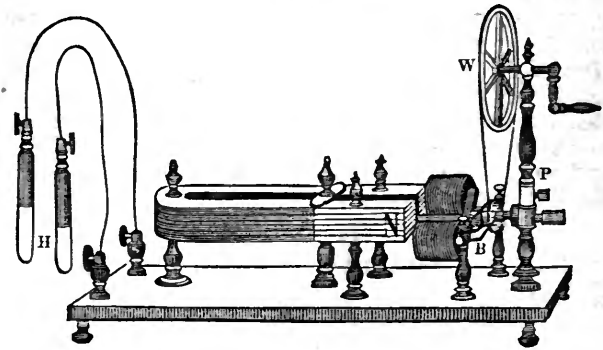
301. Of what does magneto-electricity treat? How are electric currents excited?

from them, its magnetism disappears: and this alternation of magnetic states causes the flow of a current of electricity, which may be directed in its course to screw-cups, from which it may be received by means of wires connected with the cups.

3. The Magneto-Electric Machine.—Fig. 150 represents the magneto-electric machine, in which an armature, bent

Fig. 150.



twice at right angles, is made to revolve rapidly in front of the poles of a compound steel magnet of the U form. The U magnet, whose north pole is seen at N, is fixed in a horizontal position, with its poles as near the ends of the armature as will allow the latter to rotate without coming into contact with them. The armature is mounted on an axis, extending from the pillar P to a small pillar between the poles of the magnet. Each of its legs is enclosed in a helix of fine insulated wire. The upper part of the pillar P slides over the lower part, and can be fastened in any position by a binding screw. In this way the band connecting the two wheels may be tightened at pleasure, by increasing the distance between them. This arrangement also renders the machine more portable. By means of the multiplying-wheel W, which is connected by a band with a small wheel on the axis, the armature is made to revolve rapidly, so that the magnetism induced in it by the steel magnet is alternately destroyed and renewed in

Explain the magneto-electric machine, Fig. 150

a reverse direction to the previous one. When the legs of the armature are approaching the magnet, the one opposite the north pole acquires south polarity, and the other north polarity. The magnetic power is greatest while the armature is passing in front of the poles. It gradually diminishes as the armature leaves this position, and nearly disappears when it stands at right angles with the magnet. As each leg of the armature approaches the other pole of the U magnet, by the continuance of the motion, magnetism is again induced in it, but in the reverse direction to the previous one. These changes in the magnetic state of the armature excite electric currents in the surrounding helices, powerful in proportion to the rapidity with which the magnetic changes are produced.

4. Shocks may thus be obtained from the machine, and if the motion is very rapid, in a powerful machine, the torrent of shocks becomes insupportable—the muscles of the hands which grasp the handles are involuntarily contracted, so that it is impossible to loosen the hold. The shocks, however, are instantly suspended by bringing the metallic handles into contact.*

THERMO-ELECTRICITY.

302. Thermo-electricity expresses a form of electricity developed by the agency of heat.†

* For a further explanation of the magneto-electric machine, the student is referred to Davis' excellent "Manual of Magnetism;" a volume which ought to be in the hands of all who wish to become acquainted with the subjects of magnetism and chemical electricity.

† In the year 1822, Professor Seebeck, of Berlin, discovered that currents of electricity might be produced by the partial application of heat to a circuit composed exclusively of *solid* conductors. The electrical current, thus excited, has been termed *Thermo-electric*, (from the Greek *Thermos*, which signifies heat,) to distinguish it from the common galvanic current; which, as it requires the intervention of a *fluid* element, was denominated a *Hydro-electric* current. The term *Stereo-electric* current has also been applied to the former, in order to mark its being produced in systems formed of solid bodies alone. It is evident that if, as is supposed in the theory of Ampère, magnets owe their peculiar properties to the con-

302. What is thermo-electricity?

1. If the junction of two dissimilar metals be heated, an electrical current will flow from the one to the other.

2. Instead of two different metals, one metal in different conditions can be used to excite the current.

3. Metals differ greatly in their power to excite a current, when associated in thermo-electric pairs. A current may be excited with two wires of the same metal, by heating the end of one, and bringing it into contact with the other. This experiment is most successful when metals are used that have the lowest conducting power of heat.

4. Thermo-electric batteries have been constructed, with sufficient power to give shocks and sparks, and produce various magnetic phenomena, indicative of great magnetic power.*

tinual circulation of electric currents in their minute parts, these currents will come under the description of the *stereo-electric* currents.

From the views of electricity which have now been given, it appears that there are, strictly speaking, *three states* of electricity. That derived from the common electrical machine is in the highest degree of tension, and accumulates until it is able to force its way through the air, which is a perfect non-conductor. In the galvanic apparatus, the currents have a smaller degree of tension; because, although they pass freely through the metallic elements, they meet with some impediments in traversing the *fluid* conductor. But in the thermo-electric currents, the tension is reduced to nothing; because, throughout the whole course of the circuit, no impediment exists to its free and uniform circulation.

* The subject of thermo-electricity is more fully treated in Davis' "Manual of Magnetism," to which reference has already been made, and to which the author acknowledges he has been indebted for much information in the departments of Electricity and Magnetism.

Note. To what do the magnets owe their peculiar properties? What follows from this? How many states of electricity are there? What is said of that derived from the common electrical machine? What is said of that derived from the galvanic apparatus? What is said of the thermo-electric currents?

CHAPTER XIII.

ASTRONOMY.*

303. Astronomy treats of the heavenly bodies, such as the sun, moon, stars, comets, planets, &c.

The earth on which we live is a large globe, or ball, nearly eight thousand miles in diameter, and about twenty-five thousand miles in circumference. It is known to be round,—*first,* because it casts a circular shadow, which is seen on the moon, during an eclipse; *secondly,* because the upper parts of distant objects on its surface can be seen at the greatest distance; *thirdly,* it has been circumnavigated. It is situated in the midst of the heavenly bodies, which we see around us at night, and forms one of the number of those bodies; and it belongs to that system, which, having the sun for its centre, and being influenced by its attraction, is called the *solar*† system.

304. The solar system consists of the sun, which is in the centre;

Of eight *primary* planets, named Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune;‡

Of four Asteroids, or smaller planets, namely, Ceres, Pallas, Juno, and Vesta;

Of eighteen secondary planets or moons, of which

* It is proper here to remark, that many of the branches of Natural Philosophy require in the student an intimate acquaintance with the principles of *mathematical* science. This is particularly the case with astronomy. As this book is designed for those who have made little progress in the mathematics, the following treatise on astronomy contains those facts and principles only of the science which are intelligible, without the aid of mathematical light.

† The word *solar* means belonging to the sun.

‡ This planet was very recently discovered by Verner, whose name at first was applied to it. It is now more generally called *Neptune.*

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303. Of what does Astronomy treat? What is said of the earth? How is the earth known to be round? Where is it situated?

304. Of what does the solar system consist?

the Earth has one, Jupiter four, Saturn seven, and Uranus six; and

Of an unknown number of comets.*

The stars, which we see in the night time, are supposed to be suns, surrounded by systems of planets, too distant to be seen from the earth. Although they appear so numerous on a bright night, they become much more so by the aid of glasses.

305. The planets† may be distinguished from the stars by their *steady* light; while the stars appear to twinkle. The planets, likewise, seem to change their relative places in the heavens, while those luminous bodies which are called *fixed* stars appear to preserve the same relative position.

1. The sun, the moon, the planets, and the fixed stars, which appear to us so small, are supposed to be large worlds, of various sizes, and at different but immense distances from us. The reason that they appear to us so small is, that on account of their immense distances they are seen under a small angle of vision.

2. It has been stated in the early pages of this book, that *every portion of matter* is attracted by every other portion,—and that the force of the attraction depends upon the *quantity*

* The planet Neptune, so recently discovered, is undoubtedly attended by his secondaries or moons, two of which have already been discovered. Whether more will ever be discovered, is a question which remains for the future astronomer to answer.

† The meaning of the word planet is properly a *wanderer*, or a *wandering star*. These luminaries were so called because they never retain the same situation, but are constantly changing their relative positions; while those stars which appear to retain their places are called *fixed* stars. The cause of the motion of the planets will be presently explained.

What are the stars supposed to be? Do we see more by the aid of glasses than without?

305. How may the planets be distinguished from the stars? How are the planets distinguished from the *fixed* stars? What is the meaning of the word planet? Why are they called planets? What are the fixed stars? What are the sun, moon, planets, and fixed stars supposed to be? Why do they appear so small? What has been stated with regard to the attraction of portions of matter? Upon what force does this attraction depend?

of matter and the *distance.* As attraction is *mutual,* we find that all of the heavenly bodies attract the earth; and the earth, likewise, attracts all of the heavenly bodies. It has been proved, that a body when actuated by several forces will not obey *either one,* but will move in a direction *between* them. It is so with the heavenly bodies,—each one of them is attracted by every other one; and these attractions are so nicely balanced by creative wisdom, that, instead of rushing together in one mass, they are caused to move in regular paths, (called *orbits,*) around a central body; which being attracted in *different* directions, by the bodies which revolve around it, will itself revolve around the centre of gravity of the system. Thus, the sun is the centre of what is called the *solar* system, and the planets revolve around it in different times, at different distances, and with different velocities.

306. The paths or courses in which the planets move around the sun are called their orbits.

1. In obedience to the universal law of gravitation, the planets revolve around the sun as the centre of their system; and the time that each one takes to perform an entire revolution is called its year. Thus, the planet Mercury revolves around the sun in 87 of our days. Hence, a year on that planet is equal to 87 days. The planet Venus revolves around the sun in 224 days. That is, therefore, the length of the year of that planet. Our earth revolves around the sun in about 365 days and 6 hours. Our year, therefore, is of that length.

2. The length of time that each planet takes in performing its revolution around the sun, or, in other words, the length of the year on each planet, is as follows. (*The fractional parts of the day are omitted.*)

What follows from attraction being mutual? What direction do bodies take when actuated by several forces? Is this true with regard to the heavenly bodies? What is the centre of the solar system? What is said of the revolution of the planets?

306. What are the paths in which the planets move around the sun called? Around what do the planets revolve? What is a year on each planet? How long is the year of the planet Mercury? How long is the planet Venus performing her revolution around the sun? How long is the earth performing her revolution around the sun? What is the length of the year on the planet Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? Neptune?

	Days.		Days.		Days.
Mercury	87	Vesta	1,325	Jupiter	4,332
Venus	224	Juno	1,592	Saturn	10,759
Earth	365	Ceres	1,681	Herschel	30,686
Mars	686	Pallas	1,686	Neptune	*unknown.**

3. The mean distance† of each of the planets from the sun is expressed as follows, in millions of miles.

	Millions.		Millions		Millions
Mercury	36	Vesta	225	Jupiter	495
Venus	68	Juno	254	Saturn	908
Earth	95	Ceres	263	Herschel	1,827
Mars	145	Pallas	264	Neptune	—

4. While the planets revolve around the sun, each also turns around upon its own axis, and thus presents each side successively to the sun.

5. The time in which they turn upon their axes is called their day, and is thus expressed in hours and minutes of our time.

	H.	M.		H.			H.	M.
Mercury	24	5	Vesta		(*unknown.*)	Jupiter	9	55
Venus	23	20	Juno	27	(*probably.*)	Saturn	10	16
Earth	23	56	Ceres		(*unknown.*)	Herschel	(*unknown.*)	
Mars	24	39	Pallas		(*unknown.*)	Neptune	—	

The sun turns on its axis in about 25 days and 10 hours.

* The elements of this planet are not yet sufficiently determined to give them with any degree of certainty.

† The paths or orbits of the planets are not exactly circular, but elliptical. They are, therefore, sometimes nearer to the sun than at others. The mean distance is the medium between their greatest and least distance. Those planets which are nearer to the sun than the earth are called inferior planets, because their orbits are *within* that of the earth; and those which are farther from the sun are called superior planets, because their orbits are *outside* that of the earth.

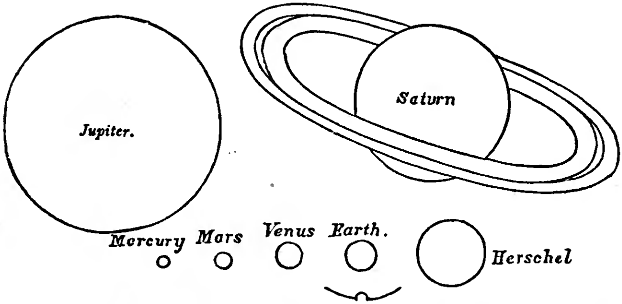
Note. Of what form are the orbits of the planets? What is meant by the mean distance? What planets are called inferior? Why? What planets are called superior? Why? What is the distance of the planet Mercury from the sun? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? Neptune? Have the planets any motion besides that around the sun? What is the time in which they turn upon their axes called? What is the length of a day on the planet Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? Neptune?

307. The relative size of the bodies belonging to the solar system, as expressed by the length of their diameters, is as follows:

	Miles.		Miles.		Miles.
The Sun	877,547	Mars	4,222	Pallas	2,025
Mercury	2,984	Vesta	269	Jupiter	86,255
Venus	7,621	Juno	1,393	Saturn	81,954
Earth	7,924	Ceres	1,582	Herschel	34,363
The Moon	2,180				

Fig. 151 is a representation of the comparative size of the planets.*

Fig. 151.



* Sir J. F. W. Herschel gives the following illustration of the comparative size and distance of the bodies of the solar system: "On a well-levelled field place a globe, two feet in diameter, to represent the Sun; Mercury will be represented by a grain of mustard-seed on the circumference of a circle 164 feet in diameter for its orbit; Venus, a pea, on a circle 284 feet in diameter; the Earth, also a pea, on a circle of 430 feet; Mars, a rather large pin's head, on a circle of 654 feet; Juno, Ceres, Vesta, and Pallas, grains of sand, in orbits of from 1000 to 1200 feet; Jupiter, a moderate-sized orange, in a circle nearly half a mile in diameter; Saturn, a small orange, on a circle of four-fifths of a mile in diameter; and Herschel a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half in diameter.

"To imitate the motions of the planets in the above-mentioned orbits,

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307. What is the diameter of the Sun? Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? The Moon? What does Fig. 151 represent? What illustration of the comparative size and distance of the bodies of the solar system is given? What is necessary in order to mitate the motions of the planets in the above-mentioned orbits?

308. The ecliptic is the apparent path of the sun, or the real path of the earth.

It is called the ecliptic, because every *eclipse,* whether of the sun or the moon, must be upon it.

309. The zodiac is a space or belt, 16 degrees broad, 8 degrees each side of the ecliptic.

It is called the *zodiac,* from a Greek word, which signifies *an animal,* because all the stars in the twelve parts into which the ancients divided it, were formed into constellations, and most of the twelve constellations were called after some animal.*

310. The zodiac is divided into twelve signs,† each sign containing thirty degrees of the great celestial cir-

Mercury must describe its own diameter in 41 seconds; Venus in 4 minutes and 14 seconds; the Earth in 7 minutes; Mars in 4 minutes and 48 seconds; Jupiter in 2 hours 56 minutes; Saturn in 3 hours 13 minutes; and Herschel in 12 hours 16 minutes."

* Sir J. F. W. Herschel, in his excellent treatise on Astronomy, says· "Uncouth figures and outlines of men and monsters, are usually scribbled over celestial globes and maps, and serve, in a rude and barbarous way, to enable us to talk of groups of stars, or districts in the heavens, by names which, though absurd or puerile in their origin, have obtained a currency, from which it would be difficult, and perhaps wrong, to dislodge them. In so far as they have really (as some have) any slight resemblance to the figures called up in imagination by a view of the more splendid 'constellations,' they have a certain convenience; but as they are otherwise entirely arbitrary, and correspond to no *natural* subdivisions or groupings of the stars, astronomers treat them lightly, or altogether disregard them, except for briefly naming remarkable stars; as '*Alpha Leonis,*' '*Beta Scorpii,*' &c., by letters of the Greek alphabet attached to them.

"This disregard is neither supercilious nor causeless. The constellations seem to have been almost purposely named and delineated to cause as much confusion and inconvenience as possible. Innumerable snakes twine through long and contorted areas of the heavens, where no memory can follow them; bears, lions, and fishes, large and small, northern and southern, confuse all nomenclature, &c. A better system of constellations might have been a material help as an artificial memory."

† The signs of the Zodiac and the various bodies of the Solar system, are often represented in almanacs and astronomical works, by signs or

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308. What is the ecliptic? Why is it called the ecliptic?
309. What is the zodiac? Why is it called the zodiac?

cle.* The names of these signs are sometimes given in Latin, and sometimes in English. They are as follows:

Latin.	English.	Latin.	English.
1 Aries,	The Ram.	7 Libra,	The Balance.
2 Taurus,	The Bull.	8 Scorpio,	The Scorpion.
3 Gemini,	The Twins.	9 Sagittarius,	The Archer.
4 Cancer,	The Crab.	10 Capricornus,	The Goat.
5 Leo,	The Lion.	11 Aquarius,	The Water-bearer.
6 Virgo,	The Virgin.	12 Pisces,	The Fishes.

311. The orbits of the other planets are inclined to that of the earth; or, in other words, they are not in the same plane.

1. Fig. 152 represents an oblique view of the plane of the

characters. In the following list the characters of the planets, &c., are represented.

☉ The Sun.	⊕ The Earth.	⚳ Ceres.
☾ The Moon	♂ Mars.	⚴ Pallas.
☿ Mercury.	⚶ Vesta.	♃ Jupiter.
♀ Venus.	⚵ Juno.	♄ Saturn.
	♅ Herschel.	

The following characters represent the signs of the Zodiac.

♈ Aries.	♌ Leo.	♐ Sagittarius.
♉ Taurus.	♍ Virgo.	♑ Capricornus.
♊ Gemini.	♎ Libra.	♒ Aquarius.
♋ Cancer.	♏ Scorpio.	♓ Pisces.

From an inspection of Fig. 152 it appears, that when the earth, as seen from the sun, is in any particular constellation, the sun, as viewed from the earth, will appear in the opposite one.

* The *constellations* of the zodiac do not now retain their original names. Each constellation is about 30 degrees eastward of the sign of the same name. For example, the constellation Aries is 30 degrees eastward of the sign Aries, and the constellation Taurus 30 degrees eastward of the sign Taurus, and so on. Thus the sign Aries lies in the constellation Pisces; the sign Taurus in the constellation Aries; the sign Gemini in the constellation Taurus, and so on. Hence the importance of distinguishing between the *signs* of the zodiac and the *constellations* of the zodiac. The cause of the difference is the precession of the equinoxes, a phenomenon which will be explained in its proper connexion.

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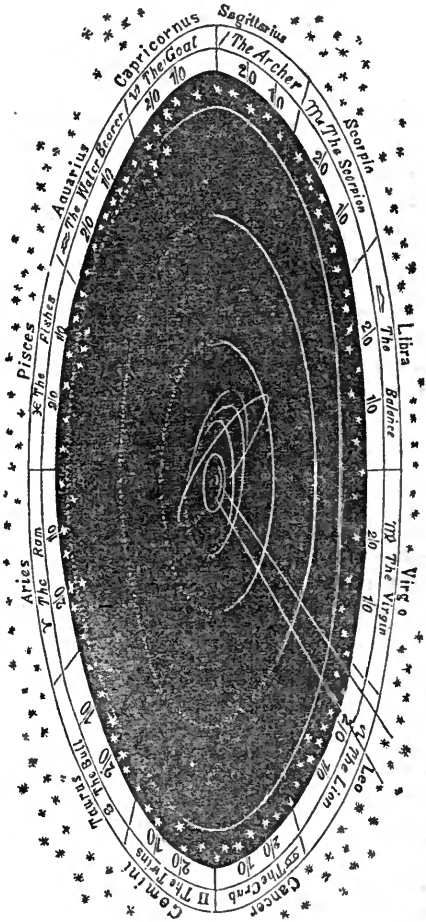
310. What are the names of the twelve constellations? How many degrees does each sign contain?

311. Are the orbits of the other planets in the same plane with that of the earth?

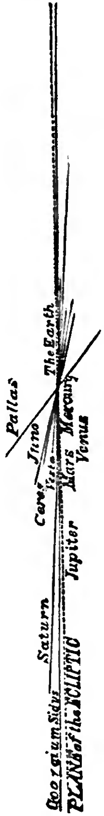
ecliptic, the orbits of all the primary planets, and of the comet of 1680. That part of each orbit which is above the plane is

Fig. 152.



shown by a white line; that which is below it, by a dark line. That part of the orbit of each planet where it crosses the ecliptic, or, in other words, where the white and dark lines in the figure meet, are called the nodes of the planet, from the Latin *nodus*, a knot or tie.

Fig. 153.



2. Fig. 153 represents a section of the plane of the ecliptic, showing the inclination of the orbits of the planets. As the zodiac extends only eight degrees on each side of the ecliptic, it appears from the figure that the orbits of some of the planets are wholly in the zodiac, while those of others rise above and descend below it. Thus, the orbits of Juno, Ceres, and Pallas, rise above, while those of all the other planets are confined to the zodiac.

312. When a planet or heavenly body is in that part of its orbit which appears to be near any particular constellation, it is said to be in that constellation.

Thus, in Fig. 152, the comet of 1680 appears to approach the sun from the constellation Leo.

313. The perihelion* and aphelion* of a heavenly body express its situation with regard to the sun. When a body is nearest to the sun, it is said to be in its perihelion. When farthest from the sun, it is said to be in its aphelion.

The earth is three millions of miles nearer to the sun in its perihelion than in its aphelion.

314. The apogee* and perigee* of a

* The plural of *Perihelion* is *Perihelia*, and of *Aphelion* is *Aphelia*. When a planet is so nearly on a line with the earth and the sun as to pass between them, it is said to be in its *inferior conjunction;* when behind the sun, it is said to be in its *superior conjunction;* but when behind the earth, it is said to be in *opposition*.

What does Fig. 152 represent? What are the nodes of a planet? What does Fig. 153 represent?

312. When is a planet said to be in any particular constellation?

313. What do the perihelion and aphelion of a heavenly body express? When is a body said to be in its perihelion? When is a body said to be in its aphelion? How much nearer is the earth to the sun in its perihelion than in its aphelion?

heavenly body express its situation with regard to the earth. When the body is nearest to the earth, it is said to be in perigee; when it is farthest from the earth, it is said to be in apogee.

315. The perihelia of the planets are in the following signs of the zodiac:—Mercury in *Sagittarius*,—Venus in *Aquarius*,—the Earth in *Capricornus*,—Mars in *Virgo*,—Vesta in *Cancer*,—Juno in *Scorpio*,—Ceres in *Pisces*,—Pallas in *Aquarius*,—Jupiter in *Libra*,—Saturn in *Capricornus*,—and the Georgium Sidus in *Aries*.

316. The axes of the planets in their revolution around the sun, are not perpendicular to their orbits, nor to the plane of the ecliptic, but are inclined in different degrees.

This is one of the most remarkable circumstances in the science of Astronomy, because it is the cause of the different seasons, spring, summer, autumn, and winter; and because it is also the cause of the difference in the length of the days and nights in the different parts of the world, and at the different seasons of the year.

317. The motion of the heavenly bodies is not uniform. They move with the greatest velocity when

The words *perihelion, aphelion, apogee,* and *perigee*, are derived from the Greek language, and have the following meaning:

Perihelion, *near* the sun.
Aphelion, *from* the sun.
Perigee, *near* the earth.
Apogee, *from* the earth.

Note. When is a planet said to be in its inferior conjunction? When is it said to be in its superior conjunction? When is it said to be in opposition?

314. What do the apogee and perigee of a heavenly body express? When is a body said to be in its perigee? When is it said to be in its apogee?

315. In what sign is the perihelion of the planet Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Georgium Sidus?

316. What is said with regard to the axes of the planets in their revolution around the sun? What does this inclination of their axes cause?

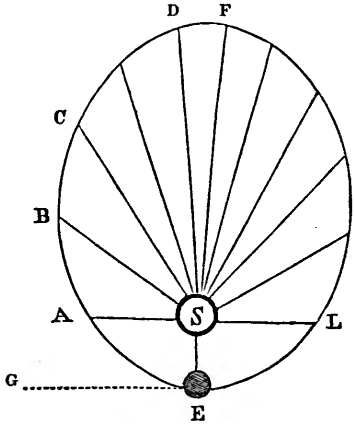
317. What is said with regard to the motion of the heavenly bodies?

they are *in perihelion*, or in that part of their orbit which is nearest to the sun; and slowest when *in aphelion.*

318. It has been proved by Kepler, that when a body moves around a point to which it is attracted, a line* drawn from the point to the body passes over or describes equal areas in equal times. This is called Kepler's law.

In Fig. 154, let S represent the sun, and E the earth, and the ellipse, or oval, be the earth's orbit, or path around the sun. By lines drawn from the sun at S to the outer edge of the figure, the orbit is divided into twelve areas of different shapes, but each containing the same quantity of space. Thus, the spaces E S A, A S B, D S F, &c., are all supposed to be equal. Now if the earth in the space of one month, will move in its orbit from E to A, it will, in another month, move from A to B, and in the third month from B to C, &c., and thus will describe equal areas in equal times.

Fig. 154.



The reason why the earth (or any other heavenly body) moves with a greater degree of velocity in its perihelion, than in its aphelion, may likewise be explained by the same figure. Thus,—

The earth, in its progress from F to L, being *constantly* urged forward by the sun's attraction, must (as is the case with a falling body) move with an accelerated motion. At L, the

* This line is called the *radius-vector.*

When do they move with the greatest velocity? When is their motion the slowest?

318. What is Kepler's law? Illustrate this by Fig. 154. Explain, by Fig 154, the reason why the earth, or any other heavenly body, moves with a greater degree of velocity in its perihelion than in its aphelion.

sun's attraction becomes stronger, on account of the nearness of the earth; and, consequently, in its motion from L to E, the earth will move with greater rapidity. At E, which is the perihelion of the earth, it acquires its greatest velocity. Let us now detain it at E, merely to consider the direction of the forces by which it is urged. If the sun's attraction could be destroyed, the force which has carried it from L to E, would carry it off in the dotted line from E to G, which is a tangent to its orbit. But while the earth has this tendency to move towards G, the sun's attraction is continually operating with a tendency to carry it to S. Now, when a body is urged by two forces, it will move between them; but as the sun's attraction is constantly exerted, the direction of the earth's motion will not be in a straight line, the diagonal of *one* large parallelogram, but through the diagonal of a number of infinitely small parallelograms; which, being united, form the curve line E A.

It is thus seen, that, while the earth is moving from L to E, the attraction of the sun is stronger than in any other part of its orbit, and will cause the earth to move rapidly. But in its motion from E to A, from A to B, from B to C, and from C to F, the attraction of the sun, operating in an opposite direction, will cause its motion from the sun to be retarded, until, at F, the direction of its motion is reversed, and it begins again to approach the sun. Thus, it appears that, in its passage from the perihelion to the aphelion, the motion of the earth, as well as that of all the heavenly bodies, must be constantly retarded; while, in moving from their aphelion to perihelion, it is constantly accelerated; and at their perihelion, the velocity will be the greatest. The earth, therefore, is about seven days longer in performing the aphelion part of its orbit, than in traversing the perihelion part; and the revolution of all the other planets being the result of the same cause, is affected in the same manner as that of the earth.

319. The earth is about three millions of miles nearer to the sun in winter than in summer.

What is said of the motion of the heavenly bodies from perihelion to aphelion? What is their motion from aphelion to perihelion? When is their velocity the greatest? How much longer is the earth in performing the aphelion part of its orbit than the perihelion part?

319. How much nearer is the earth to the sun in winter than in summer?

The heat of summer, therefore, cannot be caused by the near approach of the earth to the sun.

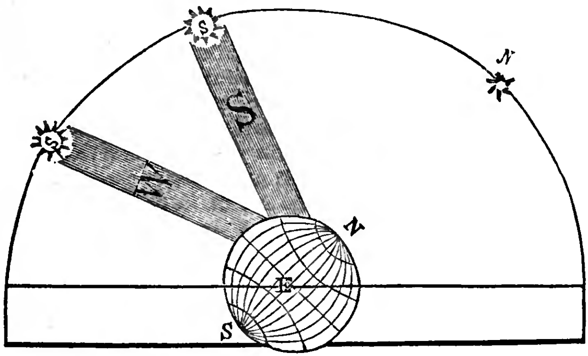
Snow and ice never melt on the tops of high mountains; and they who have ascended in the atmosphere, in balloons, have found that the cold increases as they rise.

320. On account of the inclination of the earth's axis, the rays of the sun fall more or less obliquely on different parts of the earth's surface, at different seasons of the year. The heat is always the greatest when the sun's rays fall *vertically;* and the more obliquely they fall, the less heat they appear to possess.

1. This is the reason why the days are hottest in summer, although the earth is farther from the sun at that time.

2. Fig. 155 represents the manner in which the rays of the sun fall upon the earth in summer and in winter. The north pole of the earth, at all seasons, constantly points to the north

Fig. 155.



star N; and when the earth is nearest to the sun, the rays from the sun fall as indicated by W, in the figure; and as their direction is very oblique, and they have a larger portion

320. What follows from the inclination of the earth's axis, with regard to the direction of the sun's rays? When is the heat always the greatest? What is said of oblique rays? What is the reason that the heat is greater in summer than in winter? Illustrate this by Fig. 155. How is the earth situated with regard to its distance from the sun in winter?

of the atmosphere to traverse, much of their power is lost. Hence we have *cold* weather when the earth is nearest to the sun. But when the earth is in aphelion, the rays fall almost vertically or perpendicularly, as represented by S, in the figure; and, although the earth is then nearly three millions of miles farther from the sun, the heat is greatest, because the rays fall more directly, and have a less portion of the atmosphere to traverse.*

3. For a similar reason, we find, even in summer, that early in the morning, and late in the afternoon, it is much cooler than at noon, because the sun then shines more obliquely. The heat is generally the greatest at about three o'clock in the afternoon; because the earth retains its heat for some length of time, and the additional heat it is constantly receiving from the sun, causes an elevation of temperature, even after the rays begin to fall more obliquely.

It is the same cause which occasions the variety of climate in different parts of the earth. The sun always shines in a direction nearly perpendicular, or vertical, on the equator; and with different degrees of obliquity on the other parts of the earth. For this reason, the greatest degree of heat prevails at the equator during the whole year. The farther any place is situated from the equator, the more obliquely will the rays fall, at different seasons of the year; and, consequently, the greater will be the difference in the temperature.

4. If the axis of the earth were perpendicular to its orbit, those parts of the earth which lie under the equator would be constantly opposite to the sun; and as, in that case, the sun would, at all times of the year, be vertical to those places equally distant from both poles, so the light and heat of the sun would be dispersed with perfect uniformity towards each

* This may be more familiarly explained, by comparing summer rays to a ball or stone thrown directly *at* an object, so as to strike it with all its force; and winter rays to the same ball or stone, thrown obliquely, so as merely to *graze* the object.

What illustration of oblique and perpendicular rays is given in the note? Why is it generally cooler early in the morning and late in the afternoon than at noon? Why is the heat the greatest at about three o'clock? What causes the variety of climate in different parts of the earth? Where does the sun always shine in a vertical direction? What would follow were the axis of the earth perpendicular to its orbit? What causes the variety of the seasons, the different lengths of days and nights, &c?

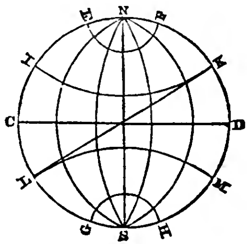
pole; we should have no variety of seasons; day and night would be of the same length; and the heat of the sun would be of the same intensity every day throughout the year.

5. *It is*, therefore, as has been stated, *owing to the inclination of the earth's axis, that we have the agreeable variety of the seasons, days and nights of different lengths, and that wisely-ordered variety of climate, which causes so great a variety of productions, and which has afforded so powerful a stimulus to human industry.**

6. In order to understand the illustration of the causes of the seasons, &c., it is necessary to have some knowledge of the circles which are drawn on the artificial representations of the earth. It is to be remembered that all of these circles are wholly imaginary; that is, that there is on the earth itself no such circles or lines. They are drawn on maps merely for the purpose of illustration.

7. Fig. 156 represents the earth. N S is the axis, or imaginary line, around which it daily turns; N is the north pole, S is the south pole. These poles, it will be seen, are the extremities of the axis N S. C D represents the equator, which is a circle around the earth, at an equal distance from each pole. The curved lines proceeding from N to S, are meridians. They are all circles surrounding the earth, and passing through the poles. These meridians may be multiplied at pleasure.

Fig. 156.



The lines E F, I K, L M, and G H, are designed to represent cir-

* The wisdom of Providence is frequently displayed in *apparent* inconsistencies. Thus, the very circumstance which, to the *short-sighted* philosopher, appears to have thrown an insurmountable barrier between the scattered portions of the human race, has been wisely ordered, to establish an interchange of blessings, and to bring the ends of the earth in communion. Were the same productions found in every region of the earth, the stimulus to exertion would be weakened, and the wide field of human labor would be greatly diminished. It is our mutual *wants* which bind us together.

What is necessary in order to understand the illustration of the causes of the seasons? Explain Fig. 156. What are the poles?

cles, all of them parallel to the equator, and for this reason they are called parallels of latitude. These also may be multiplied at pleasure.

But in the figure, these lines, which are parallel to the equator, and which are at a certain distance from it, have a different name, derived from the manner in which the sun's rays fall on the surface of the earth.

Thus the circle I K, $23\frac{1}{2}$ degrees from the equator, is called the *tropic* of Cancer,* and the circle L M is called the *tropic* of Capricorn. The circle E F is called the Arctic Circle. It represents the limit of perpetual day, when it is summer in the northern hemisphere, and of perpetual night when it is winter.

The circle G H is the Antarctic Circle, and represents the limit of perpetual day and night in the southern hemisphere. The line L K represents the circle of the ecliptic, which, as has already been stated, is the *apparent* path of the sun, or the *real* path of the earth. This circle, although it is generally drawn on the terrestrial globe, is, in reality, a circle in the heavens; and differs from the zodiac only in its width, —the zodiac extending eight degrees on each side of the ecliptic.

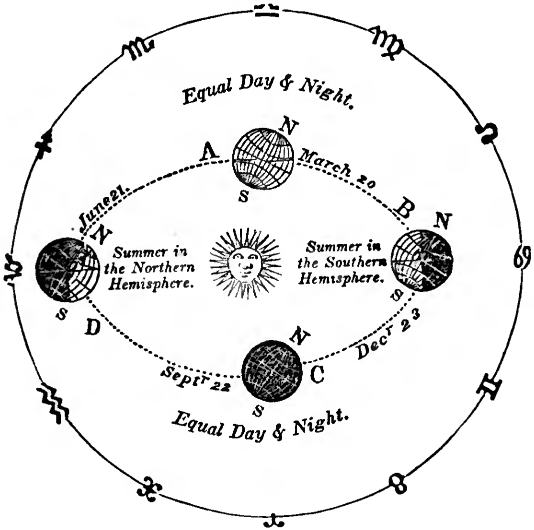
8. Fig. 157 represents the manner in which the sun shines on the earth in different parts of its orbit; or, in other words, the cause of the change in the seasons. S represents the sun, and the dotted oval, or ellipse, A B C D, the orbit of the

* Thus on the 21st of March, the rays of the sun fall vertically on the equator, and on each succeeding day on places a little to the north, until the 21st of June, when they fall vertically on places $23\frac{1}{2}$ degrees north of the equator. Their vertical direction then *turns* back again towards the equator, where the rays again fall vertically on the 23d of September, and on the succeeding days a little to the south, until the 21st of December, when they fall vertically on the places $23\frac{1}{2}$ south of the equator. Their vertical direction then again *turns* towards the equator. Hence the circles I K and L M are called the *tropics* of Cancer and Capricorn. The word *tropic* is derived from a word which signifies *to turn*. The tropics, therefore, are the boundaries of the sun's apparent path north and south of the equator, or the lines at which the sun *turns* back.

Why is the circle I K called the tropic of Cancer? What is the meaning of the word tropic? Why is the circle L M called the tropic of Capricorn? What are the tropics? What is the circle E F called? What does it represent? What is the circle G H called? What does it represent?

earth. The outer circle represents the zodiac, with the position of the twelve signs or constellations. On the 21st of

Fig. 157.



June, when the earth is at D, the whole northern polar region is continually in the light of the sun. As it turns on its axis, therefore, it will be day to all the parts which are exposed to the light of the sun.* But, as the whole of the Antarctic

* Day and night are caused by the rotation of the earth on its axis every 24 hours. It is day to that side of the earth which is towards the sun, and night to the opposite side. The length of the days is in proportion to the inclination of the axis of the earth *towards* the sun. It may be seen by the above figure, that in summer the axis is most inclined towards the sun, and then the days are the longest. As the north pole becomes less inclined, the days shorten, till, on the 21st of December, it is inclined

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What does Fig. 157 represent? Explain the figure. Explain, by the figure, the situation of the earth on the 21st of June. What causes day and night? To what part of the earth is it day? To what part is it night? To what is the length of the day in proportion? When are the days the longest? Why? When are they the shortest? Why?

Circle is within the line of perpetual darkness, the sun can shine on no part of it. It will, therefore, be constant night to all places within that circle. As the whole of the Arctic Circle is within the line of perpetual light, no part of that circle will be turned from the sun while the earth turns on its axis. To all places, therefore, within the Arctic Circle, it will be constant day.

On the 22d of September, when the earth is at C, its axis is neither inclined *to* nor *from* the sun, but is sidewise; and, of course, while one half of the earth, from pole to pole, is enlightened, the other half is in darkness, as would be the case if its axis were perpendicular to the plane of its orbit; and it is this which causes the days and nights, of this season of the year, to be of equal length.

On the 23d of December, the earth has progressed in its orbit to B, which causes the whole space within the northern polar circle to be continually in darkness, and more of that part of the earth north of the equator to be in the shade than in the light of the sun. Hence, on the 21st of December, at all places north of the equator, the days are shorter than the nights, and at all places south of the equator, the days are longer than the nights. Hence, also, within the Arctic Circle it is uninterrupted night, the sun not shining at all; and within the Antarctic Circle it is uninterrupted day, the sun shining all the time.

On the 20th of March, the earth has advanced still further, and is at A, which causes its axis, and the length of the days and nights, to be the same as on the 20th of September.*

23½ degrees *from* the sun, when the days are the shortest. Thus, as the earth progresses in its orbit, after the days are the shortest, it changes its inclination towards the sun, till it is again inclined as in the longest days in the summer

* As the difference in the length of the days and the nights, and the change of the seasons, &c., on the earth, is caused by the inclination of the earth's axis, it follows that all the planets, whose axes are inclined, must experience the same vicissitude; and that it must be in proportion to

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Explain, by the figure, the situation of the earth on the 22d of September. On the 23d of December. On the 20th of March. What follows from the changes on the earth, caused by the inclination of the earth's axis? In what proportion are these changes? What is said of the axis of the planet Jupiter?

9. From the explanation of figure 157, it appears that there are two parts of its orbit in which the days and nights are equal all over the earth. These points are in the sign of Aries and Libra, which are therefore called the equinoxes. Aries is the vernal (or spring) equinox, and Libra the autumnal equinox.

10. There are also two other points called solstices, because the sun appears to *stand* at the *same height* in the heavens, in the middle of the day, for several days. These points are in the signs Cancer and Capricorn. Cancer is called the summer solstice, and Capricorn the winter solstice.

321. The sun is a spherical body, situated near the centre of gravity of the system of planets of which our earth is one.

1. Its diameter is 877,547 English miles; which is equal to 100 diameters of the earth; and, therefore, his cubic magnitude must exceed that of the earth one million of times.* It

the degree of the inclination of their axes. As the axis of the planet Jupiter is nearly perpendicular to its orbit, it follows that there can be little variation in the length of the days, and little change in the seasons of that planet.

There can be little doubt that the sun, the planets, stars, &c., are all of them inhabited; and although it may be thought that some of them, on account of their immense distance from the sun, experience a great want of light and heat, while others are so near, and the heat consequently so great that water cannot remain on them in a fluid state, yet as we see, even on our own earth, that creatures of different natures live in different elements, as, for instance, fishes in water, animals in air, &c., creative wisdom could, undoubtedly, adapt the being to its situation, and with as little exertion of power, form a race whose nature should be adapted to the nearest or the most remote of the heavenly bodies, as was required to adapt the fowls to the air, or the fishes to the sea.

* Spheres are to each other as the cubes of their respective diameters.

Note. Is it supposed that the sun, planets, and stars are inhabited? What is shown by Fig. 157? Where are these points? What are they called? Which is the vernal equinox? Which the autumnal? What other two points are there? Why are they called solstices? Where are these points? Which is the summer solstice? Which the winter?

321. What is said of the sun? What is its diameter? How much does its cubic magnitude exceed that of the earth?

revolves around its axis in 25 days and 10 hours. This has been ascertained by means of several dark spots which have been seen with telescopes on its surface.

2. Dr. Herschel supposed the greater number of spots on the sun to be mountains; some of which he estimated to be 300 miles in height.

3. It is probable that the sun,* like all the other heavenly bodies, (excepting, perhaps, comets,) is inhabited by beings whose nature is adapted to their peculiar circumstances.

4. Although, by some, the sun is supposed to be an immense ball of fire, on account of the effects produced at the distance of ninety-five millions of miles, yet many facts show that heat is produced by the sun's rays only when they act on a suitable medium. Thus, snow and ice remain during the year on the tops of the highest mountains, even in climates where the cold of our winters is never known.

5. The zodiacal light is a singular phenomenon, accompanying the sun. It is a faint light which often appears to stream up from the sun a little after sunset and before sunrise. It appears nearly in the form of a cone, its sides being somewhat curved, and generally but ill defined. It extends often from 50° to 100° in the heavens, and always nearly in the direction of the plane of the ecliptic. It is most distinct about the beginning of March; but is constantly visible in the torrid zone. The cause of this phenomenon is not known.

322. Mercury is the nearest planet to the sun, and is seldom seen; because his vicinity to the sun occasions his being lost in the brilliancy of the sun's rays.

1. The heat of this planet is so great that water cannot exist there, except in a state of vapor; and metals would be melted. The intenseness of the sun's heat, which is in the same proportion as its light, is seven times greater in Mercury

* In almanacs, the sun is usually represented by a small circle, with the face of a man in it, thus: 

How long is it in performing its revolution around its axis? How has this been ascertained? What did Dr. Herschel suppose these spots to be? What is the zodiacal light? At what time is it most distinct? Where is it constantly visible?

322. What planet is nearest to the sun? Why is it seldom seen? What is said of the heat of this planet? How much greater is the sun's heat in Mercury than on the earth?

than on the earth; so that water there would be carried off in the shape of steam: for, by experiments made with a thermometer, it appears that a heat seven times greater than that of the sun's beams in summer, will make water boil.

2. Mercury, although in appearance only a small star, emits a bright white light by which it may be recognised when seen. It appears a little before the sun rises, and again a little after sunset, but as its angular distance from the sun never exceeds 23 degrees, it is never to be seen longer than one hour and fifty minutes after sunset; nor longer than that time before the sun rises.

3. When viewed through a good telescope, Mercury appears with all the various phases, or increase and decrease of light, with which we view the moon; except that it never appears quite full, because its enlightened side is turned directly towards the earth only when the planet is so near the sun as to be lost to our sight in its beams. Like that of the moon, the crescent or enlightened side of Mercury is always towards the sun. As no spots are commonly visible on the disk, the time of its rotation on its axis is unknown.

323. Venus,* the second planet in order from the sun, is the nearest to the earth, and on that account appears to be the largest and most beautiful of all the planets. During a part of the year it rises before the sun, and it is then called the morning star; during another part of the year it rises after the sun, and it is then called the evening star. The heat and light at Venus are nearly double what they are at the earth.

* By the ancient poets, Venus was called *Phosphor*, or *Lucifer*, when it appeared to the west of the sun, at which time it is morning star, and ushers in the light or day; and *Hesperus* or *Vesper*, when eastward of the sun, or evening star.

In what form does water exist in Mercury? How can Mercury be recognised when seen? At what time does it appear? How does Mercury appear when viewed through a telescope?

323. What planet is nearest to the earth? When is Venus called the morning star? When is it called the evening star? How much greater are the light and heat at Venus than that at the earth? What name was given by the ancient poets to Venus, when morning star? What, when evening star?

1. Venus, like Mercury, presents to us all the appearances of increase and decrease of light common to the moon. Spots are also sometimes seen on its surface, like those on the sun. By reason of the great brilliancy of this planet, it may sometimes be seen even in the daytime, by the naked eye.* But it is never seen late at night, because its angular distance from the sun never exceeds 45 degrees. In the absence of the moon it will cast a shadow behind an opaque body.

2. Both Mercury and Venus sometimes pass directly between the sun and the earth. As their illuminated surface is towards the sun, their dark side is presented to the earth, and they appear like dark spots on the sun's disk. This is called the transit of these planets.

324. The earth is the next planet, in the solar system, to Venus. It is not a perfect sphere, but its figure is that of an *oblate spheroid*, the equatorial diameter being about 34 miles longer than its polar diameter.

It is attended by one moon, the diameter of which is about two thousand miles. Its mean distance from the earth is about 240,000 miles, and it turns on its axis in precisely the same time that it performs its revolution round the earth; namely, in twenty-nine days and a half.

325. *The earth, when viewed from the moon, exhibits precisely the same phases that the moon does to us, but in opposite order. When the moon is full to us, the earth will be dark to the inhabitants of the moon; and when the moon is dark to us, the earth will be full to*

* The reason why we cannot see the stars and planets in the daytime, is, that their light is so faint, compared with the light of the sun reflected by our atmosphere

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What is the greatest distance at which the planets, Mercury and Venus, ever appear from the sun? What is meant by the transit of these planets? What is said of the different appearances which Venus presents? Why can we not see the planets and stars in the daytime?

324. What planet is next to Venus? What is the form of the earth? How much larger is its equatorial diameter than its polar? How many moons has the earth? What is the diameter of the moon? What is its distance from the earth? What is the length of a day at the moon? How long is it in performing its revolution around the earth?

325. What phases does the earth, when viewed from the moon, exhibit?

them. The earth appears to them about 13 *times larger than the moon does to us. As the moon, however, always presents nearly the same side to the earth, there is one-half of the moon which we never see, and from which the earth cannot be seen.*

326. Next to the earth is the planet Mars. It is conspicuous for its fiery red appearance; which is supposed to be caused by a very dense atmosphere.

1. When this planet approaches any of the fixed stars, they change their color, grow dim, and often become totally invisible. This is supposed to be caused by his atmosphere. The degree of heat and light at Mars is less than half of that received by the earth.

2. The four small planets, or asteroids, Vesta, Juno, Ceres, and Pallas, have all been discovered within the present century. Vesta was discovered by Dr. Olbers, of Bremen, in 1807: its light is pure and white. Juno, by Mr. Harding, near Bremen, in 1804: its color is red, and its atmosphere appears cloudy. Pallas was discovered by Dr. Olbers in 1802: it appears to have a dense, cloudy atmosphere. Ceres was discovered at Palermo, in Sicily, by Piazzi, in 1801: it is of a ruddy color. All of these small planets undergo various changes in appearance and size, so that their real magnitude is not ascertained with any certainty; and but little is known of them.*

* It is a remarkable fact, that certain irregularities, observed in the motions of the old planets, induced some astronomers to suppose that a planet existed between the orbits of Mars and Jupiter; a supposition that arose long previous to the discovery of the four new planets just noticed. The opinion has been advanced, that these four small bodies originally composed one larger one, which, by some unknown force or convulsion, burst asunder. This opinion is maintained with much ingenuity and plau-

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How much larger does the earth appear than the moon?

326. What planet is next to the earth? What renders it conspicuous? What is supposed to cause this appearance? How much more light and heat does the earth enjoy than Mars? When were the asteroids discovered? By whom, and in what year was Vesta discovered? What is the color of its light? By whom and when was Juno discovered? What is the color of its light? When was Pallas discovered? By whom? What is said of its atmosphere? When and by whom was Ceres discovered? What is its color? What is said in the note with regard to these planets?

327. Jupiter is the largest planet of the solar system, and the most brilliant, except Venus. The heat and light at Jupiter is about 25 times less than that at the earth. This planet is attended by four moons, or satellites; the shadows of some of which are occasionally visible upon his surface.

1. The distance of those satellites from the planet are two, four, six, and twelve hundred thousand miles, *nearly*.

The nearest revolves around the planet in less than two days; the next in less than four days; the third in less than eight days; and the fourth in *about* sixteen days.

2. These four moons must afford considerable light to the inhabitants of the planet; for the nearest appears to them four times the size of our moon; the second about the same size; the third somewhat less; and the fourth about one-third the diameter of our moon.

3. As the axis of Jupiter is nearly perpendicular to its orbit, it has no sensible change of seasons.

4. The satellites of Jupiter often pass behind the body of the planet, and also into its shadow, and are eclipsed. These eclipses are of use in ascertaining the longitude of places on the earth. By these eclipses also, it has been ascertained that light is about eight minutes in coming from the sun to the earth. For, an eclipse of one of these satellites appears to us to take place sixteen minutes sooner, when the earth is in that part of its orbit nearest Jupiter, than when in the part farthest from that planet. Hence, light is sixteen minutes in crossing the earth's orbit, and of course half of that time, or eight minutes, in coming from the sun to the earth.

sibility by Dr. Brewster, in the Edinburgh Encyclopedia, *Art.* ASTRONOMY. Dr. Brewster further supposes, that the bursting of this planet may have occasioned the phenomena of meteoric stones; that is, stones which have fallen on the earth from the atmosphere

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327. Which of the planets is the largest? How much more light and heat does the earth enjoy than Jupiter? How many moons has this planet? What is the distance of these moons from the planet? In what time do they perform their revolutions around the planet? How does the size of these moons compare with that of ours? Why has Jupiter no sensible variety of seasons? Of what use are the eclipses of Jupiter's moons? How long is light in coming from the sun to the earth? How has this been ascertained?

5. When viewed through a telescope, several belts or bands are distinctly seen, sometimes extending across his disk, and sometimes interrupted and broken. They differ in distance, position, and number. They are generally dark; but white ones have been seen.

6. On account of the immense distance of Jupiter from the sun, and also from Mercury, Venus, the Earth, and Mars, observers on Jupiter, with eyes like ours, can never see either of the above-named planets, because they would always be immersed in the sun's rays.

328. Saturn is the second in size and the last but one in distance from the sun. The degree of heat and light at this planet is eighty times less than that at the earth.

1. Saturn is distinguished from the other planets by being encompassed by two large, luminous rings. They reflect the sun's light in the same manner as his moons. They are entirely detached from each other and from the body of the planet. They turn on the same axis with the planet, and in nearly the same time.* The edge of these rings is constantly at right angles with the axis of the planet. Stars are sometimes seen between the rings, and also between the inner ring and the body of the planet. The breadth of the two rings is about the same as their distance from the planet, namely, 21,000 miles. As they cast shadows on the planet, Dr. Herschel thinks them solid.

2. The surface of Saturn is sometimes diversified, like that of Jupiter, with spots and belts. Saturn has seven satellites, or moons, revolving around him at different distances, and in various times, from less than one to eighty days.

3. Saturn may be known by his pale and steady light. The

* These rings move together around the planet, but are about *thirteen minutes* longer in performing their revolution about him, than Saturn is in revolving about his axis.

How does Jupiter appear when viewed through a telescope?

328. How does Saturn compare in size with the other planets? How is Saturn distinguished from the other planets? What is said of these rings? How much longer are these rings in performing their revolution around the planet than the planet is in performing its revolution on its axis? What is the breadth of these rings? What is said of the surface of Saturn? How many moons has Saturn? How may Saturn be known?

seven moons of Saturn, except one, revolve at different distances around the outer edge of his rings. Dr. Herschel saw them moving along it, like bright beads on a white string. They do not often suffer eclipse by passing into the shadow of the planet, because the ring is generally in an oblique direction.

329. Uranus,* the third in size, is the most remote of all the old planets. It is scarcely visible to the naked eye. The light and heat at Uranus are about 360 times less than that at the earth.

1. This planet was formerly considered a small star; but Dr. Herschel, in 1781, discovered, from its motion, that it is a planet.

2. Uranus is attended by six moons, or satellites, all of which were discovered by Dr. Herschel; and all of them revolve in orbits nearly perpendicular to that of the planet. Their motion is *apparently* retrograde; but this is probably an optical illusion, arising from the difficulty of ascertaining which part of their orbit inclines towards the earth, and which declines from it.†

* This planet was long known by the name of Herschel, the discoverer, who, in announcing his discovery, named it the "Georgium sidus," in honor of King George III. The name of Uranus was given to it by the continental astronomers.

† It appears to be a general law of satellites, or moons, that *they turn on their axes in the same time in which they revolve around their primaries.* On this account, the inhabitants of secondary planets observe some singular appearances, which the inhabitants of primary planets do not. Those who dwell on the side of a secondary planet next to the primary, will always see that primary; while those who live on the opposite side will never see it. Those who always see the primary, will see it constantly in very nearly the same place. For example, those who

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What is said of the moons of Saturn? Why are they not often eclipsed?

329. How does Uranus compare in size with the other planets? How does the light and heat at Uranus compare with that of the earth? By whom was this planet discovered? What name did he give it? How many moons has Uranus? By whom were they discovered? How are their orbits situated, with regard to that of the planet? What is said of their motion? *Note.* What appears to be a general law of satellites? What follows from this with regard to the appearances which the inhabitants of the secondary planets must observe?

3. It is a singular circumstance, that, before the discovery of Herschel, some disturbances and deviations were observed by astronomers in the motions of Jupiter and Saturn, which they could account for only on the supposition that these two planets were influenced by the attraction of some more remote and undiscovered planet. The discovery of Herschel completely verified their opinions, and shows the extreme nicety with which astronomers observe the motions of planets.

330. The planet Neptune is a recent discovery of Verrier. But little is as yet known with regard to it.

331. The word comet is derived from a Greek word, which means *hair;* and this name is given to a numerous class of bodies, which occasionally visit, and appear to belong to the solar system. These bodies seem to consist of a nucleus, attended with a lucid haze, sometimes resembling flowing hair; from whence the name is derived. Some comets appear to consist wholly of this hazy or hairy appearance, which is frequently called the *tail* of the comet.*

dwell near the edge of the moon's disk, will always see the earth near the horizon, and those in or near the centre will always see it directly or nearly overhead. Those who dwell in the moon's south limb will see the earth to the northward; those in the north limb will see it to the southward; those in the east limb will see it to the westward; while those in the west limb will see it to the eastward; and all will see it nearer the horizon in proportion to their own distance from the centre of the moon's disk. Similar appearanees are exhibited to the inhabitants of all secondary planets. These observations are predicated on the supposition that the moon *is inhabited.* But it is not generally believed that our moon is inhabited, or in its present condition fitted for the residence of any class of beings.

* In ancient times, the appearance of comets was regarded with superstitious fear, in the belief that they were the forerunners of some direful calamity. These fears have now been banished, and the comet is viewed as a constituent member of the system, governed by the same harmonious and unchanging laws which regulate and control all the other heavenly bodies.

The number of comets that have occasionally appeared within the

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330. Who discovered the planet Neptune?

331. What is the meaning of the word comet? To what class of bodies is this name given? Of what do these bodies appear to consist?

1. Comets, in their revolution, describe long narrow ovals. They approach very near the sun in one of the ends of these ovals; and when they are in the opposite end of the orbit, their distance from the sun is immensely great.

2. The extreme nearness of approach to the sun gives to a comet, when in perihelion, a swiftness of motion prodigiously great. Newton calculated the velocity of the comet of 1680 to be 880,000 miles an hour. This comet was remarkable for its near approach to the sun, being no further than 580,000 miles from it, which is but little more than half the sun's diameter. Brydone calculated that the velocity of a comet, which he observed at Palermo, in 1770, was at the rate of two millions and a half of miles in an hour.

3. The luminous stream, or tail, of a comet, follows it as it approaches the sun, and goes before it when the comet recedes from the sun. Newton, and some other astronomers, considered the tails of comets to be vapors, produced by the excessive heat of the sun. Of whatever substance they may be, it is certain that it is very *rare*, because the stars may be distinctly seen through it.

limits of the solar system is variously stated, from 350 to 500. The paths or orbits of about 98 of these have been calculated from observation of the times at which they most nearly approached the sun; their distance from it, and from the earth, at those times; the direction of their movements, whether from east to west, or from west to east; and the places in the starry sphere at which their orbits crossed that of the earth, and their inclination to it. The result is, that, of these 98, 24 passed *between* the sun and Mercury, 33 passed between Mercury and Venus, 21 between Venus and the earth, 16 between the earth and Mars, 3 between Mars and Ceres, and 1 between Ceres and Jupiter; that 50 of these comets moved from east to west; that their orbits were inclined at every possible angle to that of the earth. The greater part of them ascended above the orbit of the earth, when very near the sun; and some were observed to dash down from the upper regions of space, and, after turning round the sun, to mount again.

What is the number of comets that have occasionally appeared? What discoveries have been made concerning 98 of them? What is the result? What is the form of the orbits of comets? What is said of the motion of comets when in perihelion? What did Newton calculate the velocity of the comet of 1680 to be in an hour? For what was this comet remarkable? What is said of the luminous stream of a comet as it approaches and recedes from the sun? What did Newton, and some other astronomers, consider the tails of comets to be?

4. The tails of comets differ very greatly in length, and some are attended apparently by only a small cloudy light, while the length of the tail of others has been estimated at from 50 to 80 millions of miles.*

* It has been argued that comets consist of very little solid substance, because, although they sometimes approach very near to the other heavenly bodies, they appear to exert no sensible attractive force upon those bodies. It is said that, in 1454, the moon was eclipsed by a comet. The comet must, therefore, have been very near the earth, (less than 240,000 miles;) yet it produced no sensible effect on the earth or the moon; for it did not cause them to make any perceptible deviation from their accustomed paths round the sun. It has been ascertained that comets are disturbed by the gravitating power of the planets; but it does not appear that the planets are in like manner affected by comets.

Many comets escape observation, because they traverse that part of the heavens only which is above the horizon in the daytime. They are, therefore, lost in the brilliancy of the sun, and can be seen only when a *total* eclipse of the sun takes place. Seneca, 60 years before the Christian era, states that a large comet was actually observed very near the sun, during an eclipse.

Dr. Halley and Professor Encke and Biela are the first astronomers that ever successfully predicted the return of a comet. The periodical time of Halley's comet is *about* 76 years. It appeared last in the fall of 1835: that of Encke is about 1200 days; that of Biela about 6¾ years. This last comet appeared in 1832 and in 1838.

The comet of 1758, the return of which was predicted by Dr. Halley, was regarded with great interest by astronomers, *because its return was predicted.* But four revolutions before, in 1456, it was looked upon with the utmost horror. Its long tail spread consternation over all Europe, already terrified by the rapid success of the Turkish arms. Pope Callixtus, on this occasion, ordered a prayer, in which both the comet and the Turks were included in one anathema. Scarcely a year or a month now elapses without the appearance of a comet in our system. But it is now known that they are bodies of such extreme rarity, that our clouds are massive in comparison with them. They have no more density than the air under an exhausted receiver. Herschel saw stars of the 6th magnitude through a thickness of 30,000 miles of *cometic matter* The number of comets in existence within the compass of the solar system, is stated by some astronomers *as over seven millions!*

What is said in the note with regard to comets? Who were the first astronomers that successfully predicted the return of a comet? What is the periodical time of Halley's comet? Of Encke's? Of Biela's?

332. The stars are classed into six magnitudes: the largest are of the first magnitude, and the smallest that can be seen by the naked eye, are of the sixth. Those stars which can be seen only by means of telescopes, are called telescopic stars.

1. The distance of the fixed stars cannot be determined, because we have no means of ascertaining the distance of any body which exceeds 200 thousand times that of the earth from the sun. As none of the stars comes within that limit, we cannot determine their real distance. It is generally supposed that part, if not all, of the difference in their apparent magnitudes is owing to the difference in their distance.*

2. Although the stars generally appear fixed, they all have motion; but their distance being so immensely great, a rapid motion would not perceptibly change their relative situation in two or three thousand years. Some have been noticed alternately to appear and disappear: several that were mentioned by ancient astronomers, are not now to be seen; and some are now observed, which were unknown to the ancients.

3. Many stars which appear single to the naked eye, when viewed through powerful telescopes, appear double, treble, and even quadruple. Some are subject to variation in their apparent magnitude; at one time being of the second, or third, and, at another, of the fifth or sixth magnitude.

333. The Galaxy, or Milky Way, is a remarkably light broad zone, visible in the heavens, passing from northeast to southwest. It is supposed to consist of an immense number of stars, which, from their apparent nearness, cannot be distinguished from each other.

1. Dr. Herschel saw, in the course of a quarter of an hour, the astonishing number of 116,000 stars pass through the field of his telescope, while it was directed to the milky way.

* The distance of the stars, according to Sir J. Herschel, cannot be less than 19,200,000,000,000 miles. How much greater it really is we know not.

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332. Into how many magnitudes are the stars classed? Of what magnitude are the largest? Of what are the smallest? What are telescopic stars? Why cannot the distance of the fixed stars be determined? To what is the difference in their apparent magnitudes supposed to be owing? Have the stars any motion?

333. What is the Galaxy? Of what is it supposed to consist?

2. The ancients, in reducing astronomy to a science, formed the stars into *clusters*, or *constellations*, to which they gave particular names.

3. The number of constellations among the ancients was about fifty. The moderns have added about fifty more.*

4. On a celestial globe, the largest star in each constellation is usually designated by the first letter of the Greek alphabet; and the next largest by the second, &c. When the Greek alphabet is exhausted, the English alphabet, and then numbers, are used.

5. The stars, and other heavenly bodies, are never seen in their true situation, because the motion of light is *progressive;* and, during the time that light is *coming to* the earth, the earth is constantly in motion. In order, therefore, to see a star, the telescope must be turned somewhat *before* the star, and in the direction in which the earth moves.

Hence, a ray of light passing through the centre of the telescope, to the observer's eye, does not coincide with a direct line from his eye to the star, but makes an angle with it; and this is termed the *aberration of light.*†

6. The daily rotation of the earth on its axis causes the whole sphere of the fixed stars, &c., to appear to move round the earth every twenty-four hours from east to west. To the inhabitants of the northern hemisphere, the immoveable point,

* Our observations of the stars and nebulæ are confined principally to those of the northern hemisphere. Of the constellations near the south pole we know but little.

† In determining the true place of *any* of the celestial bodies, the refractive power of the atmosphere must always be taken into consideration. This property of the atmosphere adds to the length of the days, by causing the sun to appear *before* it has actually risen, and by detaining its *appearance* after it has actually set.

How did the ancients divide the stars? What was the number of constellations among the ancients? How many have been added by the moderns? How are the stars designated on the celestial globe? What is the situation of each constellation now? Illustrate this. What is the cause of this difference? Why do we not see the stars, and other heavenly bodies, in their true situation? How can a star be seen in its true situation? What is meant by the aberration of light? What is necessary to be taken into consideration, in determining the true place of the celestial bodies? What effect has his property of the atmosphere on the length of the days?

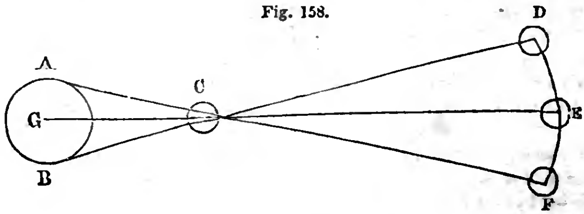
on which the whole seems to turn, is the *Pole Star*. To the inhabitants of the southern hemisphere, there is another, and a corresponding point in the heavens.

7. Certain of the stars surrounding the north pole, never set to us. These are included in a circle parallel with the equator, and in every part equally distant from the north pole star. This circle is called the circle of *perpetual apparition*. Others never rise to us; these are included in a circle equally distant from the south pole; and this is called the circle of *perpetual occultation*. Some of the constellations of the southern hemisphere are represented as inimitably beautiful, particularly *the cross*.

334. The parallax of a heavenly body is the difference between the *true* and the *apparent* situation of the body.

1. In Fig. 158, A G B represents the earth, and C the moon. To a spectator at A, the moon would appear at F; while to another at B, the moon would appear at D; but to a

Fig. 158.



third spectator at G, the centre of the earth, the moon would appear at E, which is the true situation. The distance from F to E is the parallax of the moon when viewed from A, and the distance from E to D is the parallax when viewed from B.

2. From this it appears, that the situation of the heavenly bodies must always be calculated from the centre of the earth; and the observer must always know the distance between the place of his observation and the centre of the earth, in order to make the necessary calculations, to determine the true situation of the body. Allowance also must be made for the refraction of the atmosphere.

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334. What is the parallax of a heavenly body? Explain Fig. 158 What appears from this? What allowance must also be made?

335. The moon is a secondary planet, revolving about the earth in about $29\frac{1}{2}$ days. Its distance from the earth is about 240,000 miles. It turns on its axis in precisely the same time that it performs its revolution about the earth. Consequently it always presents the same side to the earth.

1. The most obvious fact in relation to the moon,* is that

* The surface of the moon appears to be volcanic and very mountainous. Occasional volcanoes have been seen in action on the dark side. No heat has been detected in the moon's rays, even when most powerfully concentrated, that will affect the most delicate thermometer; and hence some have inferred that the moon extracts the heat from the sun's rays before it reflects them.

One of the most common errors, with regard to the moon, is that which ascribes to it an influence over the weather. Tables of the weather have been compared with the lunar phases for a period of a hundred years, and over a thousand lunations, during which time about 491 new or full moons have been attended by a change of the weather, and 509 have not.

The moon is equally innocent of putrefaction, notwithstanding the popular belief that it hastens that process, especially in fish. The same cause which produces dew, causes moisture on substances exposed to it, and this moisture is the real cause of putrefaction.

Dr. Olbers of Bremen, by a comparison of a great number of cases, arrived at the conclusion that the moon has no effect on insanity; although the popular belief is that the fits are aggravated or affected by the lunar phases.

The density of the moon is estimated at about one-fifth that of the earth; hence 10 pounds on the earth will be equal to 2 on the moon. The days and nights on the moon are each equal to 14 of our days. The axis of the moon is perpendicular to its orbit, and therefore the moon can have no variety of seasons. The moon likewise has no atmosphere, and therefore it cannot be inhabited; for there can be no vegetation, no clouds, no ocean, no liquids, no light in dwellings, no twilight; in short, nothing that could fit it for the habitation of any order of beings with which we are acquainted.

In connexion with what has now been stated with regard to the moon and its volcanic appearances, it will be proper to notice the subject of *aërolites*, or *meteoric stones;* because, according to the opinion of some, they are of lunar origin. Three theories have been broached with regard to

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335. Is the moon a primary or secondary planet? How long is it in performing its revolution about the earth? What is its distance from the earth?

its disk is constantly changing its appearance, sometimes only a semicircular edge being illuminated, while the rest is dark; at another time, the whole surface appearing resplendent. This is caused by the relative position of the moon with regard to the sun and the earth. The moon is an opaque body, and shines only by the light of the sun. When, therefore, the moon is between the earth and the sun, it presents its dark side to the earth; while the side presented to the sun, and on which the sun shines, is invisible to the earth. But when the earth is between the sun and the moon, the illuminated side of the moon is visible at the earth.

2. In Fig. 159, let S be the sun, E the earth, and A B C D the moon in different parts of her orbit. When the moon is at A, its dark side will be towards the earth, its illuminated part being always towards the sun. Hence the moon will appear to us as represented at *a*. But when it has advanced in its orbit, to B, a small part of its illuminated side coming in sight, it appears as represented at *b*, and is said to be *horned*. When it arrives at C, one-half its illuminated side is visible, and it appears as at *c*. At C, and in the opposite point of its orbit, the moon is said to be in *quadrature*. At D its appearance

them: 1st, that they are formed in the air, from materials existing there in a sublimated state; 2d, that they are parts of an exploded planet; 3d, that they are thrown from the volcanoes in the moon.

To the first of these theories there is a material objection, in the fact that gases, when in contact, must mix, and gases necessary to form these substances cannot, therefore, remain in the air unmixed.

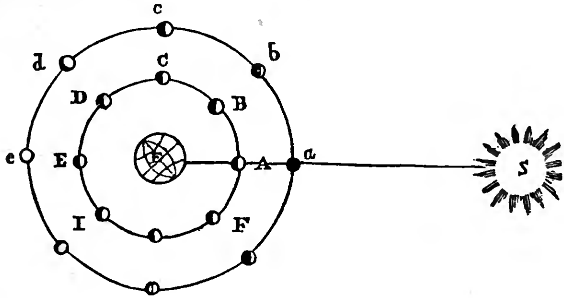
To the second hypothesis it may be objected, that if they were parts of a broken planet, they would probably be composed of more heterogeneous materials. But it is well known that all of them are composed of the same constituent parts, namely; sulphur, magnesia, manganese, iron, nickel, chromium, and in one recorded instance only, charcoal.

In favor of the third supposition, which refers them to a lunar origin, it may be remarked, that a body thrown 70 miles from the moon, would escape from the moon's attraction; and that a velocity six times greater than that of a cannon-ball, would be sufficient to throw a body beyond the moon's attraction. As terrestrial volcanoes have thrown bodies with this velocity, it is not improbable that lunar volcanoes may do the same.

What is the most obvious fact in relation to the moon? How is this caused? What kind of a body is the moon? By what light does it shine?

is as represented at *d*, and it is said to be *gibbous*. At E all illuminated side is towards us, and we have a full moon. During the other half of its revolution, less and less of its illuminated side is seen, till it again becomes invisible at A.*

Fig. 159.



3. The mean difference in the rising of the moon, caused by its daily motion, is a little less than an hour. But on account of the different angles formed with the horizon by different parts of the ecliptic, it happens that for six or eight nights

* The following signs are used in our common almanacs to denote the different positions and phases of the moon.) or ☽ denotes the moon in the *first* quadrature; that is, the quadrature between change and full; (or ☾ denotes the moon in the *last* quadrature; that is, the quadrature between full and change; ○ denotes new moon; ● denotes full moon.

When viewed through a telescope, the surface of the moon appears wonderfully diversified. Large dark spots, supposed to be excavations or valleys, are visible to the eye; some parts also appear more lucid than the general surface. These are ascertained to be mountains, by the shadows which they cast. Maps of the moon's surface have been drawn, on which most of these valleys and mountains are delineated, and names are given to them. Some of these excavations are thought to be 4 miles deep and 40 wide. A high ridge generally surrounds them, and often a mountain rises in the centre. These immense depressions probably very much resemble what would be the appearance of the earth at the moon, were all the seas and lakes dried up. Some of the mountains are supposed to be volcanic.

How does the moon appear when viewed through a telescope? What causes the difference in the rising of the moon? What is the mean difference in the rising of the moon?

near the full moons of September and October, the moon rises nearly as soon as the sun is set. As this is a great convenience to the husbandman and the hunter, inasmuch as it affords them light to continue their occupation, and, as it were, lengthens out their day, the first is called the *harvest* moon, and the second the *hunter's* moon. These moons are always most beneficial when the moon's ascending node is in or near *Aries*.*

OF THE TIDES.

336. The tides are the regular rising and falling of the water of the ocean twice in about 25 hours. They are occasioned by the attraction of the moon upon the matter of the earth; and they are also affected by that of the sun.

1. Let M, Fig. 160, be the moon revolving in her orbit; E the earth covered with water, and S the sun. Now the weight of

Fig. 160.

* The reader who wishes a simple and clear illustration of the causes which produce the harvest moon, is referred to Wilkins's Astronomy, page 69. To those who wish a fuller treatise on astronomy than is contained in this volume, Phillip's "Eight Familiar Lectures" are recommended. They give a clear illustration of those portions of the subject which do not require the aid of the mathematics.

What is the harvest moon? What is the hunter's moon? When are the moons always the most beneficial?

336. What are tides? By what are they occasioned?

a particle of matter is its tendency towards the centre of the earth, and whatever goes to separate the centre from any particle, diminishes that tendency, and consequently lessens the weight in the same proportion. Now since the water at and about A, is nearer the moon than that between A and C, and between A and D, it will be more strongly attracted; and consequently, such attraction will diminish the weight of the water more at A than at the points between A and C and between A and D: hence, the water being made lighter at A, will by the force of the hydrostatic pressure rise, until the whole mass comes into equilibrium.

Again, the waters at C and D, and between C and B and D and B, being nearer the moon than the water at B, will be more attracted by it, and hence its weight will be increased more than that of the water at B, which latter weight is also diminished by the effort of the moon to separate the centre E, and the particle of matter at B. Therefore, the water being made lighter at B will rise, the same as at A, and this rise will also be increased by the motion of the moon and earth around their common centre of gravity.

2. Thus any particular place, as A, while passing from under the moon till it comes under the moon again, has two tides. But the moon is constantly advancing in its orbit, so that the earth must a little more than complete its rotation, before the place A comes under the moon. This causes high water at any place about fifty minutes later each successive day.

3. As the moon's orbit varies but little from the ecliptic, the moon is never more than 29° from the equator, and is generally much less. Hence the waters about the equator being nearer the moon, are more strongly attracted, and the tides are higher than towards the poles.

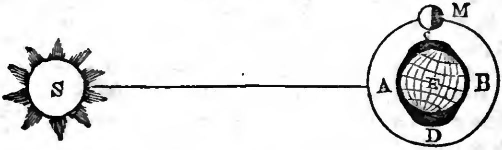
4. The sun attracts the waters as well as the moon. When the moon is at full or change, being in the same line of direction, (see Fig. 160,) the sun acts with it; that is, the sun and moon tend to raise the tides at the same place, as seen in the figure. The tides are then very high, and are called *spring* tides.

But when the moon is in its quarters, as in Fig. 161, the

Explain the theory from Fig. 160. What is the greatest distance of the moon from the equator? Where are the tides highest? Why? Has the sun any effect on the tides? What are spring tides? When do the occur?

sun and moon being in lines at right angles tend to raise tides

Fig. 161.



at different places; namely, the moon at C and D, and the sun at A and B. Tides that are produced when the moon is in its quarters, are low, and are called *neap* tides.*

OF ECLIPSES.

337. An eclipse is a total or partial obscuration of one heavenly body by the intervention of another.

1. The situation of the earth with regard to the moon, or rather of the moon with regard to the earth, occasions eclipses both of the sun and moon. Those of the sun take place when the moon, passing between the sun and earth, intercepts his rays. Those of the moon take place when the earth, coming between the sun and moon, deprives the moon of his light. Hence, an eclipse of the sun can take place only when the moon changes, and an eclipse of the moon only when the moon fulls;

* There are so many natural difficulties to the free progress of the tides, that the theory by which they are accounted for is, in fact, and necessarily, the most imperfect of all the theories connected with astronomy. It is, however, indisputable, that the moon has an effect upon the tides, although it be not equally felt in all places, owing to the indentations of the coast, the obstructions of islands, continents, &c., which prevent the free motion of the waters. In narrow rivers, the tides are frequently very high and sudden, from the resistance afforded by their banks to the free ingress of the water, whence what would otherwise be a tide, becomes an accumulation. It has been constantly observed, that the spring tides happen at the new and full moon, and the neap tides at the quarters. This circumstance is sufficient in itself to prove the connexion between the influence of the moon and the tides.

What are neap tides? When do they take place?

337. What is an eclipse? When does an eclipse of the sun take place? When does an eclipse of the moon take place?

for *at the time of an eclipse*, either of the sun or the moon, *the sun, earth, and moon must be in the same straight line.*

2. If the moon revolved around the earth in the same plane in which the earth revolves around the sun, that is, in the ecliptic, it is plain that the sun would be eclipsed at every new moon; and the moon would be eclipsed at every full. For at each of these times, these three bodies would be in the same straight line. But the moon's orbit does not coincide with the ecliptic, but is inclined to it at an angle of about 5° 20′. Hence, since the apparent diameter of the sun is but about ½ a degree, and that of the moon about the same, no eclipse will take place at new or full moon, unless the moon be within ½ a degree of the ecliptic, that is, in or near one of its nodes. It is found that if the moon be within 16½° of a node at time of change, it will be so near the ecliptic, that the sun will be more or less eclipsed; if within 12° at time of full, the moon will be more or less eclipsed.

3. It is obvious that the moon will be oftener within 16½° of a node at the time of change, than within 12° at the time of full; consequently there will be more eclipses of the sun than of the moon in a course of years. As the nodes commonly come between the sun and earth but twice in a year, and the moon's orbit contains 360°, of which 16½°, the *limit* of solar eclipses, and 12°, the *limit* of lunar eclipses, are but small portions, it is plain there must be many new and full moons without any eclipses.

4. Altnough there are more eclipses of the sun than of the moon, yet more eclipses of the moon will be visible at a particular place, as Boston, in a course of years, than of the sun. Since the sun is very much larger than either the earth or moon, the shadow of these bodies must always terminate in a point; that is, it must always be a cone. In Fig. 162, let S be the sun, *m* the moon, and E the earth. The sun constantly illuminates half the earth's surface, that is, a hemisphere; and consequently it is visible to all in this hemisphere. But the

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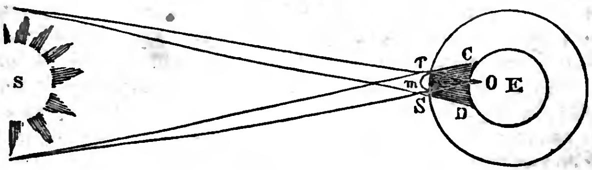
What is necessary at the time of an eclipse? How often would there be an eclipse, if the moon went round the earth in the same plane in which the earth goes round the sun? Why? What is the inclination of the moon's orbit to the ecliptic? What is the apparent diameter of the sun and moon? What follows from this? When is the sun eclipsed? When the moon? Does an eclipse happen every time there is a full or new moon? What must the shadows of these bodies always be? Why?

moon's shadow falls upon a part only of this hemisphere; and hence the sun appears eclipsed to a part only of those to whom

Fig. 162.



it is visible. Sometimes, when the moon is at its greatest distance, its shadow, O *m*, terminates before it reaches the earth. In eclipses of this kind, to an inhabitant directly under the point O, the outermost edge of the sun's disk is seen, forming a bright ring around the moon; from which circumstance these eclipses are called *annular,* from *annulus,* a Latin word for ring.

Besides the dark shadow of the moon, *m* O, in which all the light of the sun is intercepted, (in which case the eclipse is called *total,*) there is another shadow, *r* C D S, distinct from the former, which is called the *penumbra.* Within this, only a part of the sun's rays are intercepted, and the eclipse is called *partial.* If a person could pass, during an eclipse of the sun, from O to D, immediately on emerging from the dark shadow, O *m,* he would see a small part of the sun; and would continually see more and more till he arrived at D, where all shadow would cease, and the whole sun's disk be visible. Appearances would be similar if he went from O to C. Hence the penumbra is less and less dark, (because a less portion of the sun is eclipsed,) in proportion as the spectator is more remote from O, and nearer C or D. Though the penumbra be continually increasing in diameter, according to its length, or the distance of the moon from the earth, still, under the most favorable circumstances, it falls on but about half of the illuminated hemisphere of the earth. Hence, by half the inhabitants on this hemisphere, no eclipse will be seen.

5. Fig. 163 represents an eclipse of the moon. The instant the moon enters the earth's shadow at *x*, it is deprived of the sun's light, and is eclipsed to all in the unilluminated hemi-

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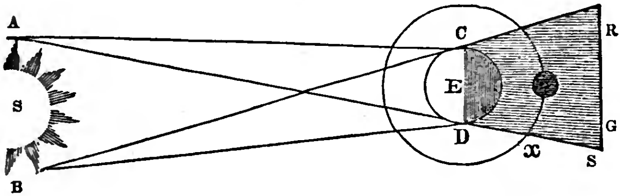
Explain Fig. 162. When is an eclipse called annular? Explain by Fig. 163. What is a penumbra?

sphere of the earth. Hence, eclipses of the moon are visible to at least twice as many inhabitants as those of the sun can

Fig. 163.



be; generally the proportion is much greater. Thus, the inhabitants at a particular place, as Boston, see more eclipses of the moon than of the sun.

6. The reason why a *lunar* eclipse is visible to all to whom the moon at the time is visible, and a *solar* one is not so to all to whom the sun at the time is visible, may be seen from the nature of these eclipses. We speak of the sun's being eclipsed; but, properly, it is the earth which is eclipsed. No change takes place in the sun; if there were, it would be seen by all to whom the sun is visible. The sun continues to diffuse its beams as freely and uniformly at such times as at others. But these beams are intercepted, and the earth is eclipsed only where the moon's shadow falls, that is, on only a part of a hemisphere. In eclipses of the moon, that body ceases to receive light from the sun, and, consequently, ceases to reflect it to the earth. The moon undergoes a change in its appearance; and, consequently, this change is visible at the same time to all to whom the moon is visible; that is, to a whole hemisphere of the earth.

7. The earth's shadow (like that of the moon) is encompassed by a penumbra, C R S D, which is faint at the edges towards R and S, but becomes darker towards F and G. The shadow of the earth is but little darker than the region of the penumbra next to it. Hence it is very difficult to determine the exact time when the moon passes from the penumbra into

Why are eclipses of the moon visible to more inhabitants than those of the sun? Why is a lunar eclipse visible to all to whom the moon is visible at the time? What is said of the earth's shadow? Explain by the figure.

the shadow, and from the shadow into the penumbra; that is, when the eclipse begins and ends. But the beginning and ending of a solar eclipse may be determined almost instantaneously.

8. The diameters of the sun and moon are supposed to be divided into 12 equal parts, called *digits*. These bodies are said to have as many digits eclipsed as there are of those parts involved in darkness.

9. There must be an eclipse of the sun as often, at least, as one of the moon's nodes comes between the sun and the earth.

10. The greatest number of both solar and lunar eclipses that can take place during a year is seven. The usual number is four—two solar and two lunar.

11. A total eclipse of the sun is a very remarkable phenomenon.

12. June 16, 1806, a very remarkable total eclipse took place at Boston. The day was clear, and nothing occurred to prevent accurate observation of this interesting phenomenon. Several stars were visible; the birds were greatly agitated; a gloom spread over the landscape, and an indescribable sensation of fear or dread pervaded the breasts of those who gave themselves up to the simple effects of the phenomenon, without having their attention diverted by efforts of observation. The first gleam of light, contrasted with the previous darkness, seemed like the usual meridian day, and gave indescribable life and joy to the whole creation. A total eclipse of the sun can last but little more than three minutes. An annular eclipse of the sun is still more rare than a total one.

OF TIME.

338. When time is calculated by the sun, it is called solar time, and the year a solar year; but when it is calculated by the stars,* it is called sidereal time, and

* The solar year consists of 365 days, 5 hours, 48 minutes, and 48 sec-

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Into what are the diameters of the sun and moon supposed to be divided? How many digits are these bodies said to have eclipsed? How often must there be an eclipse of the sun? What is the greatest number, of both lunar and solar eclipses, that can take place in a year? What is the usual number? What is said of the eclipse of the sun in 1806?

338. What is time called when calculated by the sun? What is sidereal time? How much longer is the sidereal year than the solar?

the year a sidereal year. The sidereal year is 20 minutes and 24 seconds longer than the solar year.

1. A solar year* is measured from the time the earth

onds; but our common reckoning gives 365 days only to the year. As the difference amounts to nearly a quarter of a day every year, it is usual, every fourth year, to add a day. Every fourth year, the Romans reckoned the 6*th of the calends of March, and the following day as one day;* which, on that account, they called bissextile, or twice the 6th day; whence we derive the name of bissextile for the leap year, in which we give to February, for the same reason, 29 days every fourth year.

* As it may be interesting to those who have access to a celestial globe, to know how to find any particular star or constellation, the following directions are subjoined:

There is always to be seen, on a clear night, a beautiful cluster of seven brilliant stars, which belong to the constellation "*Ursa Major*," or the Great Bear. Some have supposed that they will aptly represent a plough; others say that they are more like a wagon and horses, the four stars representing the body of the wagon, and the other three the horses. Hence they are called by some the *plough*, and by others they are called *Charles's wain*, or *wagon*.

Fig. 164.

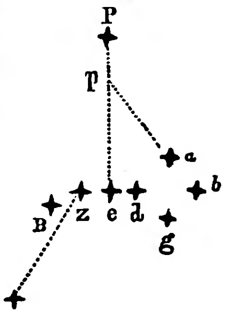


Fig. 164 represents these seven stars: *a b d g* represent the four, and *e z* B the other three stars. Perhaps they may more properly be called a large dipper, of which *e z* B represent the handle. If a line be drawn through the stars *b* and *a*, and carried upwards, it will pass a little to the left, and nearly touch a star represented in the figure by P. This is the polar star, or the north pole star; and the stars *b* and *a*, which appear to point to it, are called the *pointers*, because they appear to point to the polar star.

The polar star shines with a steady and rather dead kind of light. It always appears in the same position; and the north pole of the earth always points to it *at all seasons of the year*. The other stars seem to move round it as a centre. As this star is always in the north, the cardinal points may at any time be found by starlight.

By these stars we can also find any other star or constellation.

How is a solar year measured? What is the length of a solar year? Why is a day added every fourth year, to the year? How is a sidereal year measured?

sets out from a particular point in the ecliptic, as an equinox, or solstice, until it returns to the same point again. A sidereal year is measured by the time that the earth takes in making an entire revolution in its orbit; or, in other words, from the time that the sun takes to return into conjunction with any fixed star.

2. Every equinox occurs at a point, 50″ of a deg. of the great circle, preceding the place of the equinox, 12 months before; and this is called the *precession of the equinoxes.* It is this circumstance which has caused the change in the situation of the constellations of the zodiac, of which mention has already been made.

3. The earth's diurnal motion on an inclined axis, together with its annual revolution in an elliptic orbit, occasions so much complication in its motion, as to produce many irregularities; therefore true equal time cannot be measured by the sun. A clock, which is always perfectly correct, will, in some parts of the year, be before the sun, and, in other parts, after it. There are but four periods in which the sun and a perfect clock will agree: these are the 15th of April, the 16th of June, the 23d of August, and the 24th of December.

4. The greatest difference between true and apparent time amounts to between sixteen and seventeen minutes. Tables of equation are constructed for the purpose of pointing out and correcting these differences between solar time and equal or mean time, the denomination given by astronomers to true time.

Thus, if we conceive a line drawn from the star *z*, leaving B a little to the left, it will pass through the very brilliant star A. By looking on a celestial globe for the star *z*, and supposing the line drawn on the globe, as we conceive it done on the heavens, we shall find the star and its name, which is Arcturus.

Conceiving another line drawn through *g* and *b*, and extended some distance to the right, it will pass just above another very brilliant star. On referring to the globe, we find it to be Capella, or the goat.

In this manner, the student may become acquainted with the appearance of the whole heavens.

What is the precession of the equinoxes? What change has this circumstance caused, with regard to the situation of the constellations? Can true equal time be measured by the sun? Why? At what periods of the year do the sun and a perfect clock agree? What is the greatest difference between true and apparent time?

Many of the foregoing facts, with some others relating to the bodies which compose the Solar System, are arranged in the following Tables. The numbers in these Tables differ, in some respects, from those contained in the body of the work, as they were taken from a different authority.

TABLE I.—*Of the Sun and Primary Planets.*

	Dist. in Millions.	Time of revolving around the Sun.	Time of turning on their Axis.	Diameter in Miles.	The Earth being 1.			Greatest Dist. from the Ecliptic.	Hourly Motion in Miles.	Eccent., Mean Dist. 1.
					Bulk.	Heat & Light.	Density.			
SUN,	* *	* *	24.5 d.	883,217	1,380,000	* *	$\frac{1}{4}$	* *	* *	* *
Mercury,	37	87.98 d.	24. h.	3,123	$\frac{1}{15}$	6.68	2	7° 40′	110,000	0.205
Venus,	68	224.7 "	23.36 "	7,702	$\frac{8}{9}$	1.91	$1\frac{1}{4}$	3° 23′	84,000	0.007
Earth,	93	365.25 "	24. "	7,916	1	1.00	1	0	68,000	0.017
Mars,	144	687.00 "	24.64 "	4,398	$\frac{7}{24}$	.43	$\frac{7}{10}$	1° 50′	54,000	0.093
Vesta,	223	1313.00 "	unknown	unknown	unknown	.18	unknown	7° 9′	45,000	0.097
Juno,	253	1586.00 "	†27. h.	†1,545	†$\frac{1}{135}$	.14	unknown	13°	42,000	0.254
Pallas,	263	1680.00 "	unknown	†2,280	†$\frac{1}{42}$	.13	unknown	34° 30′	41,000	0.246
Ceres,	263	1980.00 "	unknown	†1,761	†$\frac{1}{90}$	.13	unknown	10° 30′	41,000	0.076
Jupiter,	490	4332.60 "	9.94 h.	89,170	1,400	.037	$\frac{23}{100}$	1° 19′	30,000	0.048
Saturn,	900	10759.00 "	10.27 "	79,042	1,000	.011	$\frac{9}{100}$	2° 29′	22,000	0.056
Uranus,	1800	30688.00 "	unknown	35,100	90	.0027	$\frac{1}{5}$	0° 49′	15,000	0.047

† Those figures marked † are not certain

TABLE II.—*Of Secondary Planets.*

OF THE MOON.

Distance from the Earth. Miles.	Inclination of Orbit to the Ecliptic. Deg.	Min.	Revolution around the Earth. Days.	Hours.	Min.
240,000	5	50	27	7	43

Moon's diameter, 2159. Bulk (that of the earth being 1) 1—49.

Period from change to change, 29 days, 12 hours, 44 minutes.

OF THE SATELLITES OF JUPITER.

	Distance from Jupiter. Miles.	Inclination of Orbits to the Orbit of Jupiter. Deg.	Min.	Sec.	Revolution around Jupiter. Days.	Hours.	Min.
I	264,490	3	18	38	1	18	27
II	420,815	3	18	00	3	14	58
III	671,234	3	13	58	7	3	42
IV	1,180,582	2	36	00	16	16	32

OF THE SATELLITES OF SATURN.

	Distance from Saturn. Miles.	Inclination of Orbits to the Orbit of Saturn. Deg.	Min.	Revolution around Saturn. Days.	Hours.	Min
VII	119,627	30		0	22	37
VI	153,496	30		1	8	53
I	190,044	30		1	21	18
II	243,449	30		2	17	44
III	240,005	30		4	12	25
IV	788,258	30		15	22	41
V	2,297,541	42	45	79	7	54

OF THE SATELLITES OF URANUS.

	Distance from Uranus. Miles.	Inclination of Orbits to the Orbit of Uranus. Deg.	Min.	Sec.	Revolution around Uranus. Days.	Hours.	Min.
I	224,155	99 or 80	43 / 16	53 / 7	5	21	25
II	290,821	do.			8	16	57
III	339,052	do.			10	23	4
IV	388,718	do.			13	10	56
V	777,481	do.			38	1	48
VI	1,555,872	do.			107	16	42

INDEX.

QUESTIONS FOR REVIEW AND EXAMINATION.

DIVISIONS OF THE SUBJECT.

Art. 1.—What is Natural Philosophy?

Art. 2.—What are the principal branches of Natural Philosophy? What is Mechanics? Of what does Pneumatics treat? Of what does Hydrostatics treat? Hydraulics? Acoustics? Pyronomics? Optics? Astronomy? Electricity? Of what is Galvanism a branch? Of what does Magnetism treat? Electro-Magnetism? Magneto-Electricity?

OF MATTER AND ITS PROPERTIES.

Art. 3.—What is Matter?

Art. 4.—How many essential properties of matter are there? What are they? Why are they called essential properties? What other properties exist in different bodies? Why are they called accidental properties? Are color and weight essential or accidental properties? Why? What terms are used in Philosophy to express the state in which matter exists? What follows from this?

Fig. 1. Explain the principles which Fig 1 illustrates. What example can you give to prove the impenetrability of water? What of the air? What of solids?

Art. 5.—What is meant by Impenetrability? Does impenetrability belong to fluids? Why do fluids appear less impenetrable than solid bodies? What is supposed to be the form of the particles of fluids?

Art. 6.—What is meant by Extension? What terms are used to express the size of a body? What is length? Breadth? Height, depth, or thickness? What is the difference between height and depth?

Art. 7.—What is meant by Figure? May bodies be of the same shape or figure and of different dimensions? Give an example. What constitutes figure?

Art. 8.—What is meant by Divisibility? Is there any known limit to the divisibility of matter? Mention some examples of the extreme divisibility of matter.

Art 9.—What is meant by the Indestructibility of matter? May it be changed in form and in external appearance? Give examples of such changes.

Art 10.—What is meant by Inertia? Can a body at rest put itself in motion? Can a body in motion stop itself? When a stone or ball is thrown from the hand, how many forces continually operate to stop it? What are they? How could a body in motion be made to move forever?

Fig. 1.

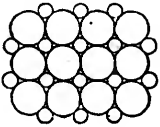


Fig. 2.

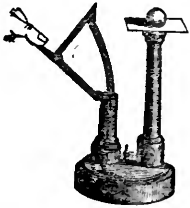


Fig. 2. Explain the apparatus for illustrating inertia, as shown in Fig. 2.

Art. 11.—What is attraction? Is every portion of matter attracted by every other portion of matter? How does this attraction increase and diminish?

Art. 12.—How many kinds of attraction are there belonging to all matter? What is the attraction of gravitation, or gravity? What is the attraction of cohesion, or cohesive attraction? What causes a stone to fall to the ground? By what are the particles which compose the stone held together? Of what is matter composed? Is the cohesive power which unites them the same in all bodies? How may cohesive attraction be illustrated? Do the particles of matter in bodies absolutely touch each other? What are the spaces between them called? What do you understand by density? What by rarity?

Art. 13.—What is compressibility? Are all substances susceptible of it?

Art. 14.—What is expansibility?

Art. 15.—What is mobility?

Art. 16.—What is elasticity? What substance possesses this property in a remarkable degree?

Art. 17.—What is malleability? Does this property belong to all the metals? What metal possesses it in the highest degree?

Art. 18.—What is brittleness? What bodies are most brittle?

Art. 19.—What is ductility? Which is the most ductile of the metals?

Art. 20.—What is tenacity? Which is the most tenacious of the metals?

OF GRAVITY AND WEIGHT.

Art. 21.—What do you understand by the term gravity? Do all bodies possess this attraction? To what is its force proportional? If a body be unsupported, will it remain stationary? Why will it fall?

Art. 22.—What causes weight? When you say that a body weighs an ounce, what do you mean by it? What, therefore, is weight?

Art. 23.—Where is the force of gravity greatest? How does it change? How does it decrease above the surface of the earth? How below?

Art. 24.—In what direction will a falling body approach the surface of the earth? Will the lines of suspension of different bodies ever be parallel? Where will they meet, if sufficiently produced?

Fig. 3. Explain Fig. 3.

Art. 25.—Will all bodies at equal distances from the earth, fall to it in the same time? Why not? What bodies fall fastest? To what is the resistance of the air proportional?

Art. 26.—In what proportion are all substances influenced by gravity? Is air affected by it? How far does the air extend above the surface of the earth? What causes the air to be more dense at the surface of the earth? What causes this pressure? Why does not the air fall to the earth like other bodies? Where is the air heaviest? What effect have gravity and elasticity upon the air?

Art. 27.—What is specific gravity? Illustrate this. Does the attraction of the earth cause all bodies to fall? What bodies will fall? What rise? How does the air cause them to rise? Why do not cork and other light bodies sink in water? Explain the principle upon which balloons rise. What effect has gravity on bodies lighter than the air? What effect on bodies of equal weight? What effect on those that are heavier? What affects the rapidity of their descent? To what is the resistance of the air proportioned?

MECHANICS—LAWS OF MOTION.

Art. 28.—What is Mechanics?

Art. 29.—What is motion? Why cannot a body put itself in motion? Why cannot a body stop itself when in motion?

Art. 30.—What is force? What is resistance?

Art. 31.—When is the motion of a body in a straight line? In what direction will it move?

Art. 32.—What is meant by velocity?

Art. 33.—To what is the velocity of a moving body proportional?

Art. 34.—How is the velocity of a moving body determined? If one body go through six miles in an hour, and another twelve, how does the velocity of the latter compare with that of the former? What is meant by absolute velocity? Give an example. When is the velocity of a body termed relative? Give an example.

Art. 35.—How is the velocity of a body measured? Illustrate this.

Art. 36.—How do you ascertain the time employed by a body in motion? Illustrate this.

Art. 37.—How can you ascertain the space? Illustrate this.

Art. 38.—How many terms are applied to motion to express its kind? What are they? What is uniform motion? Accelerated? Retarded?

Art. 39.—How is uniform motion produced? Why is not a ball struck by a bat, or a stone thrown from the hand, an instance of uniform motion? How can it be made an instance?

Art. 40.—How is accelerated motion produced? Give an instance of accelerated motion. How far does a stone fall the first second of time? The second? Third? Fourth? How can you measure the height of a building, or the depth of a well?

Art. 41.—How is retarded motion produced? Give an example. How does the time of the ascent of a body thrown perpendicularly upwards, compare with that of its descent? Why cannot perpetual motion be produced?

Art. 42.—What is the momentum of a body? How can the momentum of a body be ascertained? Does the quantity of motion communicated to a body affect the duration of the motion? If but little motion is communicated, how will the body move? If a great degree? How long will the motion continue? How can a light body be made to have a greater momentum than a heavy one? Give an instance of this.

Art. 43.—What is meant by action? Reaction? Illustrate this.

Art. 44.—How do action and reaction compare?

Fig. 4. Explain Fig. 4.

Fig. 3.

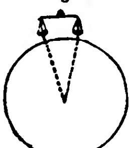


Fig. 4.

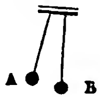


Fig. 5. Explain the experiment of Fig. 5.

Fig. 6. Explain the experiment of Fig. 6. Upon what principle do birds fly? Explain how. Upon what principle do fishes swim? Upon what principle do boats move upon the water? Explain how.

Art. 45.—How may motion be caused? When caused by action, what is it called? When caused by reaction, what is it termed?

Art. 46.—What is the angle of incidence? What is an angle? Upon what does the size of an angle depend? What is a circle? What are radii? What lines in Fig. 8 are radii? What are diameters? In Fig. 8, what line is the diameter? How is the circumference of all circles divided? Into how many parts does the diameter of a circle divide it? How are all angles measured?

Fig. 8. Illustrate this by Fig. 8. How many degrees do right angles contain? Acute? Obtuse? Illustrate these angles by Fig. 8. What is a perpendicular line? What line is perpendicular in Fig. 8? What is a tangent? What line is a tangent in Fig. 8? What is a square? What is a parallelogram? A rectangle? What is a diagonal? What lines are diagonals in Figs. 9, 10, and 11?

Fig. 7. Explain the angle of incidence by Fig. 7.

Art. 47.—What is the angle of reflection? Illustrate this by Fig. 7

Art. 48.—How do the angles of incidence and reflection compare with each other? Illustrate this by Fig. 7. What follows from what has been stated with regard to the angles of incidence and reflection?

Art. 49.—What is compound motion?

Art. 50.—In what direction will a body, struck by two equal forces in opposite directions, move?

Art. 51.—When struck by two forces inclined to each other, how will it move? What is this line called?

Fig. 9. Illustrate these, first, by Fig. 9, which represents a ball struck by two equal forces in different directions.

Fig. 10. Second, by Fig. 10, which represents a ball struck by two unequal forces, acting at right angles.

Fig. 11. Third, by Fig. 11, where the forces operate in the direction of an acute angle. Fourth, by Fig. 11, where the forces cperate in the direction of an obtuse angle.

Art. 52.—What is circular motion? How is it caused? Illustrate this.

Art. 53.—How many different centres are there which require to be noticed? Define each of them.

Art. 54.—Is the centre or axis of motion supposed to be at rest, or does it move? To what do the terms centre of motion and axis of motion relate?

Art. 55.—What are the two forces called which produce circular motion? What is the name of each? What do the words centripetal and centrifugal mean?

Art. 56.—Define a centripetal force. Also a centrifugal force.

Art. 57.—If the centrifugal force be destroyed, to what point will the body tend? What would be its direction if the centripetal force were destroyed? Give an example.

Art. 58.—What parts of a body move with the greatest velocity? In what proportion does the velocity of all the parts diminish?

Fig. 12. What does Fig. 12 represent?

Art. 59.—What follows, with regard to the motion of the earth, from the illustration of Fig. 12?

Art. 60.—Of what is curvilinear motion always the result? Why?

Fig. 5.

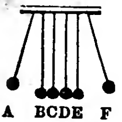


Fig. 6.

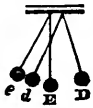


Fig. 7.

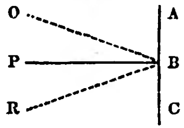


Fig. 8.

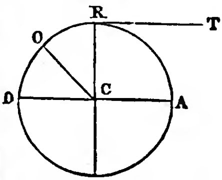


Fig. 9.

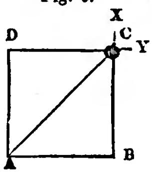


Fig. 10.

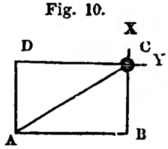


Fig. 11.

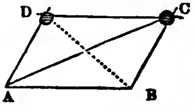
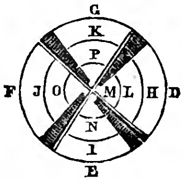


Fig. 12.



Art. 61.—How many forces act upon a ball thrown in a horizontal direction? What are they? Why do bodies fall to the ground?

Art. 62.—Does the force of gravity either increase or decrease the force of projection? Give an illustration.

Fig. 13. Explain Fig. 13.

Art. 63.—What is a projectile? What lines do projectiles describe? From what cause? Give the illustration.

Fig. 14. Explain Fig. 14. How great is the resistance of the air calculated to be to a cannon-ball of two pounds weight, with the velocity of 2000 feet in a second?

Art. 64.—When a body is thrown horizontally, or upwards or downwards obliquely, in what curve will it move? In what line will it move when thrown upwards or downwards perpendicularly?

Fig. 15. Explain Fig. 15.

Art. 65.—What is the random of a projectile? At what angle does the greatest random take place?

Fig. 16. Explain Fig. 16.

Art. 66.—When the centre of gravity of a body is supported, will the body stand or fall? What if the centre be unsupported? What is a line of direction?

Art. 67.—What is the base of a body?

Fig. 17. Explain the base in Fig. 17.

Fig. 18. Explain what is meant by the base in Fig. 18.

Art. 68.—If the line of direction falls within the base, will the body stand or fall? Give an illustration.

Art. 69.—What shaped bodies are easily overturned? What bodies must stand more firmly than others? Why? Why do bodies which have a narrow base overturn more easily than those which have broad bases? Why can a person carry two pails of water more easily than one? Why is a pyramid the firmest of all structures?

Art. 70.—If two bodies of equal weight are fastened together, where is the centre of gravity? If one be heavier than the other?

Fig. 19. What does Fig. 19 represent?

Fig. 20. What does Fig. 20 represent?

Fig. 21. What does Fig. 21 represent? Explain each one separately.

RESULTANT MOTION AND THE PENDULUM.

Art. 71.—What is resultant motion? Give the examples of this kind of motion.

Fig. 22. Explain Fig. 22.

Art. 72.—Of what does a pendulum consist? By whom was the pendulum invented? What led him to the discovery? By whom was the principle of gravitation discovered? What led him to the discovery?

Art. 73.—What are the movements of the pendulum called? What is meant by its arc? What causes its vibrations?

Art. 74.—How do the vibrations of pendulums of equal length compare?

Fig. 23. Explain this by Fig. 23.

Art. 75.—Upon what does the time of the vibrations of a pendulum depend?

Art. 76.—What is the length of a pendulum which vibrates sixty times in a minute? Do different situations affect the vibrations? How can a pendulum which vibrates seconds at the equator be made to vibrate seconds at the poles?

Fig. 13.

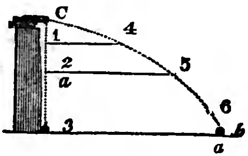


Fig 14.

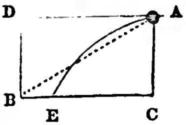


Fig. 15.

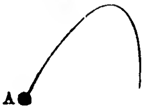


Fig. 16.

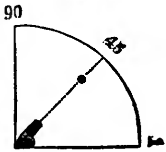


Fig. 17

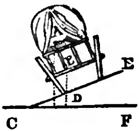


Fig. 18.

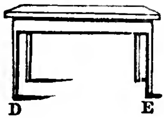


Fig. 19.

Fig. 21.

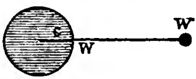


Fig. 23.

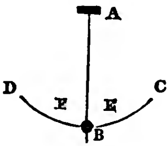


Fig. 20.

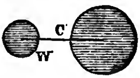
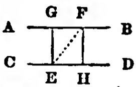


Fig. 22.



Art. 77.—How is a clock regulated? What effect has the lengthening of the pendulum? The shortening? What is a clock? Of what use is the weight? What do the wheels show? Why do clocks go slower in summer than in winter? How does a watch differ from a clock?

OF THE MECHANICAL POWERS.

Art. 78.—What are the mechanical powers? How many things are to be considered in order to understand the power of a machine? What is the first? Second? Third? Fourth? Fifth? What is the power that acts? What is the resistance to be overcome? What is the fulcrum? What is the velocity?

Art. 79.—How many mechanical powers are there? What are they?

Art. 80.—What is a lever? How many kinds of levers are there? How do they differ?

Art. 81.—What is a lever of the first kind? What figure illustrates this?

Fig. 24. Explain it by Fig. 24. To what is the advantage gained by this lever proportional? What follows from this? What is meant by an inflexible bar? What is a fundamental principle in Mechanics?

Fig 25. Illustrate this by Fig. 25. Does this principle apply to all the mechanical powers?

Fig. 26. Explain the common steelyard in Fig. 26.

Fig. 27. Also in Fig. 27. What is a balance, or pair of scales? Give some examples of levers of the first kind.

Fig. 28. Explain Fig. 28.

Art. 82.—What is a lever of the second kind? What figure illustrates this?

Fig. 29. Explain Fig. 29. To what is the advantage gained by this lever proportional? Give some examples of levers of the second kind.

Art. 83.—What is a lever of the third kind? In what proportion must the power exceed the weight in this lever?

Fig. 30. Explain Fig. 30. Give some examples of levers of the third kind.

Art. 84.—What is a pulley? How many kinds of pulleys are there? What are they? What is a fixed pulley?

Fig. 31. Explain Fig. 31. What advantage is gained by this pulley? What is the use of this pulley? Upon what principle does the fixed pulley operate?

Art. 85.—How does the moveable pulley differ from the fixed pulley?

Fig. 32. Explain Fig. 32.

Fig. 24.

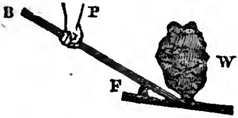
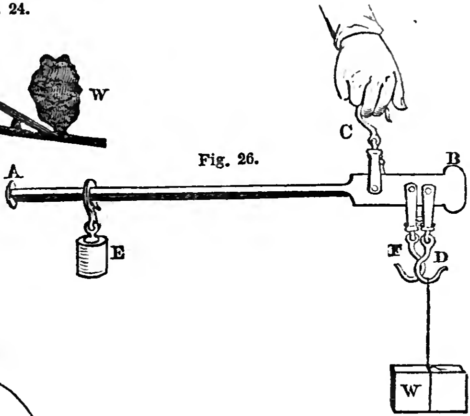


Fig. 26.



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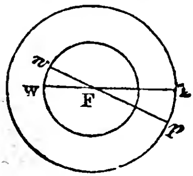

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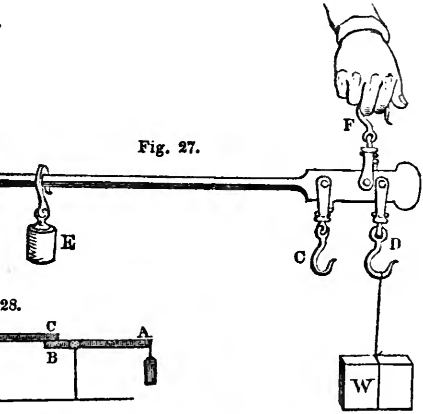

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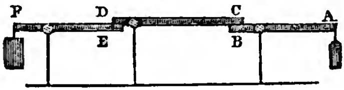

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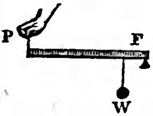

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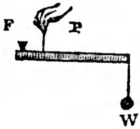
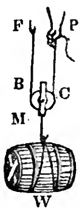


Fig. 31

Fig. 32.



Art. 86.—How can the power gained by the use of the moveable pulley be ascertained? What illustration of this is given?

Fig. 33. What does Fig. 33 represent? Explain it.

Art. 87.—Upon what principle do pulleys act? What advantage is gained by the use of pulleys and other mechanical powers? What are some of the practical uses of the pulley? What is a tackle and fall? Is there any time or velocity gained by the power in the mechanical powers? To what is the product of the weight, multiplied by its velocity, always equal? What rule is given?

Art. 88.—Of what does the wheel and axle consist? What is a cylinder? What figures illustrate the wheel and axle? Explain. To what is the advantage gained in proportion?

Fig. 34. What does Fig. 34 represent? Explain it.

Fig. 35. What does Fig. 35 represent? Explain it.

Art. 89.—Upon what principle are the wheel and axle constructed? Explain how. Upon what principle is the capstan on board of vessels constructed? Of what does it consist? What other things are mentioned as constructed upon this principle? Are wheels an essential part to most machines? Are they applied in more than one way? When they are affixed to the axle, in what proportion is the power increased? What are fly-wheels, and for what are they used? How are they made to revolve? When once set in motion, what causes them to move on for some time? Of what service are they in a machine? For what are cranks sometimes connected with the axle of a wheel? How are they made?

Fig. 36. What does Fig. 36 represent? Explain it. For what are cranks often used? How does the velocity of the wheel compare with that of the axle? To what is this velocity in proportion? Is any advantage taken of this in driving machinery where the speed is to be increased or diminished? How would rapid motion be produced? Slow motion?

Fig. 37. Explain Fig. 37. What is the usual way of transmitting the action of the axles to the adjoining wheels? What are the cogs on the surface of the wheel called? Those on the axle? What is a pinion?

Fig. 38. Explain Fig. 38. By what are wheels sometimes turned? What figure represents one? In what way can the motion be made direct or reversed?

Fig. 39. What does Fig. 39 represent? Explain it.

Fig. 40. What does Fig. 40 represent? Explain it. In what way can different directions be given to the motion produced by wheels?

Fig. 33.

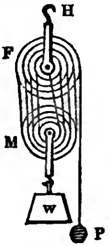
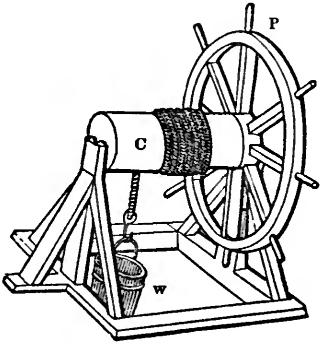


Fig 34



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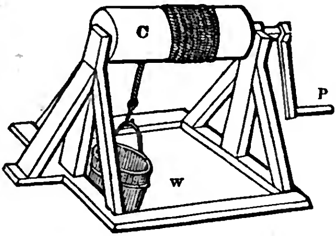

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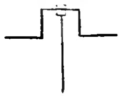

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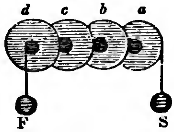

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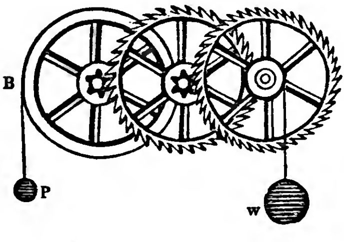
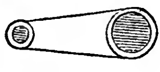


Fig. 39



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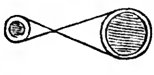


Fig. 41. What does Fig. 41 represent? Explain it.

Fig. 42. What does Fig. 42 represent? Explain it.

ART. 90.—What is an inclined plane? What figure represents an inclined plane?

Fig. 43. Explain Fig. 43. To what is the advantage gained by the use of the inclined plane in proportion? What follows from the greater or less inclination of the plane? Give some instances of the application of the inclined plane. Is any time gained by the use of the inclined plane? Upon what principle are chisels and other cutting instruments, which are sloped only on one side, constructed?

ART. 91.—Of what does the wedge consist?

Fig. 44. What does Fig. 44 represent? Explain it. To what is the advantage gained by the wedge in proportion? Of what use is the wedge? Give some examples of the wedge.

ART. 92.—Of what does the screw consist? Of how many parts is it generally composed? What are they?

Fig. 45. What figure represents the screw and the nut? Explain the figure.

Fig. 46. How does Fig. 45 differ from Fig. 46? Is the screw a simple or compound power? How is the power of the screw estimated? How does the closeness of tho thread affect the power? What is the use of the screw? How can its power be increased? To what is the screw applied? What is meant by friction in machinery? How many kinds of friction are there? What are they? How is the rolling friction produced? The sliding? Which is overcome with the less difficulty, the rolling or sliding? What allowance must always be made, in calculating the power of a machine? What proportion of the power is usually computed to be destroyed by friction? Between which is friction the less, rolling bodies or those that slide? What causes friction? In what proportion is it diminished? In what manner can it be lessened? What is the use of wheels? In what proportion do they overcome the obstacles, such as stones, &c., in the road? Why, in descending a steep hill, are the wheels of a carriage often locked? How do castors, which are put upon furniture, facilitate the moving of it? How is the motion of all bodies influenced?

ART. 93.—What is meant by a medium? Give examples.

ART. 94.—To what is the resistance of a medium in proportion? What illustration is given? When would a machine be perfect?

ART. 95.—Of what does the main-spring of a watch consist? What is its use? Does the spring exert a stronger force when closely coiled, or when partly loosened? What is done in order to correct this inequality?

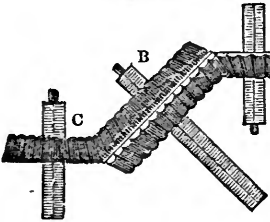
Fig. 47. What does Fig. 47 represent? Explain it.

Art 96.—What is a governor?

Fig. 48. Explain Fig. 48. What is said of the use of the governor?

Art. 97.—Of what does the knee-joint, or toggle-joint, consist? In what proportion does it increase in power?

Fig. 41.



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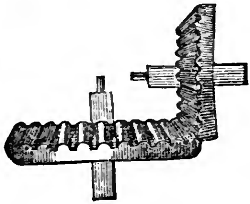

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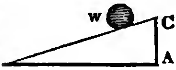

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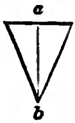

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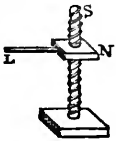

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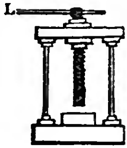

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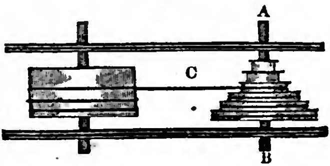


Fig. 48

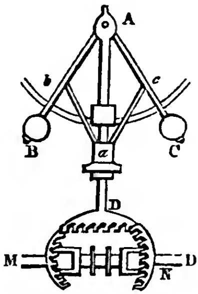


Fig 49 What does Fig. 49 represent? Explain the figure. Give an instance of the operation of the toggle-joint. What is its use in printing-presses?

HYDROSTATICS.

Art. 98.—Of what does Hydrostatics treat?

Art. 99.—What is a fluid? Does the attraction of cohesion have much influence on the particles of fluids? What follows from this?

Art. 100.—How do fluids differ from liquids? Can water be compressed? What is supposed to be the primary cause of the fluid form of bodies? What effect has heat upon bodies? What illustration is given? Why do fluids gravitate in a more perfect manner than solids? What is inferred from the slight degree of cohesion in the particles of fluids? Why smooth? Why globular? Why cannot fluids be formed into figures, or preserved in heaps? What do you understand by capillary attraction? Explain the reason of it. Explain why the same takes place in all porous substances. Explain all the circumstances attending the burning of a lamp. Explain the experiment with the glass plates.

Art. 101.—What is meant by the level or equilibrium of fluids? Have all fluids a tendency to preserve this equilibrium? What follows from this? Of what is this level or equilibrium of fluids the natural result? How does the gravitation of solid bodies differ from that of fluids?

Art. 102.—Do fluids of different densities all preserve their own equilibrium? What illustration is given to prove this?

Art. 103.—Upon what principle is a water-level constructed? Of what does it consist? For what is it used?

Fig. 50. What figure represents a water-level? Explain the figure.

Art. 104.—In what manner do solid bodies gravitate? What is the centre of gravity? What effect has gravity on the particles of fluids?

Art. 105.—How is the pressure of fluids exerted? How long will the particles of fluids remain at rest?

Fig. 51. Explain Fig. 51.

Fig. 52. What does Fig. 52 represent? Explain it. If the equality of the pressure be undisturbed, what will follow? If the fluid be agitated, when will it again come to a state of rest? How is the downward pressure of fluids shown? The lateral pressure? The upward pressure?

Art. 106.—To what is the pressure of a fluid in proportion? In what direction is this pressure exerted? What illustrations are given to prove this? Why can a bottle, filled with water or any other liquid, be let down to any depth without injury? What experiment is mentioned in the note? What opinion have some philosophers expressed?

Art. 107.—What causes the lateral pressure? What follows from this?

Fig 53. Explain Fig. 53.

Art. 108.—Does the length or the width of the vessel in which a fluid is contained have any effect upon the lateral pressure? By what is it affected?

Art. 109.—How does the lateral pressure on one side of a cubical vessel compare with the pressure downwards? How would you explain this?

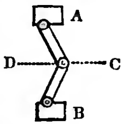
Art. 110.—What causes the upward and downward pressure?

Fig. 54. Illustrate this by Fig. 54.

Art. 111.—Upon what does the force of pressure depend? What is meant by the hydrostatic paradox? What is the use of the hydrostatic bellows?

Fig. 55. What figure represents the hydrostatic bellows? Explain the figure. What is the fundamental principle of Mechanics? Is this the principle of the hydrostatic bellows?

Fig. 49.



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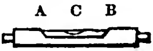


Fig. 51.

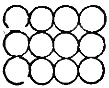
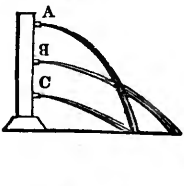


Fig. 49.

Fig. 53.



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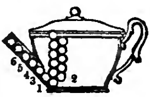

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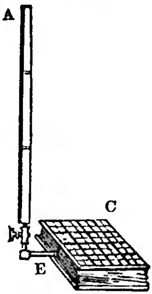


Fig. 56. What does Fig. 56 represent? Explain why fluids press according to the heights, and not according to the quantity.

Art. 112.—What fact is mentioned in this number in regard to the pressure of water? Upon what principle is Bramah's hydrostatic press constructed?

Fig. 57. What figure represents this? Explain the figure. To what uses is this press applied?

Art. 113.—When will one fluid float upon another?

Art. 114.—What is stated with regard to a body specifically lighter than a fluid? What illustration is given of this? How do the specific gravities of water and cork compare with each other? Upon what principle is it that boats, ships, &c., are made to float upon the water? What rules have been formed from the knowledge of the specific gravity of water and the materials of which vessels are composed?

Art. 115.—What standard has been adopted to estimate the specific gravity of substances in general? Why could not metals have been adopted? Why is distilled water used? What bodies will sink when immersed in water? What will float? What is the weight of a cubic foot of water? What is the use of the table? How does the specific gravity of living men compare with that of water? Which is the greater, the specific gravity of sea water, or of lakes and rivers? Why?

Art. 116.—How is the specific gravity of bodies that will sink in water ascertained? What illustration is given?

Fig. 58. Explain Fig. 58. Why will gold weigh less in the water than out of it? How does this upward pressure of the particles compare with the downward pressure of a quantity of water of the same dimensions? What follows from this? What rule is given with regard to all bodies heavier than water that are immersed in it? What is the specific gravity of a body? What is the reason that a bucket of water, drawn from a well, is heavier when it rises above the surface of the water, than while it is below it?

Art. 117.—How can the specific gravity of a body that will not sink in water be ascertained? What illustration is given? By whom was the method of ascertaining the specific gravities of bodies discovered? In what manner did he ascertain it?

Art. 118.—What is an hydrometer? Upon what principle is it constructed? Explain its construction. In what proportion does the scale sink?

HYDRAULICS.

Art. 119.—Of what does Hydraulics treat? What retards the motion of water? Why does the surface of a canal or river have a greater velocity than any other part?

Art. 120.—Does the fulness of a vessel, from the orifice of which a fluid is running, have any effect upon its velocity?

Fig. 56.

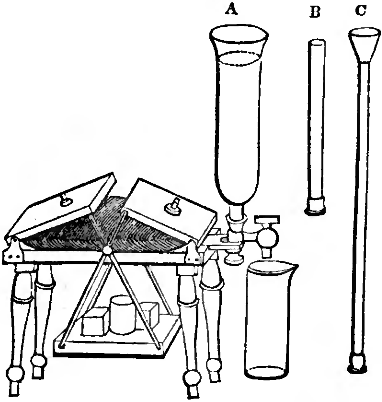
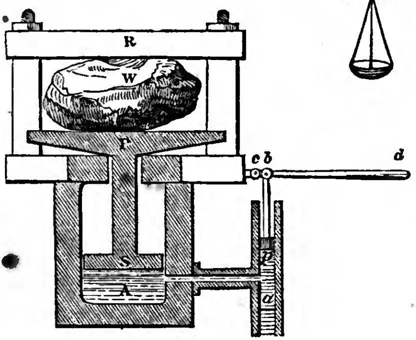


Fig. 58.

Fig. 57.



Art. 121.—When a fluid spouts from several orifices in the side of a vessel, from which is it thrown to the greatest distance?

Art. 122.—What effect will a pipe, fitted to an orifice, have with regard to the quantity discharged? What will be the effect if the pipe project into the vessel? How can the quantity discharged through a pipe or orifice, be increased? Why will heat increase it?

Art. 123.—How can the velocity of a current of water be ascertained?
Fig. 59. What does Fig. 59 represent? Explain it. How is the rapidity of the current estimated? What is the use of the instrument?

Art. 124.—What causes waves? What is sometimes done to remove this friction?

Art. 125.—What instruments are used for raising liquids?

Art. 126.—Where is the chain-pump used? What figure represents it?
Fig. 60. Explain the figure.

Art. 127.—What is said of the screw of Archimēdes?
Fig. 61. Explain the use of the screw by Fig. 61.

Art. 128.—How are springs and rivulets formed?
Fig. 62. Explain Fig. 62.

Art. 129.—How high will a spring rise?

Art. 130.—How are fountains formed? How high will the water spout through the ducts? What prevents the fluid from rising to the same height with the reservoir?
Fig. 63. Explain the method of making artificial reservoirs by Fig. 63.

Art. 131.—What is the siphon?
Fig. 64. What figure represents a siphon? Explain it. In what manner is the siphon used? How can the siphon be used to show the equilibrium of fluids? How high will the liquid rise in each side of the siphon? What is Tantalus' cup?
Fig. 65. What does Fig. 65 represent? Explain it.

Art. 132.—How, and for what purposes is water used as a mechanical agent? How many kinds of water-wheels are there? What are they?

Art. 133.—What is the overshot wheel? Where does it receive its motion?
Fig. 66. Explain Fig. 66. What causes the wheel to turn? How does this wheel compare in power with the other water-wheels?

Art. 134.—What is the undershot wheel? Where does it receive its motion?

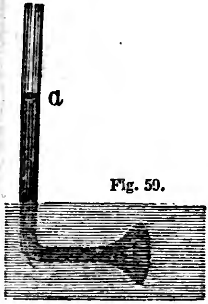
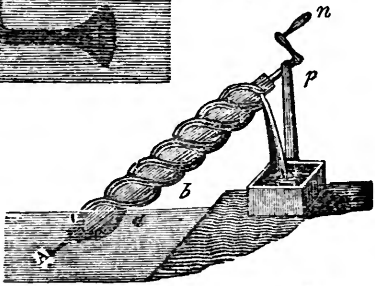


Fig. 59.

Fig 60.



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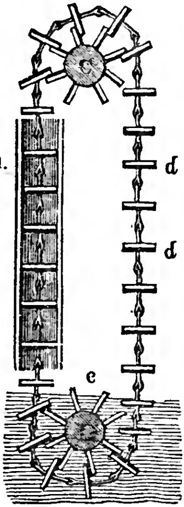
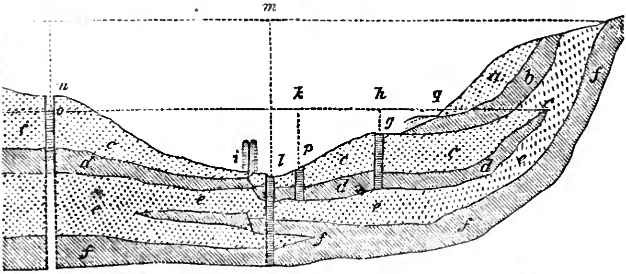


Fig. 62



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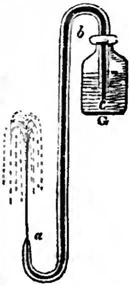


Fig. 64.

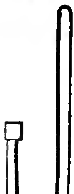


Fig. 65.

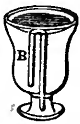


Fig. 66

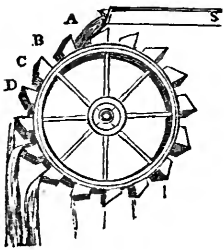


Fig. 67 What does Fig. 67 represent? How does this wheel differ from the overshot?

ART. **135.**—What is the breast-wheel? How is it set in motion?

Fig. 68. What figure represents the breast-wheel? Explain it. To what is the motion given to the wheels which have been described, communicated?

PNEUMATICS.

ART. **136.**—Of what does Pneumatics treat?

ART. **137.**—What is the air which we breathe? How far does it extend above the surface of the earth? Does it possess properties common to liquids in general? How does its specific gravity compare with that of water? Of what two principal ingredients does the air consist? What is the proportion of these parts to each other?

ART. **138.**—What other fluids are named belonging to the class of elastic fluids?

ART. **139.**—Have the air and other similar fluids weight? With what power alone has heat to contend in aëriform fluids?

ART. **140.**—What two principal properties has the air?

ART. **141.**—What is the weight of a column of air one inch square at the base, and reaching to the top of the atmosphere? Is the pressure exerted equally in all directions?

ART. **142.**—What is meant by the elasticity of the air? How do the aëriform fluids differ from liquids? When is the air said to be rarefied? When condensed? Is the air near the surface of the earth rare or dense?

ART. **143.**—How does the air become a mechanical agent?

ART **144.**—What is a vacuum?

ART. **145.**—What is a barometer? What does the word barometer mean? What is a thermometer? What does the word thermometer mean? What is a hygrometer? What does the word hygrometer mean?

Fig. 69. What figure represents a barometer? Explain its construction. What height of mercury is the pressure of the atmosphere capable of sustaining? What effect has the pressure of the atmosphere on the mercury in the tube? In what proportion does the mercury rise and fall? In what way can barometers be made of other fluids? Why is merçury used in preference to any other fluid? Is the air heaviest in wet or dry weather? On what principle is the pressure of the atmosphere on the mer-

cury, in the cup of a barometer, exerted? What follows from this? For what other purpose, besides measuring the pressure of the atmosphere, and foretelling the variations of the weather, is the barometer used? Is the air the more dense at the surface of the earth or upon a hill? What is a thermometer?

Fig. 70 What figure represents a thermometer? Explain its construction. What effect have heat and cold on most substances? What follows from this? Whose scale is generally used in this country? For what is the hygrometer used? Of what kind of substances may it be constructed? What experiment is given in the note to show the quantity of moisture raised from the ground by the heat of the sun?

Fig. 67.

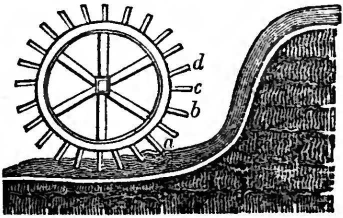


Fig. 69.

Fig. 68.

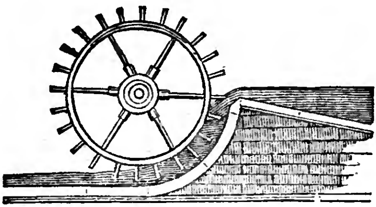
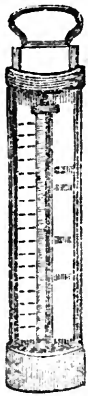


Fig. 70



Art. 146.—Is air impenetrable, like other substances? How is this shown? Upon what principle is the diving-bell constructed?

Fig. 71. What figure represents the diving-bell? Why does not the water rise in the bell? Explain the figure.

Art. 147.—By what means is water raised in the common pump? How is the pressure removed?

Fig. 72. What figure represents the common pump? Explain it. Which of the mechanical powers is the handle of the pump? How high can water be raised by the common pump? Why? Why is the common pump sometimes called the lifting-pump?

Art. 148.—How does the forcing-pump differ from the common pump?

Fig. 73. What figure represents the forcing-pump? Explain it.

Art. 149.—What is wind? In what two ways may the motion of the air be explained? Explain the manner in which the air is put in motion. How are the north, south, east, and west winds produced

Art. 150.—What is an air-pump? What is the vessel called from which the air is exhausted? On what principle are all air-pumps constructed? Can a perfect vacuum ever be obtained?

Fig. 74. Describe the air-pump represented by Fig. 74.

Fig. 75. Describe Wightman's patent lever air-pump, represented by Fig. 75.

Art. 151.—Experiments with the air-pump.

Fig. 76. What does Fig. 76 represent? Explain the experiments that are made with them.

Fig. 77. What does Fig. 77 represent? Explain the experiments made with it.

Fig. 71.

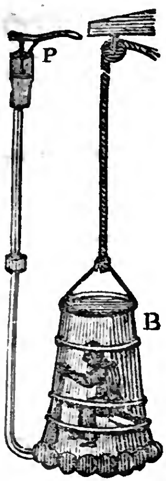


Fig 72.

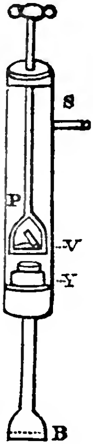


Fig. 73.

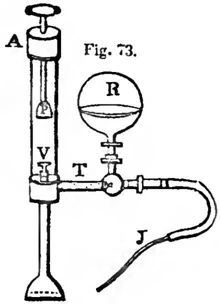
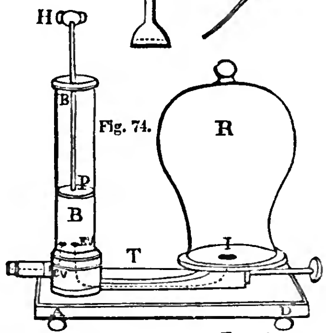


Fig. 74.



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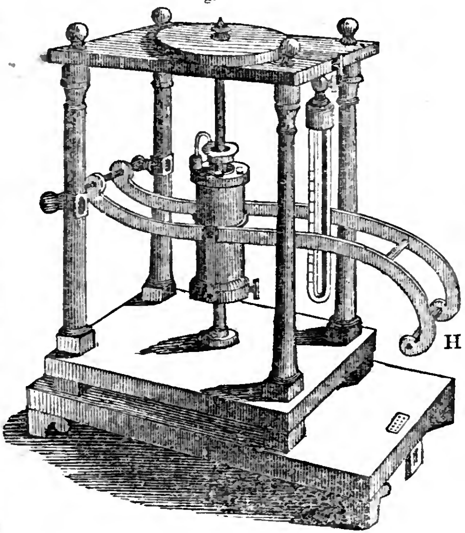

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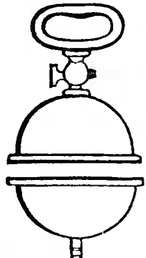


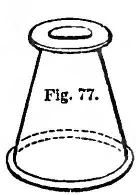


Fig. 77.

Fig. 78. What does Fig. 78 represent? Explain the experiments made with it.

Fig. 79. What does Fig. 79 represent? Explain the experiments made with it.

Fig. 80. What does Fig. 80 represent? Explain its use.

Fig. 81. What does Fig. 81 represent, and what experiments are made with it?

Fig. 82. What does Fig. 82 represent? Explain its use.

Fig. 83. What does Fig. 83 represent? Explain the experiment made with it.

Fig. 84. What does Fig. 84 represent? Explain its use.

Fig. 85, 86. Explain the uses of Figures 85 and 86.

Fig. 87. What does Fig. 87 represent? Explain its use.

Fig. 88, 89. Explain the Figures 88 and 89, and the experiments which are made with them.

Fig. 90. What does Fig. 90 represent? Explain the experiments which may be made with it.

Fig. 91. What does Fig. 91 represent? Explain the experiments to be made with it.

ACOUSTICS.

ART **152.**—What is that science called which treats of the nature and laws of sound? What does it include?

ART **153.**—What causes sound? What illustrations are given to prove this?

ART **154.**—In what proportion are sounds loud or faint? Why does a bell sound louder in cold than in warm weather? Why is sound fainter on the top of a mountain than near the surface of the earth?

ART. **155.**—What are sonorous bodies?

ART. **156.**—To what do sonorous bodies owe their sonorous property? Are all elastic bodies sonorous?

ART **157.**—What causes the sound produced by a musical string? Upon what does the height and depth of the tone depend? Which strings, in a musical instrument, produce the low tones? Why?

Fig. 78.

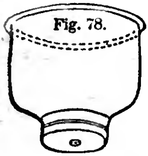


Fig. 79.

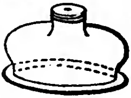
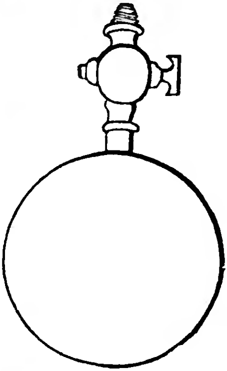


Fig. 80

Fig. 81.

Fig. 82.

Fig 84.



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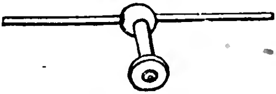


Fig. 83.

Fig. 86

Fig. 87

Fig. 88.

Fig. 89.

Fig. 90.

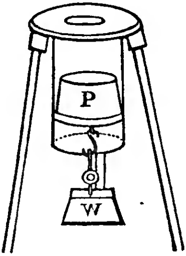


Fig. 91.

Fig. 92. Explain Fig. 92.

ART. 158.—Upon what is the science of harmony founded? How is the chord of an octave produced? How is the chord of a fifth produced? How is a musical chord produced? A discord?

ART. 159.—Upon what does the quality of the sound produced by strings depend? Upon what does that produced by wind instruments depend? What strings produce the lowest tones? How may different tones be produced from the same string? How may different tones be produced from the same wind instrument?

ART. 160.—What, in some degree, affects the quality of the sound of all musical instruments? What effect have heat and cold on the materials of which the instrument is made? What follows from this? Why are most musical instruments higher in tone, or sharper, in cold weather?

ART. 161.—Through which is sound communicated more rapidly, and with greater power, through solid bodies, or the air? How fast is it conducted by water? How fast by solids? What examples are given to show that sound is communicated more rapidly through solid bodies than the air or fluids?

ART. 162.—What is a stethescope? Of what does it consist? For what is it used?

ART. 163.—How fast does sound move? Does the force or direction of the wind make any difference in its velocity? What advantage results from this uniform velocity of sound? How can the distance of a thunder-cloud be ascertained?

ART 164.—How is an echo produced? Why cannot an echo be heard at sea, or on an extensive plain? How must a person stand in order to hear an echo? By what law is sound communicated and reflected? What anecdote is related of Dionysius? Upon what principle are speaking-trumpets constructed? Explain the manner in which the vibrations of the air are reflected. Upon what principle are hearing-trumpets constructed? How far does the musical instrument, called the trumpet, act upon the principle of the speaking-trumpet? How can the continued sound, given by some shells, when held near the ear, be explained?

ART 165.—Upon what principle may whispering-galleries be constructed?

ART 166.—In what way can sounds be conveyed to a much greater distance than through the air? What are the tubes, used to convey sounds, called? Why do the softer kinds of furniture in a room affect the quality of the sound? What general rule is given with regard to the reflection of sound? Is the air a better conductor when it is humid, or when it is dry? Why can a sound be heard better in the night than in the day?

Art. 167.—How is the sound of the human voice produced? How are the tones varied and regulated? Upon what does the management of the voice depend? What is ventriloquism? Was this art known to the ancients? What is supposed, by some authors, concerning the responses at Delphi, Ephesus, &c.? Is ventriloquism a natural gift, or an acquired one?

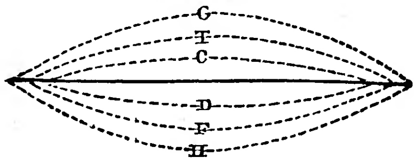
PYRONOMICS.

Art. 168.—What is Pyronomics? What is said in regard to the nature of heat? Is it ponderable or imponderable? What effect has heat upon bodies? What two forces continually act in opposition to each other? In what can the effect of heat be seen? How does it separate the particles? What would be the effect were the heat removed? Upon what has heat the most remarkable effect? How does it affect it? What effect has heat upon air? How is rain produced? What is stated with regard to heat? Can the progress of heat be arrested? What is caloric? In what two states does heat exist? What is free heat? Give some examples of free heat. What is latent heat? Give some examples of latent heat. How are the terms heat and cold generally used? What illustration of this is given?

Art. 169.—What are the three principal effects of heat on bodies to which it is applied? Give an example of each. What are the sources of heat?

Art. 170.—In what way does heat tend to diffuse itself? Why do bodies of the same absolute temperature appear to possess different degrees of heat? What illustration of this is given? What appears from this?

Fig. 92.



Atr. 171.—What causes the difference in the warmth of substances used for clothing?

Art. 172.—In what two ways is heat propagated? When is it propagated by conduction? When is it propagated by radiation?

Art. 173.—Do all bodies conduct heat with the same degree of facility? What bodies are the best conductors? In what order do the metals stand with respect to their conducting power? Is wood a good conductor of heat? Why are wool, fur, &c., so efficacious in preserving the warmth of the body? What is related in the note with regard to the conducting power of heat?

Art. 174.—What bodies reflect the heat? What bodies absorb the heat? Why do bright bodies, when placed near the fire, seldom become heated? Will snow melt most readily under white or black cloth?

Art. 175.—What effect is produced on all bodies when violently compressed or extended? What experiments are here related to illustrate this? What is said of the air when strongly compressed?

Art. 176.—Into what classes are all substances, as affected by heat, divided? What substances are combustible? What substances are incombustible?

Art. 177.—What is a pyrometer? Of what does it consist? How does Wedgewood's pyrometer measure high temperatures?

Art. 178.—What is the most obvious and direct effect of heat on a body? What application of this principle is related in the note? What is said of the effect of heat and cold on glass? When hot water is suddenly poured into a cold glass, why will the glass crack? When cold water is applied to a heated glass, why will the glass crack?

Art. 179.—Is the expansion caused by heat in solid and liquid bodies the same in all substances? How do aëriform fluids differ, in this respect, from solid and liquid bodies? Upon what does the expansion of solid bodies in some degree depend? Why has heat more power over gases and vapors?

Art. 180.—What effect has heat and cold upon the density of all substances? What exception is there to this remark? Why are the vessels, containing water and other similar fluids, so often broken when the liquid freezes in them? Why does ice float upon the water, instead of sinking in it? What is stated in the note with regard to this property of water?

Art. 181.—Can all bodies be raised to the same temperature by the same quantities of heat? What bodies retain their heat the longest?

Art. 182.—What becomes of the heat which is thrown upon a bright or polished surface? How do the angles of incidence and reflection compare with each other?

Art. 183.—When is water converted into steam or vapor?

Art. 184.—How does the temperature of the steam compare with that of the liquid from which it is formed while it remains in contact with that liquid?

Art. 185.—By what is the elasticity of steam increased and diminished? Upon what does the amount of pressure, which steam exerts, depend?

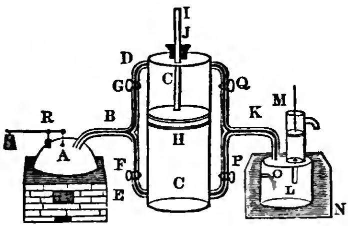
Art. 186.—What is the great and peculiar property of steam, on which its mechanical agencies depend?

Art. 187.—What is the steam-engine?

Art. 188.—How much larger space does steam occupy than water? By what mode is steam made to act? By what impulse does the piston rise? What causes the piston to descend? What improvement did Mr. Watt introduce into the steam-engine?

Fig. 93. What does Fig. 93 represent? What are the principal parts? What does A represent? What does C represent? What does B represent? What does K represent? By what is the steam led off from the cylinder? What does L represent? What does O represent? What does M represent? What does N represent? What does R represent? When the valves are all open, what becomes of the steam? When the valves F and Q are closed, and G and P open, upon what does the steam press? What does the cylinder draw with it in its descent? Which of the mechanical powers is this working-beam? What are attached to this working-beam? What is their use? What becomes of the steam when the stop-cocks G and P are closed, and

Fig. 93.



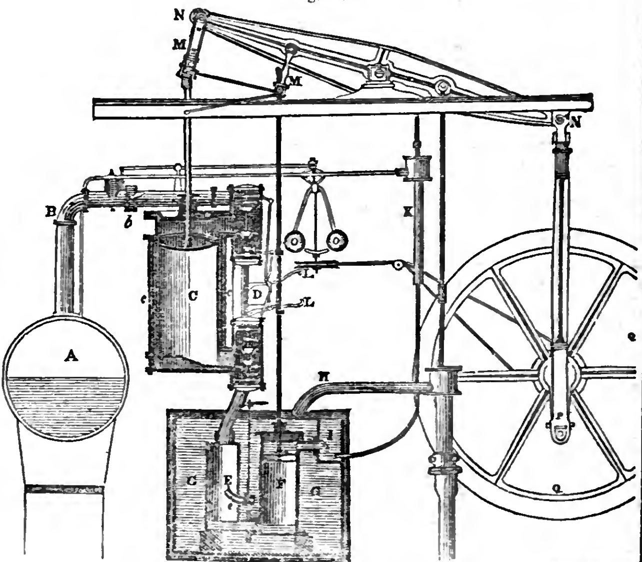
F and Q are open? How is the regular and continued motion produced? To what is this motion of the piston communicated? What is the use of the air-pump M? For what is the safety-valve R used?

Art. 189.—How is the power of a steam-engine expressed? What is an engine of 100 horse power?

Art 190.—What are the principal forms in which the steam-engine is constructed? How do they differ from each other? What becomes of the steam after having moved the piston in the non-condensing engines? What kind of engines is generally used on railroads? What becomes of the steam after having moved the piston in the condensing engines?

Fig. 94. What does Fig. 94 represent? What does A represent? What does B represent? What does C represent? What does D represent? What does E represent? What does F represent? What does G G represent? What does I represent? What does K represent? What does L L represent? What does M M represent? What does N N represent? What does O O represent? What is said of the governor?

Fig. 94.



Art. 191.—Describe the *locomotive* steam-engine.

Fig. 95. In Fig. 95, what do F and D represent? What do the following references respectively represent, namely, SSS? BBB? *pppp?* CC? X? L? P? NN? RGKK?

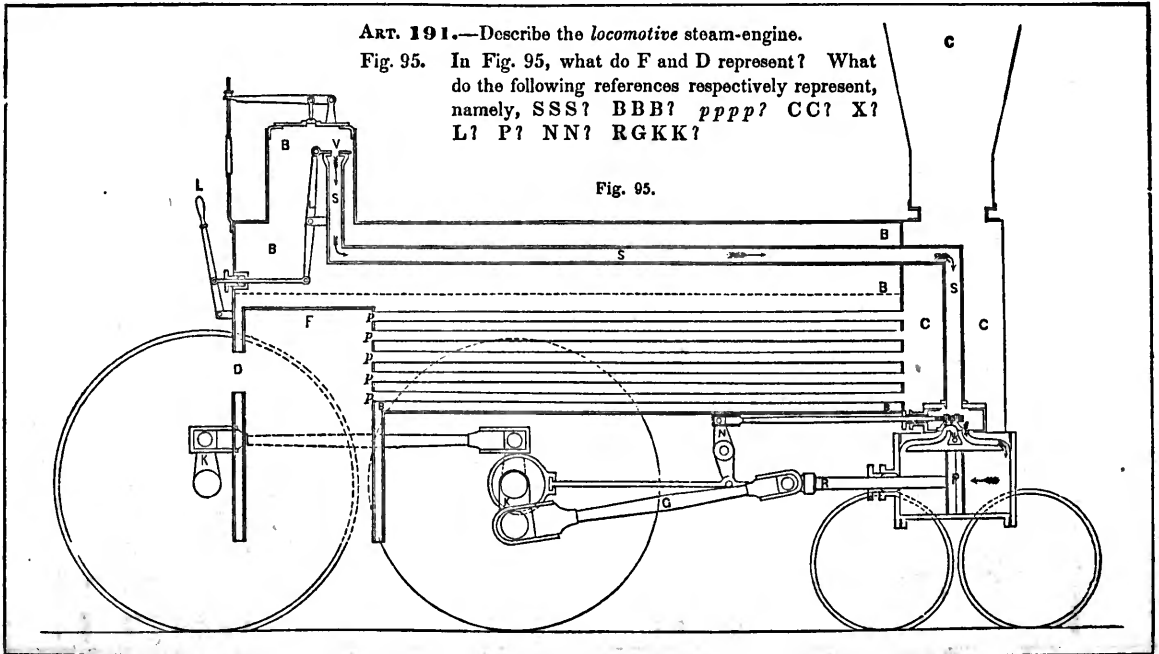


Fig. 95.

OPTICS.

Art. 192.—Of what does Optics treat? Into what classes does the science of Optics divide all substances? What are luminous bodies? Give an example of a luminous body. What are transparent bodies? Give an example of a transparent body. What are translucent bodies? Give an example of a translucent body. What are reflecting substances? Give an example of a reflecting body. What are refracting substances? What are opaque substances? What is light? What did Sir Isaac Newton suppose it to be? What other opinions have been formed concerning it?

Art. 193.—What is a ray of light?

Art. 194.—When are rays of light said to diverge?

Fig. 96. What does Fig. 96 represent?

Art. 195.—When are rays of light called converging? What is the point, at which converging rays meet, called?

Fig. 97. What does Fig. 97 represent?

Art. 196.—What is a beam of light?

Fig. 98. What does Fig. 98 represent?

Art. 197.—What is a pencil of light?

Art. 198.—What is a medium

Art. 199.—In what manner do the rays of light proceed from terrestrial bodies? In what kind of lines do the rays of light proceed from the sun?

Art. 200.—In what way is light projected forward from any luminous body? With what rapidity does it move?

Art. 201.—From what point, in a luminous body, does light radiate?

Art. 202.—How is a shadow produced? Why are shadows of different degrees of darkness? To what is the darkness of a shadow proportioned, when the shadow is produced by the interruption of the rays from a single luminous body?

Art. 203.—What is said of the shadow of the opaque body when the luminous body is the larger?

Fig. 99. Explain Fig. 99.

Art. 204.—What is said of the shadow of the opaque body when the luminous body is the smaller?

Fig. 100. Explain Fig. 100.

Art. 205.—How many shadows are produced when several luminous bodies shine upon the same object?

Fig. 101. Explain Fig. 101.

Art. 206.—What is the consequence when rays of light fall upon an opaque body which they cannot pass? What is meant by the reflection of light?

Art. 207.—What is Catoptrics?

Art. 208.—By what laws is light governed? How is light reflected when it falls perpendicularly on an opaque body? How is it reflected when it falls obliquely? How do the angles of incidence and reflection compare with each other? By what light are opaque objects seen? By what light are luminous objects seen?

Fig 102. Explain the angles of incidence and reflection. Is the same principle applicable to all kinds of surfaces? Explain its application to mirrors.

Fig. 96.

Fig. 97.

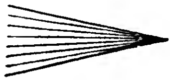


Fig. 98

Fig. 99.

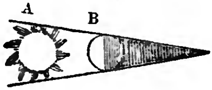
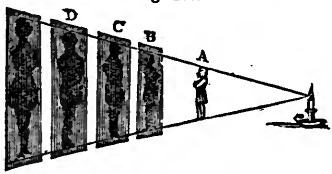


Fig. 100.



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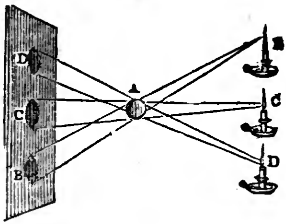
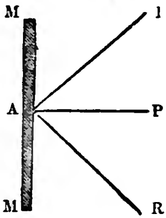


Fig. 102



Art. 209.—Why is the intensity of light diminished every time it is reflected?

Art. 210.—Does every portion of a reflecting surface reflect an entire image of the luminous body shining upon it? When the sun or moon shines upon a sheet of water, why do we not see an image reflected from every portion of the surface? Why do objects, seen by moonlight, appear fainter than when seen by daylight? By what light does the moon shine? What absorbs some of the rays of light in traversing the atmosphere?

Art. 211.—How are all objects seen? Why can none but luminous bodies be seen in the dark?

Art. 212.—What kind of an image is formed when rays of light, proceeding from an object, enter a small aperture?
Fig. 103. Illustrate this by Fig. 103. What is a camera obscura? How can a portable camera obscura be made?

Art. 213.—How is the angle of vision formed?
Fig. 104. Explain Fig. 104.
Fig. 105. What does Fig. 105 represent? What effect has the nearness of the object to the eye, on the angle? Illustrate this by the figure. Upon what does the apparent size of an object depend? Why do objects appear so large? To what is the art of perspective drawing indebted for its accuracy?

Art. 214.—How large an angle must a body subtend to be visible?

Art. 215.—When is the motion of a body invisible? Why is the motion of the heavenly bodies invisible? Upon what does the real velocity of a body, in motion round a point, depend?
Fig. 106. Explain Fig. 106. Why does the velocity of both, to an eye at E, appear to be the same?

Art. 216.—How many kinds of mirrors are there? What are plain mirrors? Do they magnify or diminish the object? What are convex mirrors? What part of a sphere is a convex mirror? What are concave mirrors? What part of a sphere is a concave mirror?
Fig. 107. In Fig. 107, which part of the sphere represents a convex mirror? Which part a concave mirror? Explain the figure.

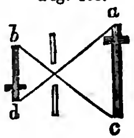
Art 217.—How does the image of an object reflected from a convex mirror compare with the object?
Fig. 108. Give the illustration.

Art. 218.—What is the focus of a concave mirror?

Art 219.—When an object is further from the concave mirror than the focus, how will the image appear? When the object is between the mirror and the focus? How must the object be placed that the image may appear upright? And as the object is removed towards the mirror?

Art. 220.—If the object be placed between the mirror and the focus, how does the image compare with the object?

Fig. 103.



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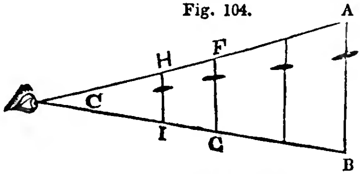

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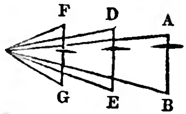

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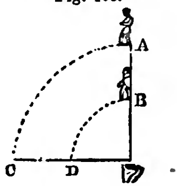


Fig 107.

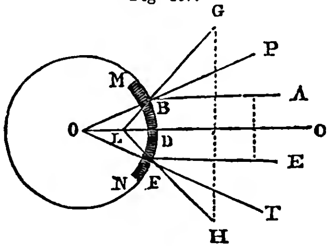


Fig 108.

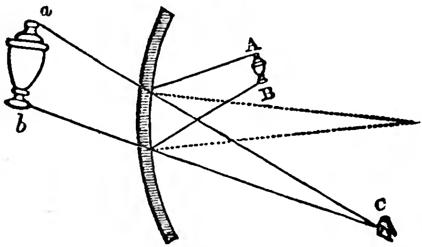


Fig. 109. Explain Fig. 109. What peculiar properties have concave mirrors? What facts are stated with regard to convex mirrors, as resulting from the fundamental law of Catoptrics? What is said of parallel rays? What is said of diverging rays? What is said of converging rays, when they tend towards the focus of parallel rays? What is said of converging rays, when they tend to a point nearer the surface than the focus? What is said of converging rays, when they tend to a point between the focus and the centre? What is said of converging rays, when they tend to a point beyond the centre? What is said of converging rays, when they tend to the centre? What is said with regard to parallel rays, when reflected from a concave surface? What is said of converging rays? What is said of diverging rays, if they diverge from a focus of parallel rays? What, if from a point nearer to the surface than that focus? What, if from a point between that focus and the centre? If from a point beyond the centre? If from the centre?

ART. **221.**—What is Dioptrics?

ART. **222.**—What is meant by the refraction of light? When does this take place?

ART. **223.**—What is a medium, in Optics? Give some examples of media. In what proportion is a medium dense or rare?

ART. **224.**—What are the three fundamental laws of Dioptrics?

Fig. 110. Illustrate the first law by the line A B, in Fig. 110. Illustrate the second law by the line C B. Illustrate the third law by the line F B. In what proportion does the refraction increase or diminish? Why does an oar or a stick, when partly immersed in water, appear bent? Why does the part which is in the water appear higher than it really is? Why does a body of water, when viewed obliquely, appear more shallow than it really is? In what direction can we look so as to cause no refraction? What experiment is here related?

ART. **225.**—Why do we not see the heavenly bodies in their real situation? In what direction do we see them? What causes twilight? Upon what does the duration of twilight depend? What other reason is given why we do not see the heavenly bodies in their true situation? When does the refraction of light not affect the appearance of the heavenly bodies? Why do the heavens appear bright in the daytime?

ART. **226.**—What effect is produced when a ray of light passes from one medium to another, and through that into the first again? Why does the refractive power of flat window-glass produce no effect on objects seen through it?

ART. 227.—What is a lens? How are all lenses to be considered? What is a single convex lens?

Fig. 111. What part of Fig. 111 represents a single convex lens? What is a single concave lens? What part of Fig. 111 represents a single concave lens? What is a double convex lens? What part of Fig. 111 represents a double convex lens? What is a double concave lens? What part of Fig. 111 represents a double concave lens? What is a meniscus? What part of Fig. 111 represents a meniscus? What is the axis of a lens? What line in Fig. 111 represents the axis of all the five lenses?

ART. 228.—What is stated with regard to the form of the lenses? How is light refracted in passing from a rarer to a denser medium? How, in passing from a denser to a rarer? What must be considered in estimating the effect of lenses? Through what must a perpendicular, to any convex or concave surface, always, when prolonged, pass? What is stated with regard to convex lenses? What, with regard to concave lenses?

ART 229.—What is the focal distance of a lens? To what is this equal in a single convex lens? To what is it equal in a double convex lens?

Fig. 109.

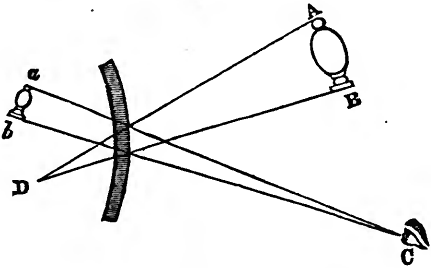


Fig 110.

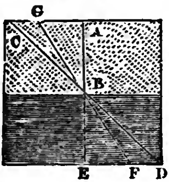
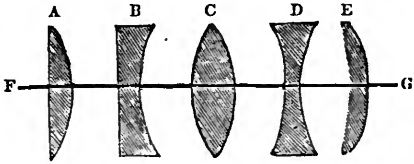


Fig. 111.



Art. 230.—When parallel rays fall on a convex lens, which one is perpendicular to its surface? How are the other rays, falling obliquely, refracted? What property of a convex lens gives it its power as a burning-glass? Where are all the parallel rays of the sun, which pass through the glass, collected? How does the heat at the focus compare with the common heat of the sun? What is related with regard to the effects of lenses produced by burning-glasses?

Art. 231.—What is the first effect related as resulting from the laws of refraction with regard to convex surfaces? What is said of diverging rays? What is said of rays converging towards the centre of convexity? What of rays converging to a point beyond the centre of convexity? What of rays converging to a point nearer the surface than the centre of convexity? When the rays proceed out of a denser into a rarer medium, what occurs? What is stated of parallel rays, proceeding from a rarer into a denser medium, through a concave surface? What is said of diverging rays? What is said of converging rays? Of what are the above eight principles the necessary consequence? What is the reason that so many different principles are produced by the operation of these laws?

Art. 232.—For what are double convex and concave glasses, or lenses, used in spectacles? What glasses are used when the eye is too flat? What are used when the eye is too round?

Art. 233.—Of what is the eye composed? What are the different parts of the eye? First? Second? Third? Fourth? Fifth? Sixth? Seventh? Eighth? Ninth? Tenth?

Fig 112. What does Fig. 112 represent? Explain the figure.

Fig. 113. What does Fig. 113 represent? Explain the figure. What part of the eye does the cornea form? Is its degree of convexity the same in all persons and all periods of life? What is its principal office? From what does the iris take its name? What is the use of the iris? What is the pupil? What is its form in the human eye? How much more light is the pupil capable of admitting, when expanded to its utmost extent, than when most contracted? What is said of those animals which are said to see in the dark? What light, only, is of use in vision? What becomes of the light which falls on the iris? What is the aqueous humor? What is its form? Of what use is it? What is the crystalline lens? What is its office? What is the vitreous humor? Why do persons sometimes experience pain when passing from a dark place into strong light? What is the shape of the vitreous humor?

Fig. 114. Explain Fig. 114. What is the retina? What is the choroid? By what is its outer and inner surface covered? What is its office? What is the opinion of some philosophers with regard to the choroid? What is the sclerotica? From what does it derive its name? What is its office? What are attached to the sclerotica? What is the optic nerve?

ART. **234.**—What philosophical instrument does the eye resemble in its construction?

Fig. 115. Explain Fig. 115. Why do the objects appear erect when the images are inverted? Why do we see only one image when an image is formed on both eyes? What are the defects which are remedied by the use of concave and convex lenses? In what other way is the eye subject to imperfection? Is there any remedy for this? By what is the convexity of the crystalline humor increased or diminished? What is effected by this means?

Fig. 112.

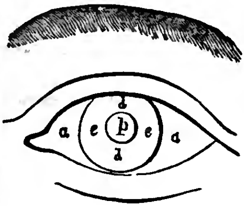
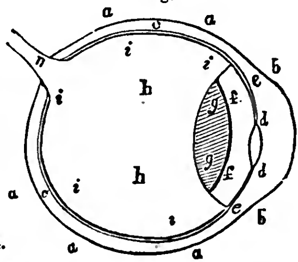


Fig. 113.



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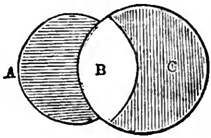

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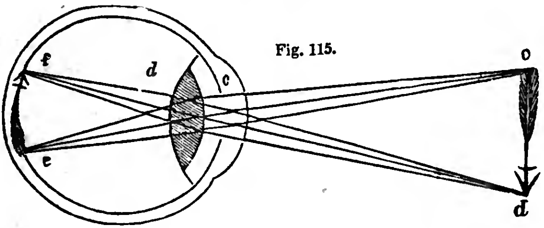


ART. **235.**—What is a single microscope? What is the use of this microscope? What figure represents a microscope?

Fig. 116. Explain Fig. 116. What lenses have the greatest magnifying power? What lenses have the shortest focus?

ART. **236.**—Of what does a double microscope consist? What is the use of these two lenses?

Fig. 117. What does Fig. 117 represent? Explain the figure.

ART. **237.**—What is the solar microscope? Of what does it consist? By what, in this microscope, are the sun's rays reflected, and upon what? For viewing what objects, only, is the microscope, above described, used? How do those microscopes, used for viewing opaque objects, differ from these? How is the image then formed? How is the magnifying power of a single microscope ascertained? Illustrate this. How is the magnifying of the compound microscope ascertained? In what proportion is the magnifying power of the solar microscope? Illustrate this. How may a lens be made to magnify or diminish an object?

ART. **238.**—What is the magic lantern? How are objects, viewed by the magic lantern, generally represented? What figure represents a magic lantern?

Fig. 118. Explain Fig. 118. In what proportion will the size of the image increase or diminish?

ART. **239.**—What is a telescope? How many kinds of telescopes are there? What are they? What is a refracting telescope? What is a reflecting telescope? Why is the image of an object, seen through a refracting telescope, less clear and perfect than when seen through a reflecting telescope? How many kinds of refracting telescopes are there? What are they? How do they differ the one from the other?

Fig. 119. What does Fig. 119 represent? Explain the figure.

Fig. 116.

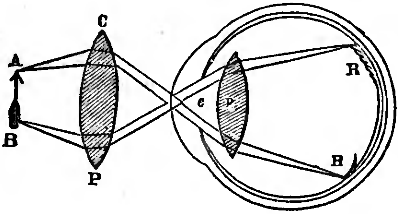


Fig. 117.

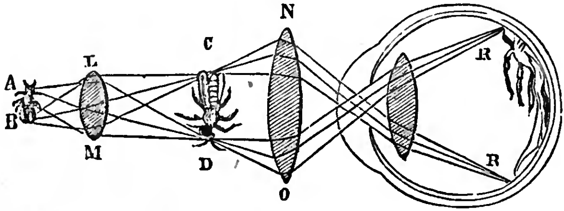


Fig. 118.

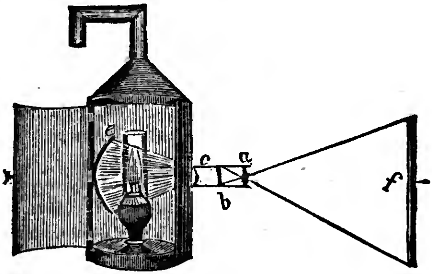


Fig. 119.

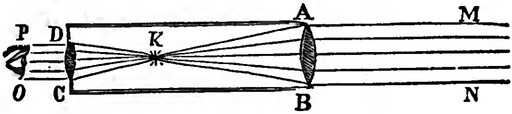


Fig 120. What does Fig. 120 represent? Explain the figure.

Fig. 121. What does Fig. 121 represent? Explain the figure. Why are mirrors used in reflecting telescopes? What is the use of the lens? What is the advantage of the reflecting telescope?

ART. **240.**—What is Chromatics? What causes color?

ART. **241.**—Of what is light composed? How can these rays be separated? By whom was this discovery made?

ART. **242.**—What is a prism? How may a prism be made?

ART. **243.**—How many colors enter into the composition of light? What are they? Do these rays all have the same degree of refrangibility?

ART. **244.**—What takes place when light is made to pass through a prism?

Fig 122. Explain Fig. 122. Why do the red rays fall on the lowest part of the screen? What is supposed with regard to the red rays? What with regard to the blue, indigo, and violet rays? Why does the sun appear red through a fog? Why does the sky appear of a blue color? What would be the appearance of the sky if the atmosphere did not reflect any rays? Is white a simple color? How is it produced? The spectrum formed by a prism being divided into 360 parts, how many of these parts does the red occupy? The orange? The yellow? The green? The blue? The indigo? The violet? What are the colors of all bodies? What appears from the experiments of Dr. Wollaston?

ART. **245.**—How is the rainbow produced? How is this proved? First? Second? Third?

ART. **246.**—Upon what does the color of all bodies depend? Of what color do bodies generally appear? When will a body appear of a compound color? Of what color will a body appear that reflects all the rays? When will a body appear black? Is color an essential property of a body? Of what color do bodies appear in the dark? Why do some bodies appear differently by candlelight? What is necessary to produce color? What experiments are related to prove the truth of the above? What rays does a body reflect in the greatest abundance? In what proportion does it reflect the other rays? Why do the green leaves of a rose appear to have a brown tinge? What does the brightness and intensity of a color show? Why do some bodies change their color?

ART. **247.**—What is a multiplying-glass? How many times will an object, viewed through a multiplying-glass, be multiplied? What is the principle of the multiplying-glass?

Art. 248.—Of what does the kaleidescope consist? From what is the word kaleidescope derived, and what does it mean? By whom was the instrument invented? What is here said with regard to the kaleidescope? In what way does Optics treat of light? What is the thermal property of light? Are the thermal properties of the rays the same, or different in each color of the prism? How do they differ? How do the chemical agencies differ? Do these powers exist in all light, or in solar light only? Where is the greatest heating power found? Where the greatest chemical power? Where the greatest optical power? In what are the chemical powers of light shown? Name the experiments and explain them. Explain the art of Photography, or Heliography. By what name is it now known? How else are the chemical effects of light seen?

Fig. 120.

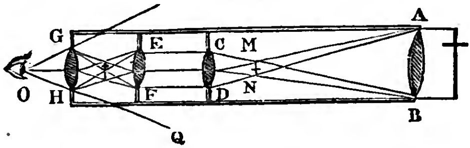


Fig. 121.

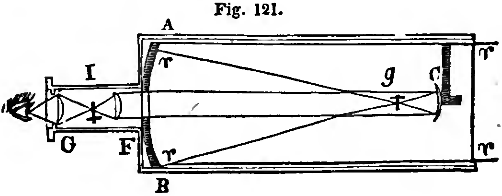
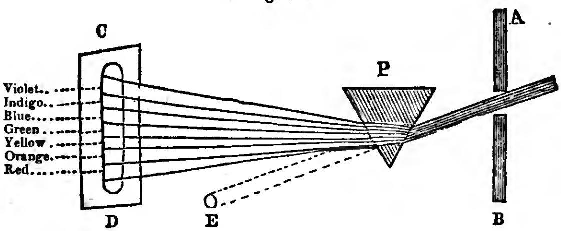


Fig. 122.



ELECTRICITY.

Art. 249.—What is electricity? How can electricity be seen? How are these effects exhibited? What illustration of this is given? What is said of the surfaces which have acquired the power of attraction? What are electrics? What are non-electrics? What is stated with regard to the word electricity? By whom was this property first discovered? What is stated with regard to the nature of electricity? Whose and what opinion is adopted in this volume? When is a substance said to be positively electrified? When is it said to be negatively electrified? What does positive electricity imply? What does negative electricity imply? In how many ways may electricity be excited? What are the different kinds of electricity called?

Art. 250.—Into how many kinds does the science of electricity divide all substances? What are they?

Art. 251.—What is said with regard to the communication of the electric fluid from one substance to another? Will all substances allow it to pass through them? What bodies are called conductors? What bodies are called non-conductors? What has been found, by experiment, with regard to electrics and non-electrics? What substances are electrics or non-conductors? Why must these substances be dry? What substances are non-electrics or conductors? What substances are mentioned as imperfect conductors?

Art 252.—When is a substance said to be insulated? Give the examples.

Art. 253.—When a communication is made between a conductor and an excited surface, where is the electricity from the excited substance conveyed? When is it said to be charged? When a communication exists by means of any conducting substance, between a body containing more than its natural share of the fluid and the earth, what will become of the redundant quantity which the body possesses? What illustration of this is given? What follows if this chain of conducting substances be interrupted?

Art. 254.—What is the simplest mode of exciting electricity? What illustration of this is given?

Art. 255.—What is the electricity excited in glass called? What is that obtained from resinous substances called?

Art. 256.—What is stated with regard to positive and negative electricity? What follows when one side of a metallic, or other conductor, receives the electric fluid? What follows when an electric is presented to an electrified body? What follows when two surfaces, oppositely electrified, are united?

Art. 257.—How do similar states of electricity act on each other? How do dissimilar states act on each other? Give the examples.

Art. 258.—For what is the Leyden jar used?
Fig. 123. What does Fig. 123 represent? What is a Leyden jar? When is the Leyden jar said to be charged? How can the jar be discharged? Can an insulated jar be charged?

Art. 259.—Of what is an electrical battery composed? How are the inner coatings of the jars connected together? How are the outer coatings connected? In what way is the battery charged?

Art. 260.—What is the jointed discharger?
Fig. 124. What does Fig. 124 represent? Of what does it consist?

Art. 261.—What is necessary when a charge of electricity is to be sent through any particular substance?

Art. 262.—In what way do metallic rods, with sharp points, attract the electric fluid? How can the electricity be made to pass off silently? Upon what principle are lightning-rods constructed? When is electricity said to be communicated by induction?

Art. 263.—When is electricity produced by transfer?

Art. 264.—For what purpose is the electrical machine constructed? Upon what principle are all electrical machines constructed?

Fig. 123.

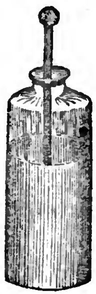
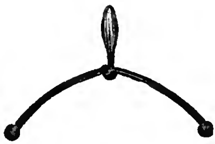


Fig. 124.



How is the electricity excited? Of what is the amalgam composed? In what form is the glass surface made? When is the machine called a plate machine? When is it called a cylinder machine?

Fig 125. What does Fig. 125 represent? Explain the figure. Explain the operation of the machine. To what must the chain be attached when positive electricity is required? To what must it be attached when negative electricity is wanted? What is the first experiment mentioned with the electrical machine? What does the word electrometer mean? Of what does it sometimes consist? What is an electroscope? What is the second experiment? What is the third? What does this show? What is the fourth? What is the fifth?

Fig. 126. What is the sixth? What is the seventh? How may the jar be filled with negative electricity? What is the eighth? What is the ninth? What is the tenth?

Fig. 127. What is the eleventh? What is the twelfth?

ART. 265.—What is the universal discharger? What is its use?

Fig. 128. What figure represents it? Of what does it consist? What is necessary in using the universal discharger? What is effected by this means? What experiments are shown by means of the universal discharger? How must the substance be placed? How may ether or alcohol be inflamed?

ART. 266.—What are the electrical bells?

Fig. 129 What figure represents them? What are they designed to show? How are they to be applied?

Fig. 130. Explain the spiral tube.

Fig. 125.

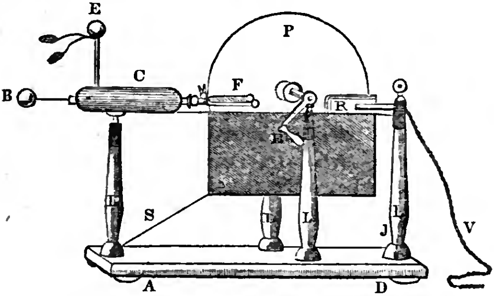


Fig. 126.

Fig. 127.

Fig. 128.

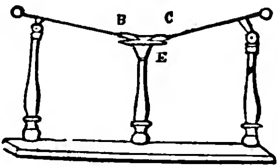


Fig. 129.

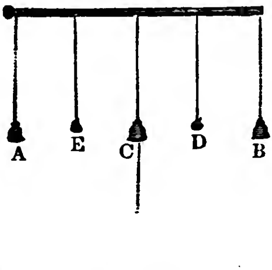


Fig. 130.

Fig. 131. Explain the hydrogen pistol.

Fig. 132. What does Fig. 132 represent?

Fig. 133. Explain Fig. 133.

Explain experiment one.

Fig. 134. Explain the second experiment. The third.

Fig. 135. Explain the fourth experiment. The fifth. The sixth. The seventh. What is lightning? What is thunder? How is the aurora borealis supposed to be caused? How is the electricity which a body manifests by being brought near to an excited body, without receiving a spark from it, said to be acquired? When an insulated, but unelectrified conductor, is brought near an insulated charged conductor, what is said with regard to the end near the excited conductor? What example is given to illustrate this? Why are square rods better than round ones to conduct electricity silently to the ground, and thus protect buildings from lightning? How far beyond the rod do lightning-rods afford protection? In what way are the most approved lightning-rods constructed? What is remarked with regard to the terms negative and positive? How can this be illustrated? What is said with regard to the time the electric fluid occupies in its passage through its circuit? What example is given to show that the fluid prefers the best conductors? In what different ways does the electric fluid sometimes pass in thunder-storms? Why is it unsafe, during a thunder-storm, to take shelter under a tree, or to hold in the hand any edge-tools? What position is the safest in a thunder-storm? When is there no danger to be apprehended from the lightning? By whom were lightning-rods first proposed? Who first discovered that thunder and lightning are the effects of electricity?

GALVANISM, OR VOLTAIC ELECTRICITY.

Art. **267.**—What is Galvanism? By whom and when was galvanism discovered? What led to the discovery? How is electricity generally produced? How is galvanic electricity produced? How does the motion of the galvanic fluid, excited by galvanic power, differ from that explained in the science of Electricity? What bodies are most easily affected by the galvanic fluid?

Art. **268.**—How is the galvanic fluid or influence excited? What illustrations of this are given?

Art. 269.—Into what are the conductors of the galvanic fluid divided? What substances are perfect conductors? What substances are imperfect conductors?

Art. 270.—What is necessary in order to produce galvanic action?

Art. 271.—Of what is the simplest galvanic circle composed? What process is usually adopted for obtaining galvanic electricity?

Fig. 136. Illustrate this by Fig. 136. What effect will be produced if,

Fig. 131.

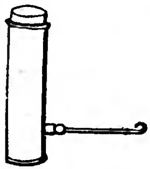


Fig. 133.

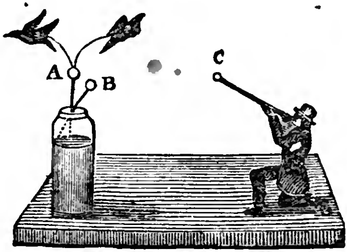


Fig. 132.

Fig. 134.

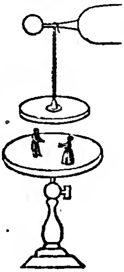


Fig. 136.

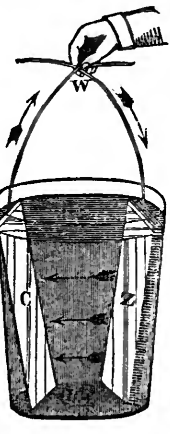
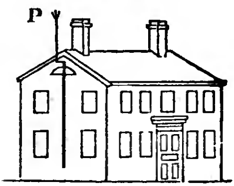


Fig. 135.



instead of allowing the metallic plates to come into direct contact, the communication between them be effected by wires? How many parts are there in the above arrangement? What are they? What effect does the acid produce? What is the electrical state of the zinc? Of the copper? What are the arrows in Fig. 136 designed to show? Where must the substance, to be submitted to the action of the fluid, be placed? What is said of the electrical effects of a simple galvanic circle? What examples are given illustrating the operation of simple galvanic circles?

ART. 272.—How may the galvanic effects of the simple circle be increased? What are compound galvanic circles?

ART. 273.—Of what does the voltaic pile consist?

Fig. 137. What does Fig. 137 represent? How may a voltaic pile be constructed? Can any other metal be used? What are the arrows in the figure designed to show?

ART. 274.—What is the voltaic battery? What is said with regard to the electricity excited by the battery?

Fig. 138. What does Fig. 138 represent? Of what does the voltaic battery consist? How is the communication between the first and last plates made? Where must the substance, which is to be submitted to galvanic action, be placed? How can a compound battery of great power be obtained?

Fig. 139. What does Fig. 139 represent? Of what does this battery consist? How can the electric shock from the voltaic battery be received by any number of persons?

Fig. 140. What figure represents Smee's galvanic battery? Describe it What liquid is employed for this battery?

Fig. 141. Describe Fig. 141.

Figs. 142, 143. Describe the sulphate of copper battery.

Fig. 137.

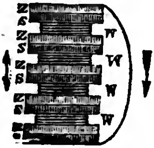


Fig. 138.

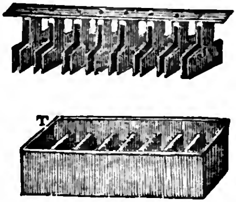


Fig. 139.

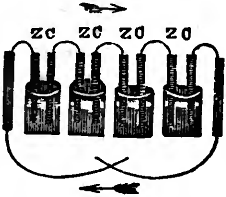


Fig. 140.

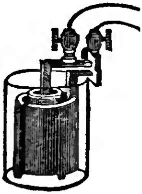


Fig. 141.

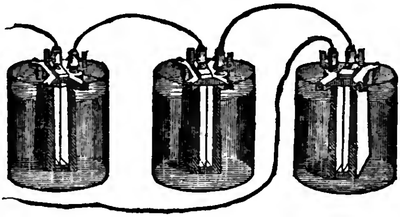


Fig. 142.

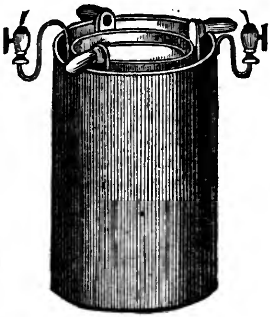


Fig. 143.

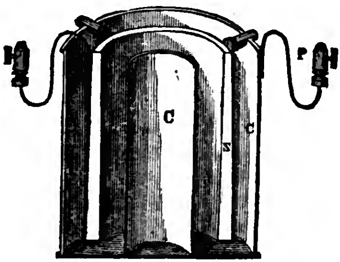


Fig. 144. Describe Grove's battery. Which is the most powerful battery? For what is it used?

ART. 275.—What effects may be produced by a spark from a voltaic battery? What precaution is taken in regard to the lines of the circuit?

ART. 276.—In how many ways does the electricity produced by the galvanic or voltaic battery differ from that obtained by the ordinary electrical machine? What is the first? What is here meant by intensity? How does the quantity of electricity obtained by galvanic action compare with that obtained by the machine? To what may the action of the electrical machine be compared? To what may the galvanic action be compared? What is the second way in which they differ? What is the third? What is said in the note with regard to the third circumstance in which the electricity obtained by the ordinary electrical machine differs from that produced by the galvanic battery? What is said of the effects of this continued current on the bodies subjected to its action?

ART. 277.—On what does the effect of the voltaic pile on the body depend? What facts in common life does galvanism explain? On what does the effects of galvanic action depend? What are batteries constructed of large plates sometimes called? Why? Describe them. Upon what principle is the calorimotor constructed? Are galvanic batteries of value?

MAGNETISM AND ELECTRO-MAGNETISM.

ART. 278.—Of what does Magnetism treat? How many kinds of magnets are there? What are they? What is the native magnet? What property does it possess? What is an artificial magnet? What magnet is preferred, for all purposes of accurate experiment? How can an artificial magnet be made?

ART. 279.—What is the first property of the magnet? Second? Third? Fourth?

ART. 280.—What is meant by the polarity of a magnet? Where is the attractive power of a magnet the strongest? When will a magnet assume a position directed nearly north or south? What is the north pole of the magnet? What is the south pole? In what ways can a magnet be supported so as to enable it to manifest its polarity?

ART. 281.—How do the same and different poles of a magnet affect each other? What is said with regard to the attraction of magnets, whether native or artificial? What analogy is there between the attractive and repulsive powers of the different kinds of electricity, and the northern and southern polarities of the magnet?

Art 282.—Can a magnet communicate its properties to other bodies? To what substances, only, can these properties be conveyed? Of what substances are all natural and artificial magnets, as well as the bodies on which they act, composed? How can the powers of a magnet be increased? What is a horse-shoe magnet? How can it be made to sustain a considerable weight? What is this bar called? How does soft iron differ from hardened iron, with respect to its acquiring and losing the magnetic power?

Art. 283.—What effect is produced when a magnet is broken or divided? Why is this a remarkable circumstance?

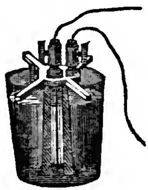
Art. 284.—Where does the magnetic power of iron or steel wholly reside? In what particulars do magnetism and electricity resemble each other? What is the first? What is the second? What is the third? What is the fourth?

Art. 285.—What effect has heat on the power of the magnet? By what is the magnetic attraction diminished? What effect has electricity on the poles of a magnet? What effect has electricity sometimes on iron and steel?

Art. 286.—What proportion do the effects produced by two magnets, used together, bear to that of either, used alone? What is meant by the inclination or dipping of the magnet?

Art. 287.—Does the magnet, when suspended, invariably point to the north and south points? What advantage has the science of magnetism rendered to commerce and navigation? Of what does the mariner's compass consist? To whom is the invention of the mariner's compass usually ascribed? How may the value of this discovery be estimated?

Fig. 144.



Art. 288.—Where are the north and south poles of a magnet the most powerful? What effect has a magnet on a piece of iron, when it is brought sufficiently near to it? How are artificial magnets made? Does the magnet which is employed in magnetizing a steel bar lose any of its power by being thus employed? What is a magnetic magazine? How is a magnetic needle made? What is said with regard to a horse-shoe magnet? How should a horse-shoe magnet be kept?

Art. 289.—Of what does Electro-Magnetism treat? What is the electric current? What does the science of electro-magnetism explain? What is the difference between the currents in the single and the compound circles? What is it thought causes magnetic attraction? What discovery was made in the year 1819? By whom? What further discovery was made soon after, and by whom? What does this philosopher maintain? How many kinds of electricity are there? How do the phenomena exhibited in these five kinds of electricity differ? Can magnetism be developed in steel not previously possessing it? Where must the steel be placed? What property has the uniting wire?

Art. 290.—What are the principal facts in connexion with the science of electro-magnetism? What is the first? What is the second? What is the third? What is the fourth? What is the fifth? What is the sixth? What is the seventh? Where have the bodies been supposed to be placed, in all the effects of electricity and galvanism that have hitherto been described? What is the eighth fact in connexion with the science of electro-magnetism? What is the ninth? What is the tenth? How can the direction of the electric current be ascertained?

Art. 291.—If a magnet be freely suspended, and a current of electricity be passed near it, what direction will it assume? What illustration of this is given? What second illustration is given? In what direction will the pole of the needle next to the negative end of the wire move, if the connecting wire be placed below the plane in which the needle moves, and parallel with it? What is said with regard to the attractions and repulsions?

Art 292.—How may the two sides of an unmagnetized steel needle become endued with the north and south polarity? Under what circumstances will it become permanently magnetic?

Art 293.—How can magnetism be communicated to iron and steel? How can the effect be more conveniently produced? What illustration of this is given? What is the helix? Why should the wire, which forms the helix, be coated with some non-conducting substance? What is said of a helix, if it be placed so that it may move freely?

Art. 294.—How can the magnetic needle be made to deviate from its proper direction? What is a needle thus prepared called?

Art. 295.—What is the electro-magnetic rotation? What illustration is given?

Fig. 145. What does Fig. 145 represent? Explain the figure. How is the freedom of motion, which is required on the wire, obtained? How can the metallic contact which is required be obtained? If the poles of a battery be connected with the horizontal external wires, *c c*, throughout, what direction will the current of electricity take? Round what pole will the moveable part of the wire rotate? Round what will the magnetic pole rotate?

Fig. 146. What does Fig. 146 represent? Of what does it consist? How will the cylinders in each revolve, if, instead of a bar-magnet, a horse-shoe magnet be employed, with an apparatus on each pole similar to that which has now been described?

Fig. 145.

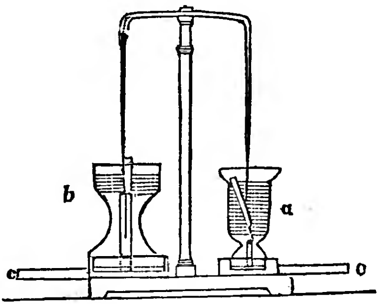
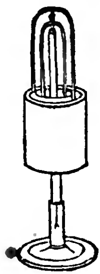


Fig. 146.



Art. 296.—How may the magnetizing power of the connecting wires be increased? Is a single circuit preferable to a straight wire?

Fig. 147. Explain Fig. 147.

Art. 297.—What is a bar called that is temporarily magnetized? How do you ascertain the poles of an electro-magnet?

Art 298.—How have magnets of great power been formed? What weight was the magnet constructed by Professor Henry and Dr. Ten Eyck capable of supporting?

Fig. 148. Explain the heliacal ring and Fig. 148

Art. 299.—How are bars of the U form most readily magnetized?

Fig. 147.

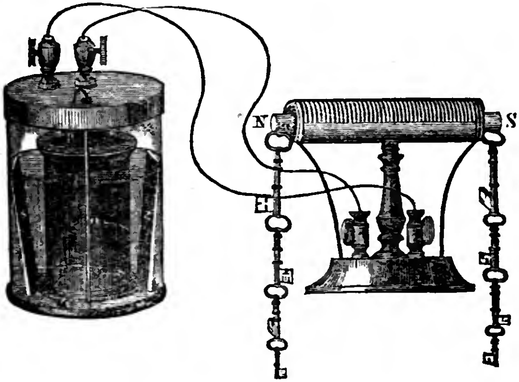


Fig. 148.

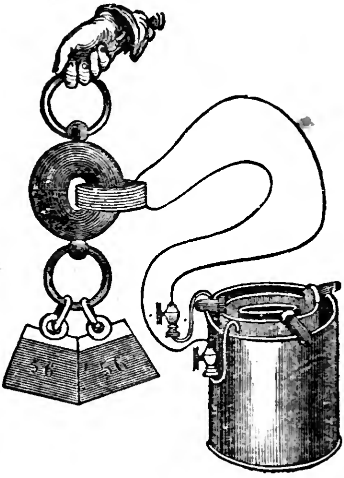


Fig. 149. Explain Fig. 149.

Art. 300.—Explain the electro-magnetic telegraph.

Art. 301.—Of what does magneto-electricity treat? How are electric currents excited?

Fig. 150. Explain the magneto-electric machine, Fig. 150.

Art. 302.—What is thermo-electricity? To what do the magnets owe their peculiar properties? What follows from this? How many states of electricity are there? What is said of that derived from the common electrical machine? What is said of that derived from the galvanic apparatus? What is said of the thermo-electric currents?

Fig. 149.

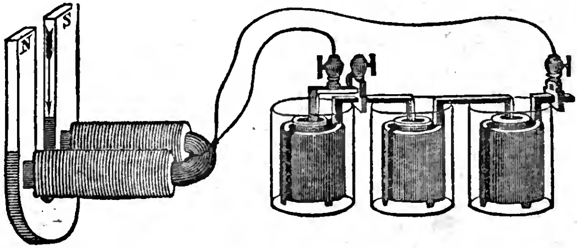
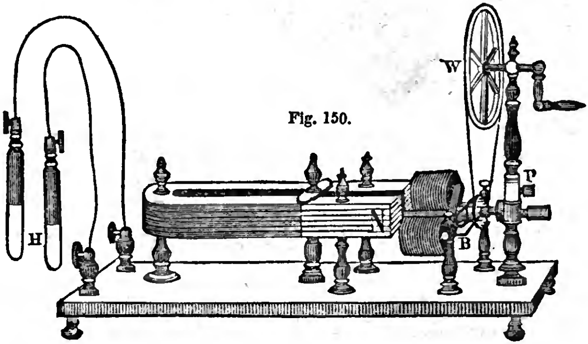


Fig. 150.



ASTRONOMY.

ART. 303.—Of what does Astronomy treat? What is said of the earth? How is the earth known to be round? Where is it situated?

ART. 304.—Of what does the solar system consist? What are the stars supposed to be? Do we see more by the aid of glasses than without?

ART. 305.—How may the planets be distinguished from the stars? How are the planets distinguished from the *fixed* stars? What is the meaning of the word planet? Why are they called planets? What are the fixed stars? What are the sun, moon, planets, and fixed stars supposed to be? Why do they appear so small? What has been stated with regard to the attraction of portions of matter? Upon what force does this attraction depend? What follows from attraction being mutual? What direction do bodies take when actuated by several forces? Is this true with regard to the heavenly bodies? What is the centre of the solar system? What is said of the revolution of the planets?

ART. 306.—What are the paths in which the planets move around the sun called? Around what do the planets revolve? What is a year on each planet? How long is the year of the planet Mercury? How long is the planet Venus performing her revolution around the sun? How long is the earth performing her revolution around the sun? What is the length of the year on the planet Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? Neptune? Of what form are the orbits of the planets? What is meant by the mean distance? What planets are called inferior? Why? What planets are called superior? Why? What is the distance of the planet Mercury from the sun? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? Neptune? Have the planets any motion besides that around the sun? What is the time in which they turn upon their axes called? What is the length of a day on the planet Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? Neptune?

ART. 307.—What is the diameter of the Sun? Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? The Moon?

Fig. 151. What does Fig. 151 represent? What illustration of the comparative size and distance of the bodies of the solar system is given? What is necessary in order to imitate the motions of the planets in the above-mentioned orbits?

ART. **308.**—What is the ecliptic? Why is it called the ecliptic?

ART. **309.**—What is the zodiac? Why is it called the zodiac?

ART. **310.**—What are the names of the twelve constellations? How many degrees does each sign contain?

ART. **311.**—Are the orbits of the other planets in the same plane with that of the earth?

Fig. 152. What does Fig. 152 represent? What are the nodes of a planet?

Fig. 153. What does Fig. 153 represent?

ART. **312.**—When is a planet said to be in any particular constellation?

ART. **313.**—What do the perihelion and aphelion of a heavenly body express? When is a body said to be in its perihelion? When is a body said to be in its aphelion? How much nearer is the earth to the sun in its perihelion than in its aphelion? When is a planet said to be in its inferior conjunction? When is it said to be in its superior conjunction? When is it said to be in opposition?

ART. **314.**—What do the apogee and perigee of a heavenly body express? When is a body said to be in its perigee? When is it said to be in its apogee?

Fig. 151.

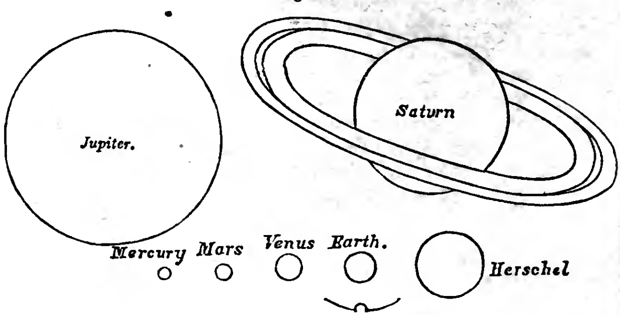


Fig. 152.

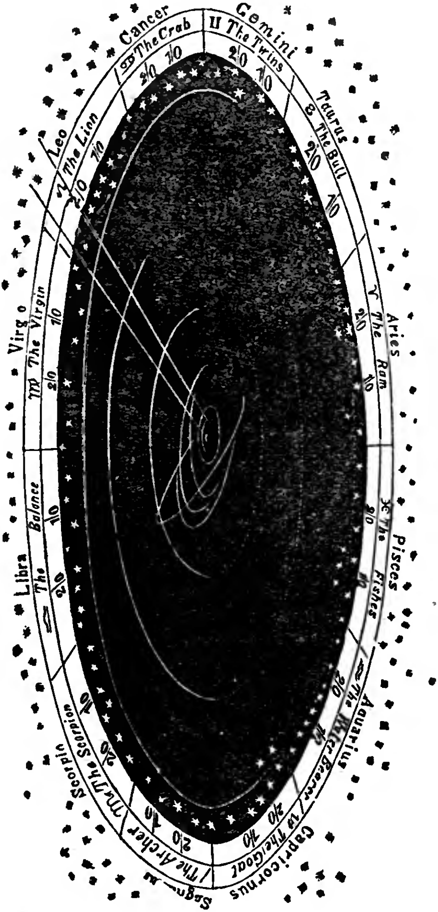
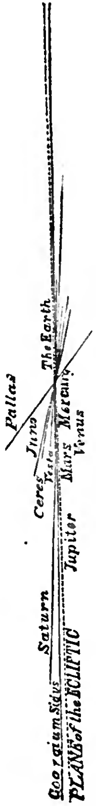


Fig. 153



Art. 315.—In what sign is the perihelion of the planet Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Georgium Sidus?

Art 316.—What is said with regard to the axes of the planets in their revolution around the sun? What does this inclination of their axes cause?

Art. 317.—What is said with regard to the motion of the heavenly bodies? When do they move with the greatest velocity? When is their motion the slowest?

Art. 318.—What is Kepler's law?

Fig. 154. Illustrate this by Fig. 154. Explain, by Fig. 154, the reason why the earth, or any other heavenly body, moves with a greater degree of velocity in its perihelion than in its aphelion. What is said of the motion of the heavenly bodies from perihelion to aphelion? What is their motion from aphelion to perihelion? When is their velocity the greatest? How much longer is the earth in performing the aphelion part of its orbit than the perihelion part?

Art. 319.—How much nearer is the earth to the sun in winter than in summer?

Art. 320.—What follows from the inclination of the earth's axis, with regard to the direction of the sun's rays? When is the heat always the greatest? What is said of oblique rays? What is the reason that the heat is greater in summer than in winter?

Fig. 155. Illustrate this by Fig. 155. How is the earth situated with regard to its distance from the sun in winter? What illustration of oblique and perpendicular rays is given in the note? Why is it generally cooler early in the morning and late in the afternoon than at noon? Why is the heat the greatest at about three o'clock? What causes the variety of climate in different parts of the earth? Where does the sun always shine in a vertical direction? What would follow were the axis of the earth perpendicular to its orbit? What causes the variety of the seasons, the different lengths of days and nights, &c.? What is necessary in order to understand the illustration of the causes of the seasons?

Fig. 156. Explain Fig. 156. What are the poles? Why is the circle I K called the tropic of Cancer? What is the meaning of the word tropic? Why is the circle L M called the tropic of Capricorn? What are the tropics? What is the circle E F called? What does it represent? What is the circle G H called? What does it represent?

Fig. 154.

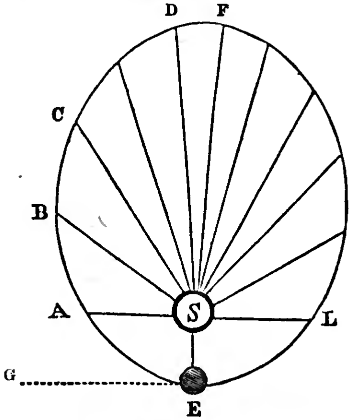


Fig. 155.

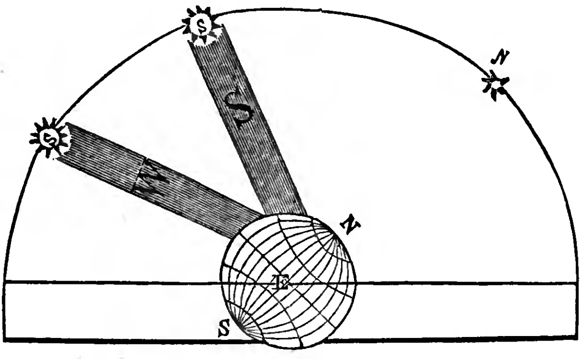


Fig. 156.

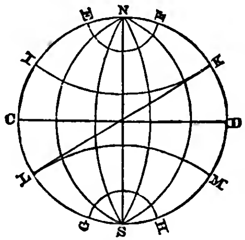


Fig. 157. What does Fig. 157 represent? Explain the figure. Explain, by the figure, the situation of the earth on the 21st of June. What causes day and night? To what part of the earth is it day? To what part is it night? To what is the length of the day in proportion? When are the days the longest? Why? When are they the shortest? Why? Explain, by the figure, the situation of the earth on the 22d of September. On the 23d of December. On the 20th of March. What follows from the changes on the earth, caused by the inclination of the earth's axis? In what proportion are these changes? What is said of the axis of the planet Jupiter? Is it supposed that the sun, planets, and stars are inhabited? What is shown by Fig. 157? Where are these points? What are they called? Which is the vernal equinox? Which the autumnal? What other two points are there? Why are they called solstices? Where are these points? Which is the summer solstice? Which the winter?

Art. **321.**—What is said of the sun? What is its diameter? How much does its cubic magnitude exceed that of the earth? How long is it in performing its revolution around its axis? How has this been ascertained? What did Dr. Herschel suppose these spots to be? What is the zodiacal light? At what time is it most distinct? Where is it constantly visible?

Art. **322.**—What planet is nearest to the sun? Why is it seldom seen? What is said of the heat of this planet? How much greater is the sun's heat in Mercury than on the earth? In what form does water exist in Mercury? How can Mercury be recognised when seen? At what time does it appear? How does Mercury appear when viewed through a telescope?

Art. **323.**—What planet is nearest to the earth? When is Venus called the morning star? When is it called the evening star? How much greater are the light and heat at Venus than that at the earth? What name was given by the ancient poets to Venus, when morning star? What, when evening star? What is the greatest distance at which the planets, Mercury and Venus, ever appear from the sun? What is meant by the transit of these planets? What is said of the different appearances which Venus presents? Why can we not see the planets and stars in the daytime?

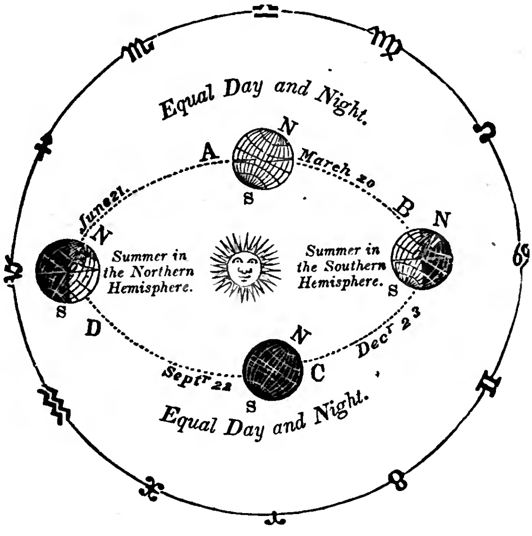
Art **324.**—What planet is next to Venus? What is the form of the earth? How much larger is its equatorial diameter than its polar? How many moons has the earth? What is the diameter of the moon? What is its distance from the earth? What is the length of a day at the moon? How long is it in performing its revolution around the earth?

ART. 325.—What phases does the earth, when viewed from the moon, exhibit? How much larger does the earth appear than the moon?

ART. 326.—What planet is next to the earth? What renders it conspicuous? What is supposed to cause this appearance? How much more light and heat does the earth enjoy than Mars? When were the asteroids discovered? By whom, and in what year was Vesta discovered? What is the color of its light? By whom and when was Juno discovered? What is the color of its light? When was Pallas discovered? By whom? What is said of its atmosphere? When and by whom was Ceres discovered? What is its color? What is said in the note with regard to these planets?

ART. 327.—Which of the planets is the largest? How much more light and heat does the earth enjoy than Jupiter? How many moons has this planet? What is the distance of these moons from the planet? In what time do they perform their revolu-

Fig. 157.



tions around the planet? How does the size of these moons compare with that of ours? Why has Jupiter no sensible variety of seasons? Of what use are the eclipses of Jupiter's moons? How long is light in coming from the sun to the earth? How has this been ascertained? How does Jupiter appear when viewed through a telescope?

Art. **328.**—How does Saturn compare in size with the other planets? How is Saturn distinguished from the other planets? What is said of these rings? How much longer are these rings in performing their revolution around the planet than the planet is in performing its revolution on its axis? What is the breadth of these rings? What is said of the surface of Saturn? How many moons has Saturn? How may Saturn be known? What is said of the moons of Saturn? Why are they not often eclipsed?

Art. **329.**—How does Uranus compare in size with the other planets? How does the light and heat at Uranus compare with that of the earth? By whom was this planet discovered? What name did he give it? How many moons has Uranus? By whom were they discovered? How are their orbits situated, with regard to that of the planet? What is said of their motion? What appears to be a general law of satellites? What follows from this with regard to the appearances which the inhabitants of the secondary planets must observe?

Art. **330.**—Who discovered the planet Neptune?

Art. **331.**—What is the meaning of the word comet? To what class of bodies is this name given? Of what do these bodies appear to consist? What is the number of comets that have occasionally appeared? What discoveries have been made concerning 98 of them? What is the result? What is the form of the orbits of comets? What is said of the motion of comets when in perihelion? What did Newton calculate the velocity of the comet of 1680 to be in an hour? For what was this comet remarkable? What is said of the luminous stream of a comet as it approaches and recedes from the sun? What did Newton, and some other astronomers, consider the tails of comets to be? What is said in the note with regard to comets? Who were the first astronomers that successfully predicted the return of a comet? What is the periodical time of Halley's comet? Of Encke's? Of Biela's?

Art. **332.**—Into how many magnitudes are the stars classed? Of what magnitude are the largest? Of what are the smallest? What are telescopic stars? Why cannot the distance of the fixed stars be determined? To what is the difference in their apparent magnitudes supposed to be owing? Have the stars any motion?

Art. 333.—What is the Galaxy? Of what is it supposed to consist? How did the ancients divide the stars? What was the number of constellations among the ancients? How many have been added by the moderns? How are the stars designated on the celestial globe? What is the situation of each constellation now? Illustrate this. What is the cause of this difference? Why do we not see the stars, and other heavenly bodies, in their true situation? How can a star be seen in its true situation? What is meant by the aberration of light? What is necessary to be taken into consideration, in determining the true place of the celestial bodies? What effect has this property of the atmosphere on the length of the days?

Art. 334.—What is the parallax of a heavenly body?

Fig. 158. Explain Fig. 158. What appears from this? What allowance must also be made?

Art. 335.—Is the moon a primary or secondary planet? How long is it in performing its revolution about the earth? What is its distance from the earth? What is the most obvious fact in relation to the moon? How is this caused? What kind of a body is the moon? By what light does it shine?

Fig. 158.

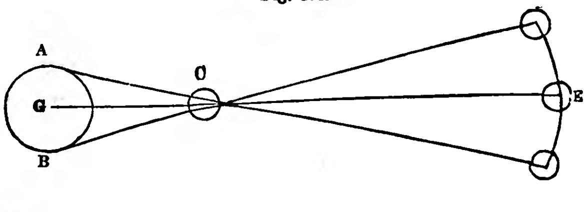


Fig. 159. Explain Fig. 159. How does the moon appear when viewed through a telescope? What causes the difference in the rising of the moon? What is the mean difference in the rising of the moon? What is the harvest moon? What is the hunter's moon? When are the moons always the most beneficial?

ART. **336.**—What are tides? By what are they occasioned?

Fig. 160. Explain the theory from Fig. 160. What is the greatest distance of the moon from the equator? Where are the tides highest? Why? Has the sun any effect on the tides? What are spring tides? When do they occur?

Fig. 161. What are neap tides? When do they take place?

ART. **337.**—What is an eclipse? When does an eclipse of the sun take place? When does an eclipse of the moon take place? What is necessary at the time of an eclipse? How often would there be an eclipse, if the moon went round the earth in the same plane in which the earth goes round the sun? Why? What is the inclination of the moon's orbit to the ecliptic? What is the apparent diameter of the sun and moon? What follows from this? When is the sun eclipsed? When the moon? Does an eclipse happen every time there is a full or new moon? What must the shadows of these bodies always be? Why?

Fig. 162. Explain Fig. 162. When is an eclipse called annular?

Fig. 159.

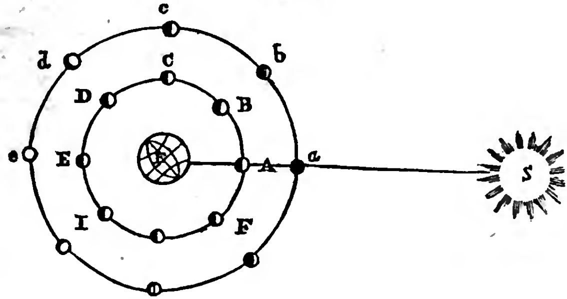


Fig. 160

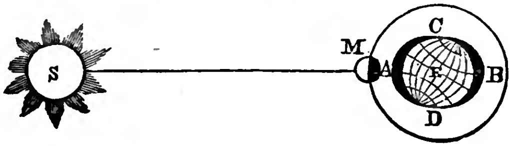


Fig. 161

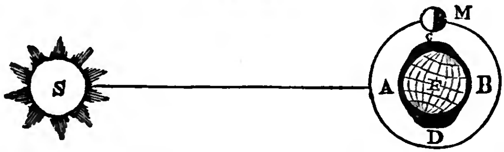


Fig. 162

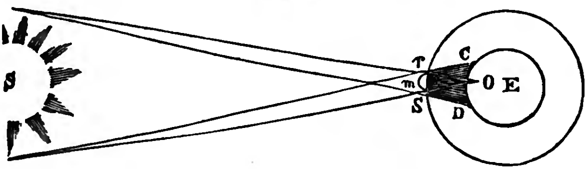


Fig. 163. Explain by Fig. 163. What is a penumbra? Why are eclipses of the moon visible to more inhabitants than those of the sun? Why is a lunar eclipse visible to all to whom the moon is visible at the time? What is said of the earth's shadow? Explain by the figure. Into what are the diameters of the sun and moon supposed to be divided? How many digits are these bodies said to have eclipsed? How often must there be an eclipse of the sun? What is the greatest number, of both lunar and solar eclipses, that can take place in a year? What is the usual number? What is said of the eclipse of the sun in 1806?

Art. **338.**—What is time called when calculated by the sun? What is sidereal time? How much longer is the sidereal year than the solar? How is a solar year measured? What is the length of a solar year? Why is a day added every fourth year, to the year? How is a sidereal year measured? What is the precession of the equinoxes? What change has this circumstance caused, with regard to the situation of the constellations? Can true equal time be measured by the sun? Why? At what periods of the year do the sun and a perfect clock agree? What is the greatest difference between true and apparent time?

Fig. 164. What does Fig. 164 represent?

Fig. 163.

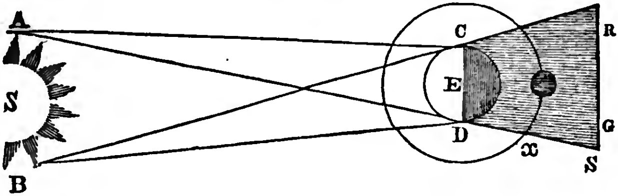


Fig. 164.