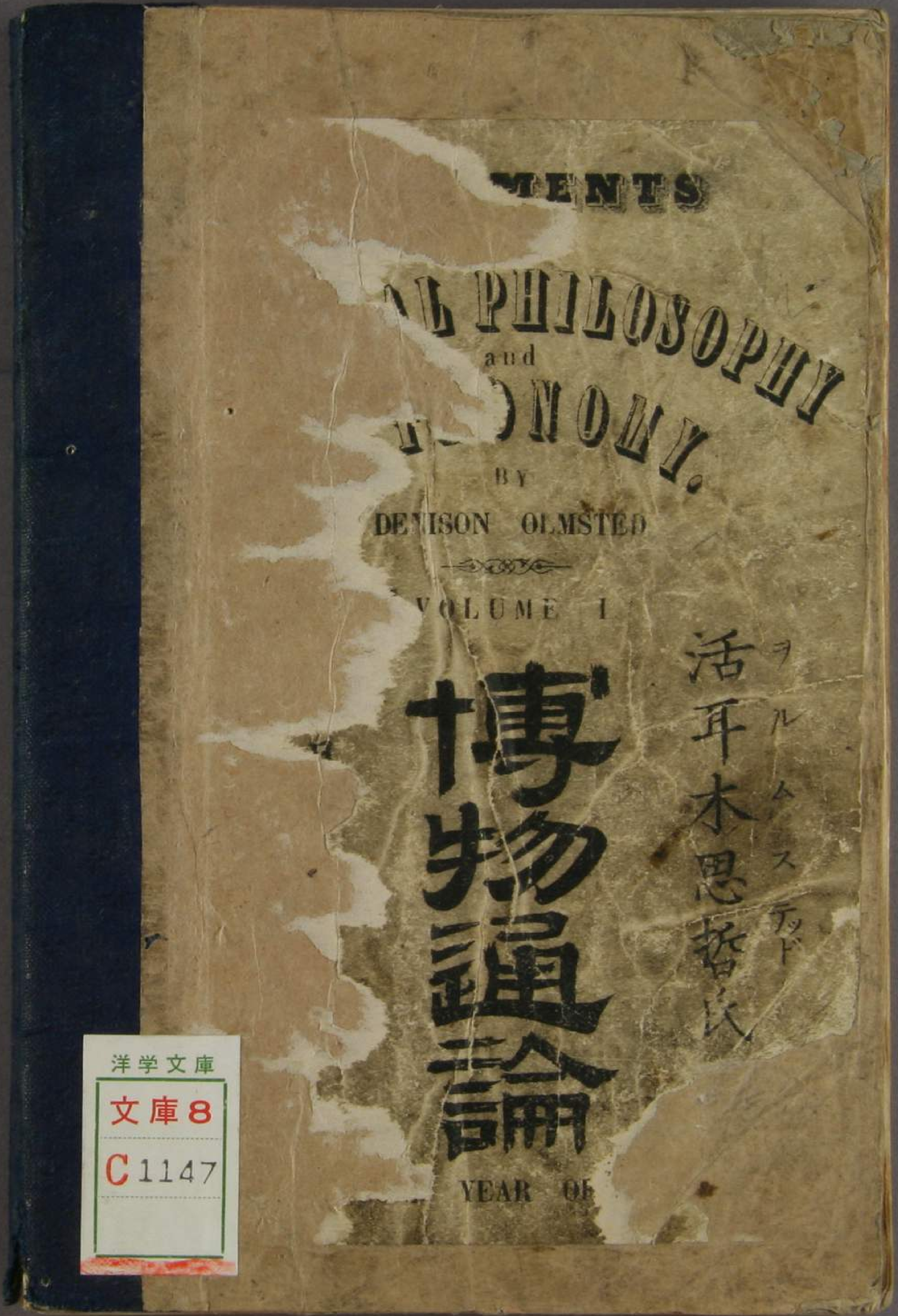

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AL PHILOSOPHY
and
ONOMY.

BY

DENISON OLMSTED

VOLUME I

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YEAR OF

RUDIMENTS

OF

NATURAL PHILOSOPHY AND ASTRONOMY:

DESIGNED FOR THE

YOUNGER CLASSES IN ACADEMIES.

AND FOR

COMMON SCHOOLS.

BY DENISON OLMSTED, LL. D.

PROFESSOR OF NATURAL PHILOSOPHY AND ASTRONOMY
IN YALE COLLEGE.

VOLUME I.

YEDO.
IN THE SECOND YEAR OF KEI-OU.

PREFACE

TO THE

REVISED EDITION.

It was originally the special object of this work, to prepare such a treatise on Natural Philosophy and Astronomy, as is suited to the more advanced pupils of the Primary Schools. I say the more *advanced* pupils; for, in my judgment, these studies—with the exception of a few simple truths which are objects of sight, and may be shown by experiment, or pointed out in nature—are but ill adapted to young children, requiring, as these subjects do, faculties, as those of reasoning and reflection, which are not usually developed in children. Accordingly, little of value can be learned by them of Natural Philosophy and Astronomy, at an earlier age than twelve or fourteen years. But a work on the *principles* of those sciences, and their applications to the arts, and to the phenomena of nature, addresses itself to minds somewhat mature and cultivated. To such minds may be communicated not merely the "beggarly elements," but the great comprehensive principles of these exalted sciences; principles which the learner can apply to practice in the various arts of life, and which will lead him to an understanding of the great laws of nature.

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I should deem myself incompetent to write a book like the present, if I had not been myself a teacher, first in a common school, and afterward in an academy, or grammar school of the higher order. No one is qualified to write text-books in any department of instruction, who does not know, by actual experience, the precise state of mind of the pupils for whom he writes. Several years of experience in teaching the rudiments of knowledge, in early life, and the education of a large family at a later period, have taught me the devices by which the minds of young learners are to be addressed, in order that subjects, at once new and requiring some powers of reflection to understand them, may be comprehended with perfect clearness, and of course with lively pleasure. Children are naturally fond of inquiring into the causes of things. We may even go further, and say that they begin from infancy to interrogate nature in the only true and successful mode—that of experiment and observation. With the taper which first fixes the gaze of the infant eye, the child commences his observations on heat and light. With throwing from him his playthings, he commences his experiments in mechanics, and pursues them successively, as he advances in age, studying the law of projectiles and rotary motion in the arrow and the hoop, of hydrostatics in the dam and the waterwheel, and pneumatics in the windmill and the kite. The boy was a genuine philosopher, who cut open the bellows to find the wind.

The advantages which it is believed this work has over some others on the same subjects, designed for the Primary Schools, are such as the following:

1. In *simplicity of language*. This quality is sought to be secured, not by adopting a puerile style, but by employing, for the most part, Saxon English, and avoiding, as far as practicable, technical terms. Gratifying assurances have been given me that this desirable end has been attained. Dr. Howe, the eminent Principal of the Massachusetts Asylum for the Blind, assigned this as one of the reasons for preparing an edition of this work in *raised letters*, for the use of the blind. On account of the simplicity and precision of the language, Rev. Samuel Porter, of the New York Institution for the Deaf and Dumb, pronounced it *the* book for their pupils; and, for similar reasons, it has been extensively used in the Mission Schools in various parts of the world

2. In the *value of the truths* selected. Amid the vast extent and variety of facts and principles embraced in the two sciences of Natural Philosophy and Astronomy, an acquaintance with these subjects equally extensive, is required, in order to know *what truths* among them all are of the highest value, in relation to the wants of those for whom the book is written. The author having been, by early education, familiar with the class of minds instructed in the common schools, and having since devoted many years to the study and teaching of these sciences, has enjoyed peculiar advantages for making such a selection.

3. In *density* and *comprehensiveness*. It is believed that few works, so limited in size, will be found to contain so much valuable information on the subjects of Natural Philosophy and Astronomy.

But, whether this treatise or some other shall be judged by the friends of popular education best adapted to the end proposed, it has long appeared to me that the leading truths of Natural Philosophy and Astronomy should be taught in all our primary schools, and thus the knowledge of them become diffused over the masses, instead of being confined to a privileged few. In addition to the intellectual and moral advantages, which might reasonably be expected from such a general diffusion of a knowledge of the laws of nature and the structure of the Universe, incalculable benefits would result to society from the acquaintance which the industrial classes would thus gain with the principles of the arts—principles which lie at the foundation of their daily operations; for " a principle in science is a rule in art." Such a knowledge of philosophical principles would suggest easier and more economical modes of performing the same labor; it would multiply inventions and discoveries; and it would alleviate toil, by mingling with it a constant flow of the satisfaction which always attends a clear understanding of the principles of the arts.

Fourteen years having elapsed since the first stereotype edition was published, there have since been made important additions both to Natural Philosophy and Astronomy. Of these such notice is taken, in the present " Revised " edition, as the limited nature of the work will allow. It is believed that no similar work presents more faithfully the two sciences, in their latest physiognomy.

As so small a book as the present cannot embrace every thing, I have deemed it advisable to give to a few choice truths, of great practical utility, full scope, rather than, by attempting too much, to make the work a mere skeleton, as is the case with many small scientific treatises designed for schools. For a full explanation of points not here introduced, the student is referred to my larger treatises, as the School philosophy, and School Astronomy, and the College Philosophy, and College Astronomy.

EXPERIMENTAL ILLUSTRATIONS.

We would strongly recommend to teachers, to accompany these lessons with at least a few experimental illustrations. These will render the subjects far more interesting and intelligible, whatever may be the age of the pupil, but to young learners experiments are almost indispensable. An advanced scholar may, by the aid of a diagram, form a clear conception of a thing, of which a younger pupil would hardly understand any thing until he *saw* it. A lad of fifteen may imagine clearly how a projectile rises and falls in a curve, or he may at least fully understand it from a diagram; but one of ten or twelve will obtain a far more correct idea of the fact by actually shooting an arrow upward, and directing his attention to the path it describes. Of such subjects as Electricity, Magnetism, and Optics, no one can obtain adequate notions without experiments. These, however, may be very simple, and performed with such apparatus as every teacher can command. Convinced of the importance of such experimental illustrations in teaching Natural Philosophy to beginners, I have given, at the end of the volume, a list of familiar experiments, to which reference is made in different parts of the book, accompanied by such plain directions that the most inexperienced teacher need not be deterred from performing them.

YALE COLLEGE, October, 1858.

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RUDIMENTS
OF
NATURAL PHILOSOPHY AND ASTRONOMY.

PART I.

NATURAL PHILOSOPHY.

INTRODUCTION.*

GRAND DIVISIONS OF THE NATURAL SCIENCES.

1. As in Geography we have a clearer understanding of particular countries, if we first learn the great divisions of the globe, so we shall see more fully the peculiar nature of the sciences we are now to study, if we first learn into what distinct provinces the great empire of science is divided.

2. To describe and classify the *external appearances* of things in nature, is the province of Natural History; to explain the *causes* of such appearances, and of all the changes that take place in the material world, is the province of Natural Philosophy. The properties of bodies which are presented to the senses, such as form, size, color, and the like, are called *external characters*; all events or occurrences in the material world, are called *phenomena*. Natural History is occupied

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* Instructors may find it expedient, in the case of very young learners, to pass over this Introduction, beginning at Chapter I; but when the state of the pupil is sufficiently advanced, we recommend its being well treasured up in the memory.

chiefly with the external characters of bodies, which it describes and classifies; Natural Philosophy, with phenomena, which it reduces under general laws. Thus, the natural historian first observes and describes the *external characters* of animals, vegetables, and minerals, and then classifies them, by arranging such as resemble each other in separate groups. The natural philosopher, also, first observes and describes the *phenomena* of nature and art, and brings together such as are similar under separate laws.

3. *A law is the mode in which the powers of nature act.* Thus, when we have examined the directions of rays of light under a great variety of circumstances, and always found them to be in straight lines, we say it is a law of light to move in straight lines. Laws are more or less extensive, according to the extent of phenomena they embrace. Thus, it is a law of the magnet that it attracts *iron:* it is a more extensive law (that of gravitation) that *all* bodies attract each other.

4. The proper method of investigating any subject in Natural Philosophy, is, first, to examine with great attention all the *facts* of the case; secondly, to *classify* these, by arranging under the same heads such as relate to the same things; and, thirdly, to state the *conclusions* to which such a comparison of the phenomena leads us. Thus, if we apply heat to various bodies, and measure them before and after heating, we find in all cases that their size is enlarged. Hence we derive the law, that *heat expands all bodies.* If we expose solid bodies to a certain degree of heat, they melt or become liquid, and liquids again are changed in the same way to vapor. Having observed these effects in a great number of individual cases, we lay it down as a law, that *heat changes solids to fluids and fluids to vapors.* By similar inquiries we ascertain all the laws of heat, which we perceive are, according to our definition, (Art. 4.) nothing more than the modes in which heat acts on various bodies. Laws or general principles like these, under one or another of which all the phenomena of the material world are reduced, constitute the elements of Natural Philosophy.

5. The laws of nature, when once learned, are applied to the explanation of the phenomena of nature or art, by a process somewhat similar to that of classification in Natural History. It would afford a partial explanation of the motion of a steamboat on the water, to refer it to the general law of elastic force, which steam has in common with air, and several other natural agents; but it would be a more complete explanation to assign the particular mode in which the force acts upon the pistons, wheels, and other parts of the machinery. *Science* is a collection of general principles or laws: *Art,* a system of rules founded on them. Arithmetic, so far as it explains the properties of numbers, is a science: so far as it furnishes rules for the solution of problems, or for calculation, it is an art. A principle in science, therefore, is a rule in art.

6. The term " Natural Philosophy " originally signified, the study of nature in general. But as the objects

that fell under its notice were multiplied, the field became too vast for one mind, and it was divided into two parts—what related to the earth belonged to Natural Philosophy, while the study of the heavenly bodies was erected into a separate department under the head of Astronomy. By and by, however, the whole of terrestrial nature, as the objects of inquiry were further multiplied, presented too wide a field for one mind to explore, and Natural Philosophy was restricted to the investigation of the *laws* of nature, while the description and classification of the productions of the several kingdoms of nature, were assigned to a distinct department under the name of Natural History.

7. Still, it was a work too vast to take note of all the *phenomena* of nature and art, and investigate all the *laws* that govern them, and hence Natural Philosophy was again divided into Mechanical Philosophy and Chemistry. Mechanical Philosophy relates to the phenomena and laws of *masses* of matter; Chemistry, to the phenomena and laws of *particles* of matter. Mechanical Philosophy considers those effects only which are not attended by any change of nature, such as change of place, (or motion,) change of figure, and the like. Chemistry considers those effects which result from the action of the particles of matter on each other, and which more or less change the nature of bodies, so as to make them something different from what they were before. Finally, it became too much for one class of laborers to investigate the changes of nature or constitution, which are constantly going on in every body in nature, and in every process, natural or artificial, and Chemistry was, therefore, restricted to

inanimate matter, while what relates to *living* matter was erected into a separate department under the head of Physiology.

8. Natural History, moreover, found for itself an empire too vast, in attempting to describe and classify the external appearances of all things in nature. Hence this study has been successively divided into various departments, the study of vegetables being referred to Botany; of animals to Zoology; of inanimate substances to Mineralogy. Still further subdivisions have been introduced into each of these branches of Natural History, as the objects embraced in it have multiplied. Thus, the study of that branch of Zoology which relates to fishes, has been erected into a separate department under the head of Ichthyology; of birds into Ornithology; and of insects into Entomology.

9. A division of the studies which relate to the world we inhabit, has also been made into three departments, Geography, Geology, and Meteorology; all objects on the *surface* of the earth being assigned to Geography; *beneath* the surface, to Geology; and *above* the surface, to Meteorology. Of these, Geography, in this extensive signification, presents the largest field, since it comprehends, among other things, MAN and his works.

10. Mechanical Philosophy is, strictly speaking, the branch of human knowledge which we now propose to learn; but it still retains the original name, Natural Philosophy, though in a sense greatly re-

stricted, compared with its ancient signification. The complete investigation of almost any subject, either of nature or art, usually, in fact, enters the peculiar province of several kindred departments of science. For example, let us follow so simple a substance as bread, from the sowing of the grain to its consumption as food, and we shall find that the successive processes involve, alternately, the principles of Mechanical Philosophy, Chemistry, and Physiology. The ploughing of the field is mechanical and not chemical, because it acts on masses of matter, and produces no change of nature in the matter on which it operates, so as to make it something different from what it was before, but merely changes its place. For similar reasons the sowing of the grain is mechanical. But now a change occurs in the nature of the seed. By the process called germination, it sprouts and grows and becomes a living plant. As this is a change which takes place between the particles of matter, and changes the nature of the body, it seems, by our definition, to belong to Chemistry, and it would do so were not the changes those of *living* matter: that brings it under the head of Physiology. All that relates to the growth and perfecting of the crop is, in like manner, physiological. The reaping, carting, and threshing the wheat, are all mechanical processes, acting as they do on masses of matter, and producing no alteration of nature, but merely a change of place. The grinding and separation of the grain into flour and bran, looks like a chemical process, because it reduces the wheat to particles, and brings out two new substances. We have, however, only changed the figure and place. The grain

consists of the same particles before and after grinding, and no new substance is really produced by the separation of the flour from the bran, for both were contained in the mixture, having the same nature before as after the separation. We next mix together flour, water, and yeast, to make bread, and bring it to the state of dough. So far the process is mechanical; but now the particles of these different substances begin to act on each other, by the process called fermentation, and new substances are produced, not existing before in either of the ingredients, and the whole mass becomes something of a very different nature from either of the articles of which it was formed. Here then is a *chemical* change. Next we make the dough into loaves and place them in the oven by processes which are mechanical; but again heat produces new changes among the particles, and brings out a new substance, bread, which is entirely different in its nature both from the original ingredients and from dough. This change, therefore, is chemical. Finally, the bread is taken into the mouth, masticated, and conveyed to the stomach by mechanical operations; but here it is subjected to the action of the principle of life that governs the animal system, and therefore again comes under the province of physiology.

11. The distinction between terms, which are apt to be confounded with each other, may frequently be expressed by single words or short phrases, although they may not convey full and precise definitions. The following are examples: History respects facts; Philosophy, causes; Physics, matter; Metaphysics, mind; Science, general principles; Art, rules and instruments. Physical laws are *modes* of action; moral and civil

laws, *rules* of action. The province of Natural Philosophy is the material world; that of Moral Philosophy is the soul. Mechanical effects result from change of place or figure; Chemical, from change of nature. Chemical changes respect inanimate matter; Physiological, living matter.

12. Mechanical Philosophy takes account of such properties of matter only as belong to all bodies whatsoever, or of such as belong to all bodies in the same state of solid, fluid, or aëriform. These are few in number compared with the peculiar properties of individual bodies, and the changes of nature which they produce on each other, all of which belong to Chemistry. Chemistry, therefore, is chiefly occupied with matter; Natural Philosophy, with motion. The leading subjects of Natural Philosophy are—

1. Matter—its general properties.
2. Mechanics—the doctrine of Motion.
3. Hydrostatics—the doctrine of Fluids in the form of *water*.
4. Pneumatics—the doctrine of Fluids in the form of *air*.
5. Meteorology—the Atmosphere and its phenomena.
6. Acoustics—the doctrine of Sound.
7. Electricity.
8. Magnetism.
9. Optics—the doctrine of Light.

CHAPTER I.

GENERAL PROPERTIES OF MATTER.

EXTENSION AND IMPENETRABILITY—DIVISIBILITY—POROSITY—COMPRESSIBILITY—ELASTICITY—INDESTRUCTIBILITY—ATTRACTION.

13. All matter has at least two properties—Extension and Impenetrability. The smallest conceivable portion of matter occupies some portion of space, and has length, breadth, and thickness. Extension, therefore, belongs to all matter. Impenetrability is the property by which a portion of matter excludes all other matter from the space which it occupies. Thus, if we drop a bullet into water, it does not penetrate the water, it *displaces* it. The same is true of a nail driven into wood. These two properties of matter are all that are absolutely essential to its existence; yet there are various other properties which belong to matter in general, or at least to numerous classes of bodies, more or less of which are present in all bodies with which we are acquainted. Such are Divisibility, Porosity, Compressibility, Elasticity, Indestructibility, and Attraction. Matter exists in three different states, of solids, liquids, and gases. These result from its relation to heat; and the same body is found in one or the other of these states, according as more or less heat is combined with it. Thus, if we combine with a mass of ice a certain portion of heat, it passes from the solid to the liquid state, forming water; and if we add to water a certain other portion of heat, it passes into the same state as air, and becomes steam. Chemistry makes known to us a great number of bodies in

the aëriform state, called *gases*, arising from the union of heat with various kinds of matter. The particles which compose water, for example, are of two kinds, oxygen and hydrogen, each of which, when united with heat, forms a peculiar kind of air or gas.

14. *Matter is divisible into exceedingly minute parts.* A leaf of gold, which is about three inches square, weighs only about the fifth part of a grain, and is only the 282,000th part of an inch in thickness. Soap bubbles, when blown so thin as to display their gaudy colors, are not more than the 2,000,000th of an inch thick; yet every such film consists of a vast number of particles. The ultimate particles of matter, or those which admit of no further division, are called *atoms*.

The atoms of which bodies are composed are inconceivably minute. The weight of an atom of lead is computed at less than the three hundred billionth part of a grain. Animalcules (insects so small as to be invisible to the naked eye, and seen only by the microscope) are sometimes so small that it would take a million of them to amount in bulk to a grain of sand; yet these bodies often have a complete organization, like that of the largest animals. They have numerous muscles, by means of which they often move with astonishing activity; they have a digestive system by which their nutriment is received and applied to every part of their bodies; and they have numerous vessels in which the animal fluids circulate. What must be the dimensions of a particle of one of these fluids!

15. *A large portion of the volume of all bodies consists of vacant spaces, or pores.* Sponge, for example, exhibits its larger pores distinctly to the naked eye.

But it, also has smaller pores, of which the more solid matter of the sponge itself is composed, which are usually so small as to be but faintly discernible to the naked eye. The cells which these parts compose are separated by a thin fibre, which itself exhibits to the microscope still finer pores; so that we find in the same body several distinct systems of pores. Even the heaviest bodies, as gold, have pores, since water, when enclosed in a gold ball and subjected to strong pressure, may be forced through the sides. Most animals and vegetables consist in a great degree of matter that is exceedingly porous, leaving abundant room for the peculiar fluids of each to circulate. Thus, a thin slip or cross section of the root or small limb of a tree, exhibits to the microscope innumerable cells for the circulation of the sap.

16. *All bodies are more or less compressible, or may be reduced by pressure into a smaller space.* Bodies differ greatly in respect to this property. Some, as air or sponge, may be reduced to a very small part of their ordinary bulk, while others, as gold and most kinds of stone, yield but little to very heavy pressures. Still, columns of the hardest granite are found to undergo a perceptible compression when they are made to support enormous buildings. Water and other liquids strongly resist compression, but still they yield a little when pressed by immense forces.

17. *Many bodies, after being compressed or extended, restore themselves to their former dimensions, and hence are called elastic.* Air confined in a bladder, a sponge compressed in the hand, and India-rubber drawn out, are familiar examples of elastic bodies. If we drop

on the floor a ball of yarn, or of ivory or glass, it rebounds, being more or less elastic; whereas, if we do the same with a ball of lead, it falls dead without rebounding, and is therefore non-elastic. When a body perfectly recovers its original dimensions, it is said to be *perfectly elastic*. Thus, air is perfectly elastic, because it completely recovers its former volume, as soon as the compressing force is removed, and hence resists compression with a force equal to that which presses upon it. Wood, when bent, seeks to recover itself on account of its elasticity; and hence its use in the bow and arrow, the force with which it recovers itself being suddenly imparted to the arrow through the medium of the string.

Fig. 1.

18. *Matter is wholly indestructible.* In all the changes which we see going on in bodies around us, not a particle of matter is lost; it merely changes its form; nor is there any reason to believe that there is now a particle of matter either more or less than there was at the creation of the world. When we boil water and it passes to the invisible state of steam, this, on cooling, returns again to the state of water, without the least loss; when we burn wood, the solid matter of which it is composed passes into different forms, some into smoke, some into different kinds of airs, or gases, some into steam, and some remains behind in the state of ashes. If we should collect all these various products, and weigh them, we should find the amount of their several weights the same as that of the body from which they were produced, so that no portion is lost. Each of the substances into which the wood was resolved, is employed in the economy of nature to construct other bodies, and may finally reappear in its original form. In the same manner, the bodies of animals, when they die, decay and seem to perish; but the matter of which they are composed merely passes into new forms of existence, and reappears in the structure of vegetables or other animals.

19. *All matter attracts all other matter.* This is true of all bodies in the Universe. In this extensive sense, attraction is called *Universal Gravitation.* In consequence of the attraction of the earth for bodies near it, they fall toward it, and this kind of attraction is called *Gravity.* Several distinct cases of this property occur also among the particles of matter. That which unites particles of the same kind (as those of a musket ball) in one mass, is called *Aggregation;* that which unites particles of different kinds, forming a compound, (as the particles of flour, water, and yeast in bread,) is *Affinity.* The term *Cohesion* is used to denote simply the union of the separate parts that make up a mass, without considering whether the particles themselves are simple or compound. Thus the *grains* which form a rock of sandstone, are united by cohesion. Magnetism and electricity also severally endue different portions of matter with tendencies either to attract or repel each other, which are called,

respectively. *Magnetic* and *Electric* attractions. *Tenacity*, or that force by which the particles of matter hang together, is only a form of cohesion. Of all known substances, iron wire has the greatest tenacity. A number of fine wires bound together constitute what is called a wire cable. These cables are of such prodigious strength that immense bridges are sometimes

Fig. 2.

suspended by them. The Menai bridge, in Wales, one of the greatest works in modern times, is thus supported at a great height, although it weighs toward two thousand tons.

CHAPTER II.

MECHANICS.

MOTION IN GENERAL—LAWS OF MOTION—CENTER OF GRAVITY—PRINCIPLES OF MACHINERY.

20. MECHANICS, or the DOCTRINE OF MOTION, *is that part of Natural Philosophy which treats of the laws of equilibrium and motion.* It considers also the nature of the *forces* which put bodies in motion, or which maintain them either in motion, or in a state of rest or equilibrium The great principles of motion are the same everywhere, being applicable alike to solids, liquids, and gases; to the most common objects around us, and to the heavenly bodies. The science of Mechanics, therefore, comprehends all that relates to the laws of motion; to the forces by which motion is produced and maintained; to the principles and construction of all machines; and to the revolutions of the heavenly bodies.

SECTION 1.—*Of Motion in general.*

21. Motion is change of place from one point of space to another. It is distinguished into real and apparent; absolute and relative; uniform and variable. In *real* motion, the moving body itself actually changes place; in *apparent* motion, it is the spectator that changes place, but being unconscious of his own motion, he refers it to objects without him. Thus, when we are riding rapidly by a row of trees, these seem to move in the opposite direction; the shore appears to recede from the sailor as he rapidly puts to sea; and the heavenly bodies have an apparent daily motion westward, in consequence of the spectator's turning with the earth on its axis to the east. *Absolute* motion is a change of place from one point of space to another without reference to any other body: *Relative* motion is a change of position with respect to some other body. Two bodies may both be in absolute motion, but if they do not change their position with respect to each other, they will have no relative motion, or will be relatively at rest. The men on board a ship under sail, have all the same absolute motion,

and so long as they are still, they have no other; but whatever changes of place occur among themselves, give rise to relative motions. If two persons are travelling the same way, at the same rate, whether in company or not, they have no relative motion; if one goes faster than the other, the latter has a relative motion backward equal to the difference of their rates; and if they are travelling in opposite directions, their relative motion is equal to the sum of both their motions. A body moves with a *uniform* motion when it passes over equal spaces in equal times; with a *variable* motion, when it passes over unequal spaces in equal times. If a man walks over just as many feet of ground the second minute as the first, and the third as the second, his motion is uniform; but if he should walk thirty feet one minute, forty the next, and fifty the next, his motion would be variable.

22. *Force is any thing that moves, or tends to move a body.* The strength of an animal exerted to draw a carriage, the impulse of a waterfall in turning a wheel, and the power of steam in moving a steamboat, are severally examples of a force. A weight on one arm of a pair of steelyards, in equilibrium with a piece of merchandise, although it does not move, but only *tends* to move the body, is still a force, since it would produce motion were it not counteracted by an equal force. The quantity of motion in a body is called its *momentum.* Two bodies of equal weight, as two cannon-balls, will evidently have twice as much motion as one; nor would it make any difference if they were united in one mass, so as to form a single body of twice the weight of the separate balls; the quantity of motion would be doubled by doubling the mass, while the velocity remained the same. Again, a ball that

moves twice as fast as before, has twice the quantity of motion. Momentum therefore depends upon two things—the velocity and quantity of matter. A large body, as a ship, may have great momentum with a slow motion; a small body, as a cannon-ball, may have great momentum with a swift motion; but where great quantity of matter (or *mass*) is united with great swiftness, the momentum is greatest of all. Thus a train of cars on a railroad moves with prodigious momentum; but the planets in their revolutions around the sun, with a momentum inconceivably greater.

23. To the eye of contemplation, the world presents a scene of boundless *activity.* On the surface of the earth, hardly any thing is quiescent. Every tree is waving, and every leaf trembling; the rivers are running to the sea, and the ocean itself is in a state of ceaseless agitation. The innumerable tribes of animals are in almost constant motion, from the minutest insect to the largest quadruped. Amid the particles of matter, motions are unceasingly going forward, in astonishing variety, that are effecting all the chemical and physiological changes to which matter is constantly subjected. And if we contemplate the same subject on a larger scale, we see the earth itself, and all that it contains, turning with a steady and never ceasing motion around its own axis, wheeling also at a vastly swifter rate around the sun, and possibly accompanying the sun himself in a still grander circuit around some distant center. Hence, almost all the phenomena or effects which Natural Philosophy has to investigate and explain are connected with motion and dependent on it.

SEC. 2.—*Of the Laws of Motion.*

24. Nearly all the varieties of motion that fall within the province of Mechanical Philosophy, have been reduced to three great principles, called the Laws of Motion. We will consider them separately.

FIRST LAW.—*Every body will persevere in a state of rest, or of uniform motion in a straight line, until compelled by some force to change its state.* This law contains four separate propositions; first, that unless put in motion by some external force, a body always remains at rest; secondly, that when once in motion it always continues so unless stopped by some force; thirdly, that this motion is uniform; and fourthly, that it is in a straight line. Thus, if I place a ball on a smooth sheet of ice, it will remain constantly at rest until some external force is applied, having no power to move itself. I now apply such force and roll it; being set in motion, it would move on forever were there no impediments in the way. It will move uniformly, passing over equal spaces in equal times, and it will move directly forward in a straight course, turning neither to the right hand nor to the left. This property of matter to remain at rest unless something moves it, and to continue in motion unless something stops it, is called *Inertia.* Thus the inertia of a steamboat opposes great resistance to its getting fully into motion; but having once acquired its velocity, it continues by its inertia to move onward after the engine is stopped, until the resistance of the water and other impediments destroy its motion. The planets continue to revolve around the sun for no other reason than this, that they were put in motion and meet with nothing to stop them. Whenever a horse harnessed to a carriage starts suddenly forward, he breaks his traces, because the inertia of the carriage prevents the sudden motion being instantly propagated through its mass, and the force of the horse being all expended on the traces, breaks them. On the other hand, if a horse suddenly stops, when on a run, the rider is thrown over his head; for having acquired the full motion of the horse, he does not instantly lose it, but, on account of his inertia, continues to move forward after the force that put him in motion is withdrawn. This principle is pleasingly illustrated in what is called the *doubling* of the hare. A hare closely pursued by a greyhound, starts from A, and when he arrives at C, the dog is hard upon him; but the hare being a lighter animal than the dog, and having of course less inertia, turns short at C and again at E, while the dog cannot stop so suddenly, but goes further round at D and also F, and thus the hare outruns him. Put a card of pasteboard across a couple of wine glasses, and two sixpences directly over the glasses, as in the figure; then strike the edge of the card at A a smart blow, and the card will slip off and leave the money in the glasses. The coins, on account of their inertia, do not instantly receive the motion communicated to the card. If the blow, however, be gentle, all will go off together.

Fig. 3.

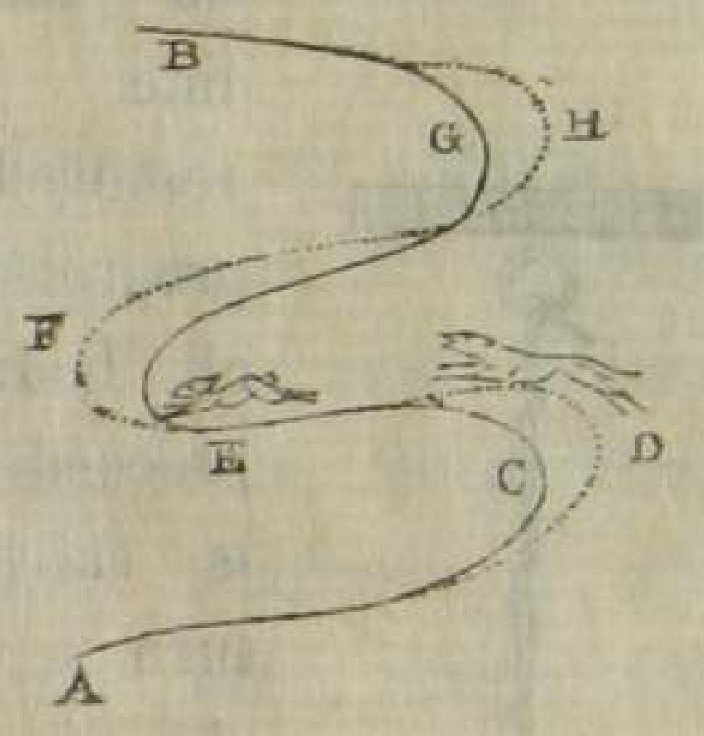
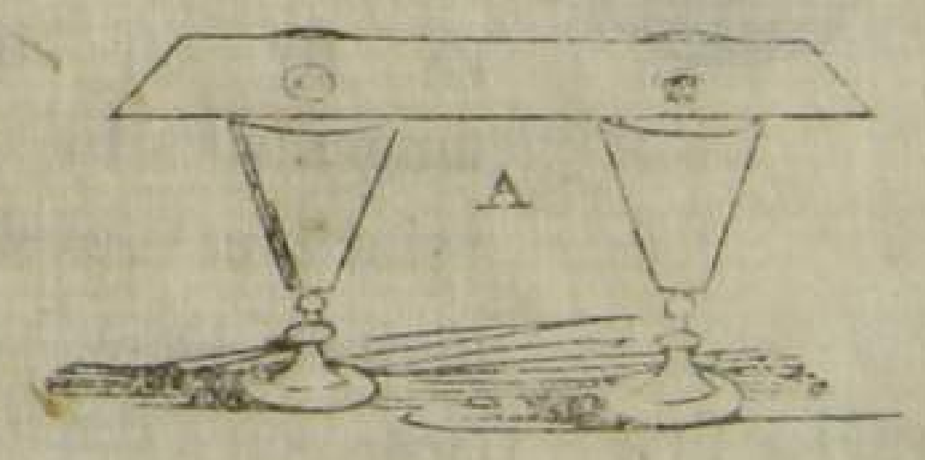
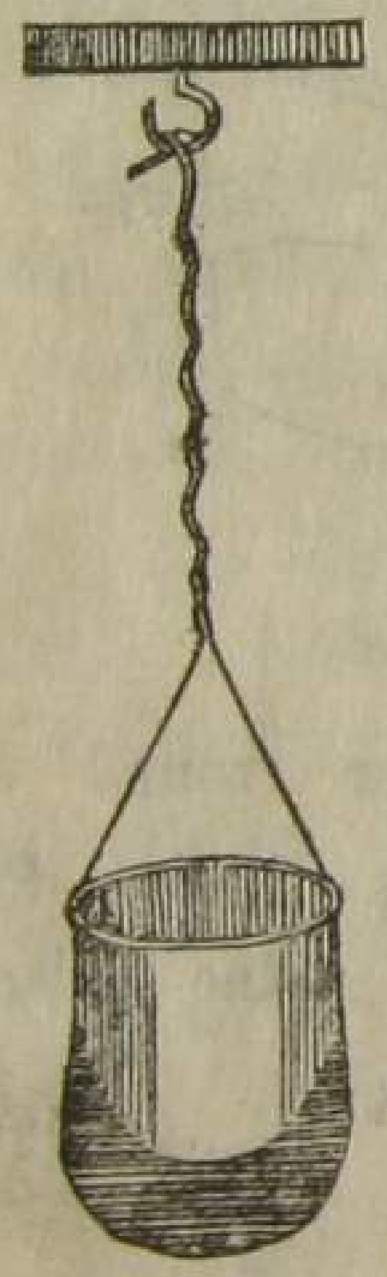


Fig. 4.





25. The first law of motion also asserts that all moving bodies have a tendency to move in *straight lines.* We see, indeed, but few examples of such motions either in nature or art. If we throw a ball upward, it rises and falls in a curve; water spouting into the air does the same; rivers usually run and trees wave in curves; and the heavenly bodies revolve in apparent circles. Still, when we attentively examine each of these cases, and every other case of motion in curves, we find one or more forces operating to cause the body to deviate from a straight line. When such cause of deviation is removed, the body immediately resumes its progress in a straight line. This effort of bodies, when moving in curves, to proceed directly forward in a straight line, is called the *Centrifugal Force.* If we turn a grindstone, the lower part of which dips into water, as the velocity increases the water is thrown off from the rim in straight lines which touch the rim and are therefore called *tangents*[*] to it; and it is a general principle, that when bodies free to move, revolve in curves about a center, they have a constant tendency to fly off in straight lines, which are tangents to the curves. We see this principle exemplified in giving a rotary motion to a pail or basin of water. The liquid first rises on the sides of the vessel, and if the rapidity of revolution be increased, it escapes from the top in straight lines which are tangents to the rim of the vessel. If we pass a cord through a staple in the ceiling of a room, and bringing down the two ends, attach them to the ears of a pail containing a little water, (suspending the vessel a few feet above the floor,) and then, applying the palms of the hands to the opposite sides of the pail, give it a steady rotary motion, the water will first rise on the sides of the vessel and finally be projected from the rim in tangents. The experiment is more striking if we suffer the cord to untwist itself freely, after having been twisted in the preceding process.

26. SECOND LAW. *Motion, or change of motion, is proportioned to the force impressed, and is produced in the line of direction in which that force acts.* First, the quantity of motion, or momentum, is proportioned to the force applied. A double blow produces a double velocity upon a given mass, or the same velocity upon twice the mass. Two horses applied with equal advantage to a load, will draw twice the load of one horse. It follows also from this law, that every force applied to a body, however small that force may be, produces *some* motion. A stone falling on the earth moves it. This may seem incredible; but if we suppose the earth divided into exceedingly small parts, each weighing only a pound for example, then we may readily conceive how the falling stone would put it in motion. Now the effect is not lost by being expended on the whole earth at once; the momentum produced is the same in both cases; but in proportion as the quantity of matter is increased the velocity is diminished, and it would be as much less

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[*] A line is said to be a tangent to a curve, when it touches the curve, but does not cut it.

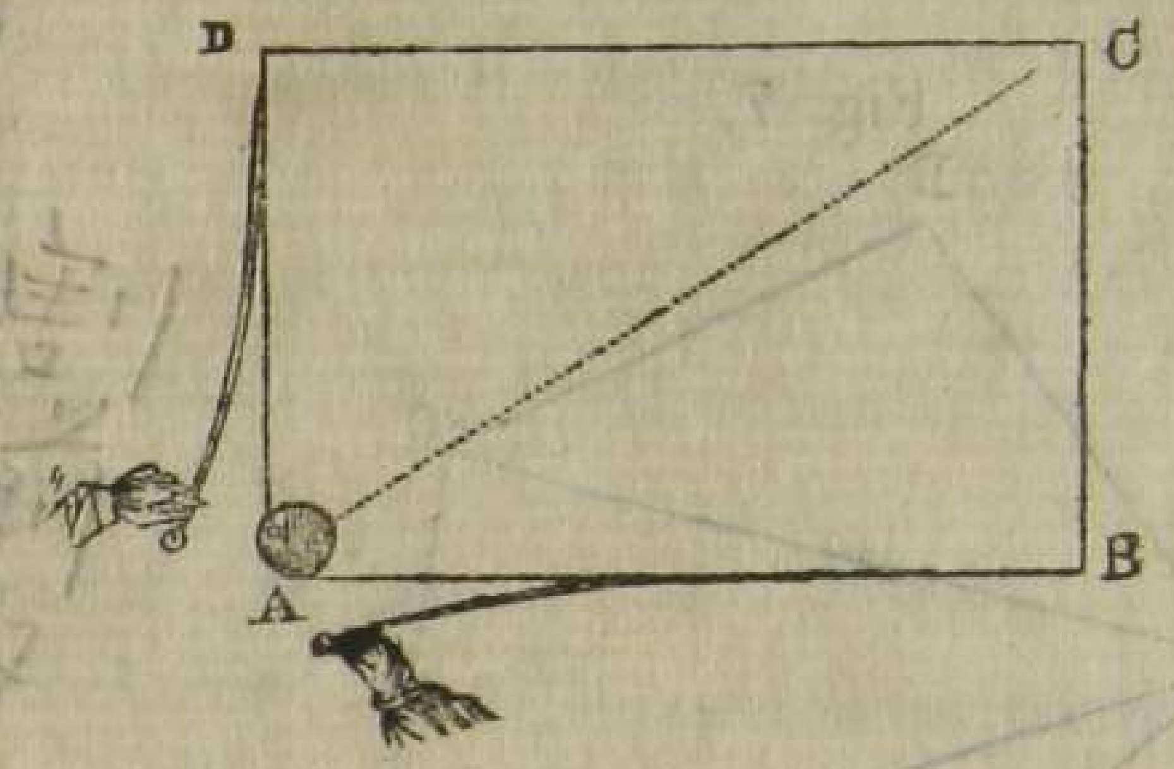
as the weight of the whole earth exceeds one pound. It would therefore be inappreciable to the senses, but still capable of being expressed by a fraction, and therefore a real quantity. " A continual dropping wears away stone. " Each drop, therefore, must contribute something to the effect, although too small to be perceived by itself.

27. Secondly, motion is produced in the line of *direction* in which the force is applied. If I lay a ball on the table and snap it with my thumb and finger, it moves in different directions according as I change the direction of the impulse; and this is conformable to all experience. A single force moves a body in its own direction, but two forces acting on a body at the same time, move it in a line that is intermediate between the two. Thus, if I place a small ball, as a marble, on the table, and at the same moment snap it with the thumb and finger of each hand, it will not move in the direction of either impulse, but in a line between the two. A more precise consideration of this case has led to the following important law:

If a body is impelled by two forces which may be represented in quantity and direction by the two sides of a parallelogram, it will describe the diagonal in the same time in which it would have described the sides separately, by the force acting parallel to that side.

Thus, suppose the parallelogram A B C D, represents a table, of which the side A B is just twice the length of A D. I now place the ball on the corner A and nail a steel spring (like a piece of watch spring) to each side of the corner, so that when bent back it may be sprung upon the ball, and move it parallel to the edge of the table. I first spring each force separately, bending back that which acts parallel to the longer side so much further than the other, that the ball will move over the two sides in precisely the same time, suppose two seconds. I now let off the springs on the ball at the same instant, and the ball moves across the table, from corner to corner, in the same two seconds. It is not necessary that the parallelogram should be right-angled like a table. The effect will be the same at whatever angle the sides of the parallelogram meet.

Fig. 6.

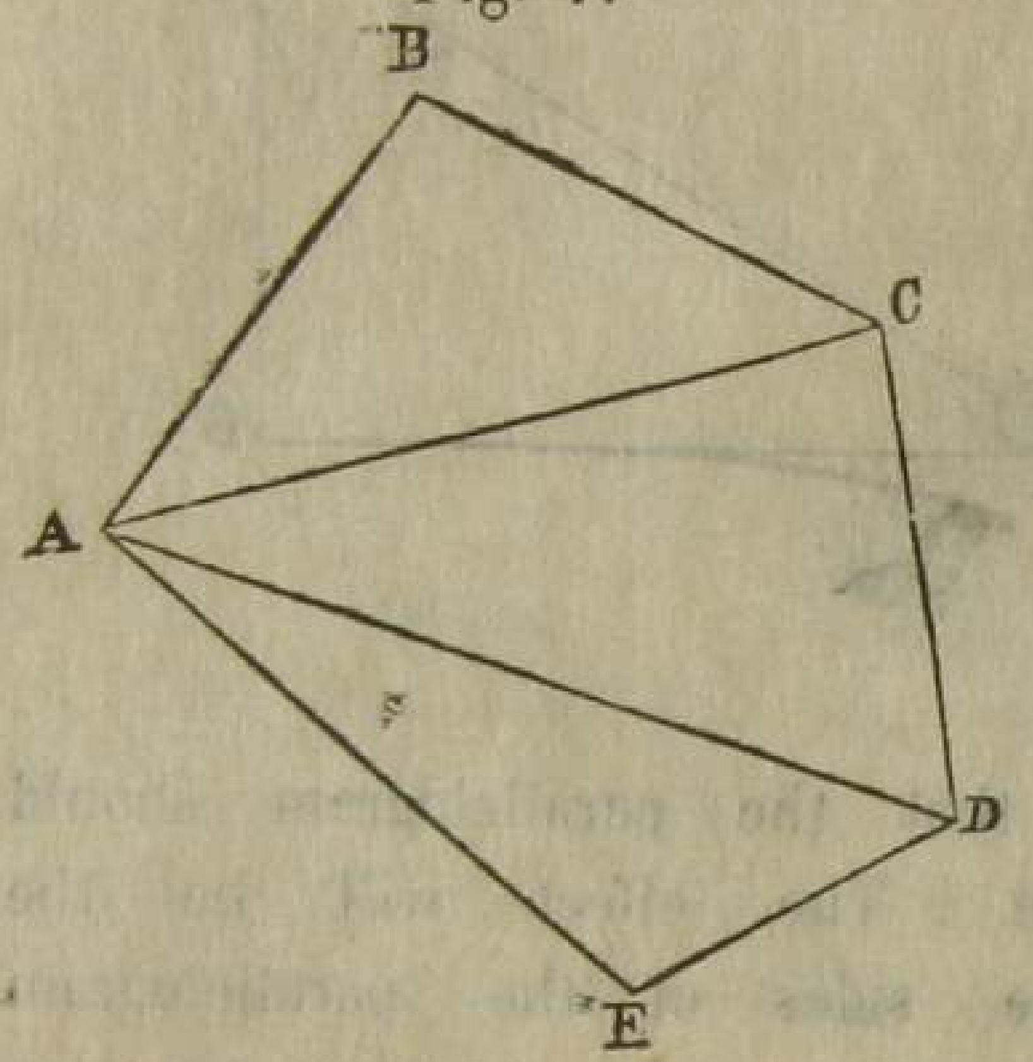


28. If I take a triangular board instead of the table, and fix three springs at one corner, so as to act parallel to the three sides of the board, and give each spring a degree of strength proportioned to the length of the side in the direction of which it acts, and then let all those springs fall upon the ball at the same instant, the ball will remain at rest. This fact is expressed in the following proposition:

If three forces, represented in quantity and direction by the three sides of a triangle, act upon a body at the same time, it will be kept at rest.

A kite is seen to rest in the air on this principle, being in equilibrium between the force of gravity which would carry it toward the earth, that of the string, and that of the wind, which severally act in the three directions of the sides of a triangle, and neutralize each other. Nor is the principle confined to *three* directions merely, but holds good for a polygon of any number of sides. For example, a body situated at A, and acted upon by five forces represented in quantity and direction by the five sides of the polygon, (Fig. 7,) would remain at rest. If the forces were only four, corresponding to all the sides of the figure except the last, EA, then the body would describe this side in the same time in which it would describe each of the sides by the forces acting separately.

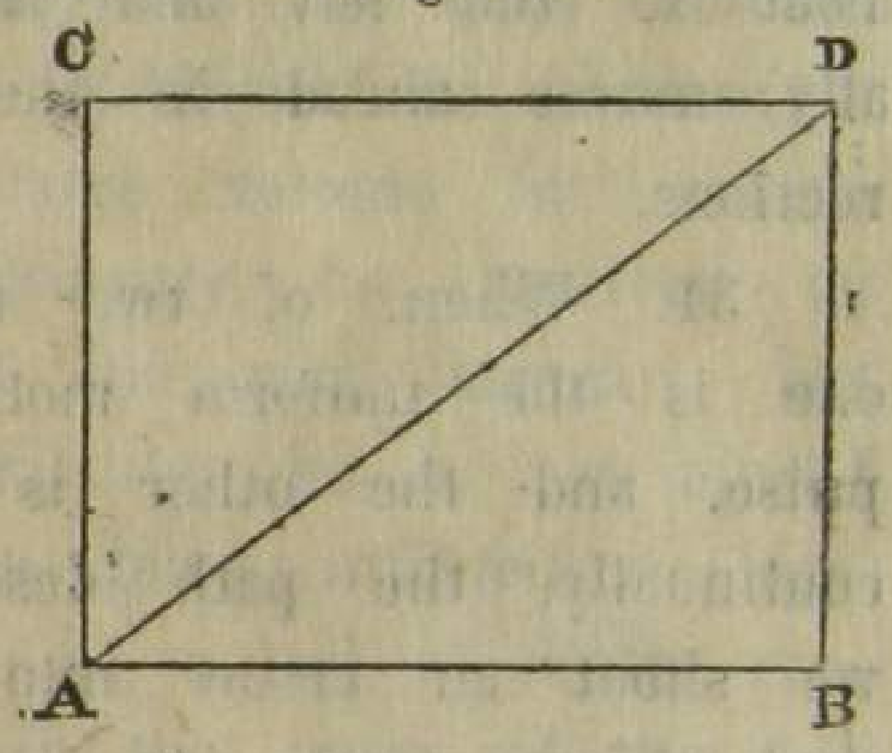
Fig. 7.



29. *Simple* motion is that produced by one force; *compound* motion, that produced by the joint action of several forces. Strictly speaking, we never witness an example of simple motion; for when a ball is struck by a single impulse, although the motion is simple relatively to surrounding bodies, yet the ball is at the same time revolving with the earth on its axis and around the sun, and subject perhaps to innumerable other motions. Although all bodies on the earth are acted on at the same moment by many forces, and therefore it is difficult or even impossible to tell what is the line each describes in space under

their joint action, yet each individual force produces precisely the same change of direction in the body as though it were to act alone. If it acts in the same direction in which the body is moving, it will add its own amount; if in the opposite direction, it will subtract it; if sidewise, it will turn the body just as far to the right or left in a given time, as it would have done had it been applied to the body at rest. Thus, if while a body is moving from A to B, (Fig. 8,) it be struck by a force in the direction of AC, it will reach the line CD, in the same time in which it would have done had it been subject to no other force. It will, however, reach that line in the point D instead of C. When a man walks the decks of a ship under sail, his motions are precisely the same with respect to the other objects on board, as though the ship were at rest; but the line which he actually describes under the two forces is very different.

Fig. 8.



30. Instances of this diagonal motion are constantly presented to our notice. In crossing a river, the boat moves under the united impulses of the oars and the current, and describes the diagonal whose sides are proportional to the two forces respectively. Equestrians sometimes exhibit feats of horsemanship by leaping upward from the horse while running, and recovering their position again. They have, in fact,

only to rise and fall as they would do were the horse at rest; for the forward motion which the rider retains by his inertia, during the short interval of his ascent and descent, carries him onward, so that he rises in one diagonal and falls in another. Two men sitting on opposite sides of a boat in rapid motion, will toss a ball to each other in the same manner as though the boat were at rest; but the actual movement of the ball will be diagonal. Rowing, itself, exemplifies the same principle; for while one oar would turn the boat to the left and the other to the right, it actually moves ahead in the diagonal between the two directions.

31. When, of two motions impressed upon a body, one is the uniform motion which results from an impulse, and the other is produced by a force which acts continually, the path described is a curve. Thus, when we shoot an arrow into the air, the impulse given by the string tends to carry it forward uniformly in a straight line; but gravity draws it continually away from that line, and makes it describe a curve. In the same manner the planets are continually drawn away from the straight lines in which they tend to move, by the attraction of the sun, and are made to describe curved orbits about that body.

32. THIRD LAW. *When bodies act on each other, action and reaction are equal, and in opposite directions.* The meaning of this law is, that when a body imparts a motion in any direction, it loses an equal quantity of its own—that no body loses motion except by imparting an equal amount to other bodies—that when a body receives a blow it gives to the striking body an equal blow—that when one body presses on another it receives from it an equal pressure—that when one body

attracts or repels another, it is equally attracted or repelled by the other. If a steamboat should run upon a sloop sailing in the same direction with a slower motion, it might drive it headlong without experiencing any great shock itself; still its own loss of motion would be just equal to that which it imparted to the sloop, but being distributed over a quantity of matter so much greater, the loss might be scarcely perceptible. If a light body, as the wad of a cannon, were fired into the air, it would be stopped by the resistance of the air; but its own motion would be lost only as it imparted the same amount to the air, and thus might be sufficient, on account of the lightness of air, to set a large volume in motion. When the boxer strikes his adversary, he receives an equal blow from the reaction of the part struck; but receiving it on a part of less sensibility, he is less injured by it than his adversary by the blow inflicted on him. One who falls from an eminence on a bed of down, receives in return a resistance equal to the force of the fall, as truly as one who falls on a solid rock; but, on account of the elasticity of the bed, the resistance is received gradually, and is therefore distributed more uniformly over the system. A boatman presses against the shore, the reaction of which sends the boat in the opposite direction. He strikes the water with his oar backward, and the boat moves forward. The fish beats the water with his tail, first on one side and then on the other, and moves forward in the diagonal between the two reactions. The bird beats the air with her wings, and the resistance carries her forward in the opposite direction. All attractions likewise are mutual. The iron attracts the magnet just as much as the magnet attracts the iron. The earth attracts the sun just as much as the sun attracts the earth. In all these cases the momentum or quantity of motion in the smaller and the larger body, is the same. Thus, when a small boat is drawn by a rope toward a large ship, the ship moves toward the boat as well as the boat toward the ship, and with the same momentum; but the space over which the ship moves is as much less than that of the boat, as its quantity of matter is greater. It makes no difference whether the boat is drawn toward the ship by a man standing in the boat and pulling at a rope fastened to the ship, or by a man standing in the ship and pulling by a rope fastened to the boat. A fisherman once fancied he could manufacture a breeze for himself by mounting a pair of huge bellows in the stern of his boat, and directing the blast upon the sail. But he was surprised to find that it had no effect on the motion of the boat. We see that the reaction of the blast would tend to carry the boat backward just as much as its direct action tended to carry the boat forward.

Fig. 9.

33. Falling bodies. When a body falls freely toward the earth from some point above it, it falls continually faster and fatser the longer it is in falling. Its motion therefore is said to be *uniformly accelerated.* All bodies, moreover, light and heavy, would fall equally fast were it not for the resistance of the air, which buoys up the lighter body more than it does the

heavier; but in a space free from air, or a vacuum, a feather falls just as fast as a guinea. If a boy knocks a ball with a bat on smooth ice, it will move on uniformly by the impulse it has received; but if several other boys strike it successively the same way, its velocity is continually increased. Now gravity is a force which acts incessantly on falling bodies, and therefore constantly increases their speed. If I ascend a high tower and let a ball fall from my hand to the ground, it will fall $16\frac{1}{12}$ feet in one second, $64\frac{1}{3}$ in two seconds, and $257\frac{1}{3}$ in four seconds; that is, a body will fall four times as far in two seconds as in one, and sixteen times as far in four seconds as in one. Now four is the square of two, and sixteen is the square of four; so that the spaces described by a falling body are proportioned, not simply to the times of falling, but to the *squares* of the times; so that a body falls in ten seconds not merely ten times as far as in one second, but the square of ten, or a hundred times as far.

34. Hence, when bodies fall toward the earth from a great height, they finally acquire prodigious speed. A man falling from a balloon half a mile high, would reach the earth in about half a minute. We seldom see bodies falling from a great height perpendicularly to the earth; but even in rolling down inclined planes, as a rock descending a steep mountain, or a rail car breaking loose from the summit of an inclined plane, we see strikingly exemplified the nature of accelerated motion. A log descending by a long wooden trough down a steep hill, has been known to acquire momentum enough to cut in two a tree of considerable

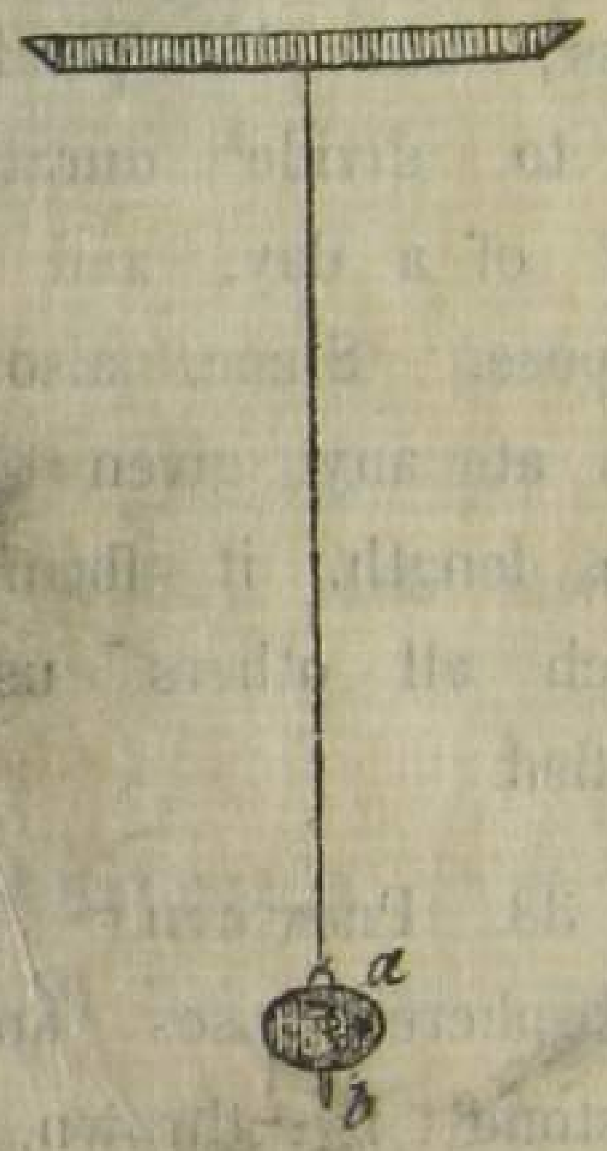
size, which it met on leaping from the trough. At a great distance from the earth, the force of gravity becomes sensibly diminished, so that if we could ascend in a balloon four thousand miles above the earth, that is, twice as far from the center of the earth as it is from the center to the surface, the force of attraction would be only one fourth of what it is at the surface of the earth, and a body instead of falling 16 feet in a second would fall only 4 feet. At ten times the distance of the radius of the earth, the force of gravity would be only one hundredth part of what it is at the earth. This fact is expressed by saying, that *the force of gravity is inversely as the square of the distance from the center of the earth*, diminishing in the same proportion as the square of the distance increases. As the moon is about sixty times as far from the center of the earth as the surface of the earth is from the center, if a body were let fall to the earth from such a distance, (the force of gravity being the square of 60, or 3600 times less than it is at the earth,) the body would begin to fall very slowly, moving the first second only the twentieth part of an inch. Were a body to fall toward the earth from the greatest possible distance, the velocity it would acquire would never exceed about 7 miles in a second; and were it thrown upward with a velocity of 7 miles per second, it would never return. This, however, would imply a velocity equal to about twenty times the greatest speed of a cannon-ball.

35. When a body is thrown directly upward, its ascent is *retarded* in the same manner as its descent is accelerated in falling; and it will rise to the height

from which it would have fallen in order to acquire the velocity with which it is thrown upward.

36. Vibratory Motion. Vibratory motion is that which is alternately backward and forward, like the motion of the pendulum of a clock. A pendulum performs its vibrations in equal times, whether they are long or short. Thus, if we suspend two bullets by strings of exactly equal lengths, and make one vibrate over a small arc and the other over a large arc, they will keep pace with each other nearly as well as when their lengths of vibration are equal. Long pendulums vibrate slower than short ones, but not as much slower as the length is greater. A pendulum, to vibrate seconds, must be four times as long as to vibrate half seconds; to vibrate once in ten seconds it must be a hundred times as long as to vibrate in one second, the comparative slowness being proportional to the *square* of the length. The motion of a pendulum is caused by *gravity*. If we draw a pendulum out of its position when at rest, and then let it fall, it will descend again to the lowest point, but will not stop there, for the velocity which it acquires in falling will be sufficient, on account of its inertia, to carry it to the same height on the other side, (Art. 35,) whence it will return again and repeat the same process; and thus, were it not for resistance of the air, and the

Fig. 10.

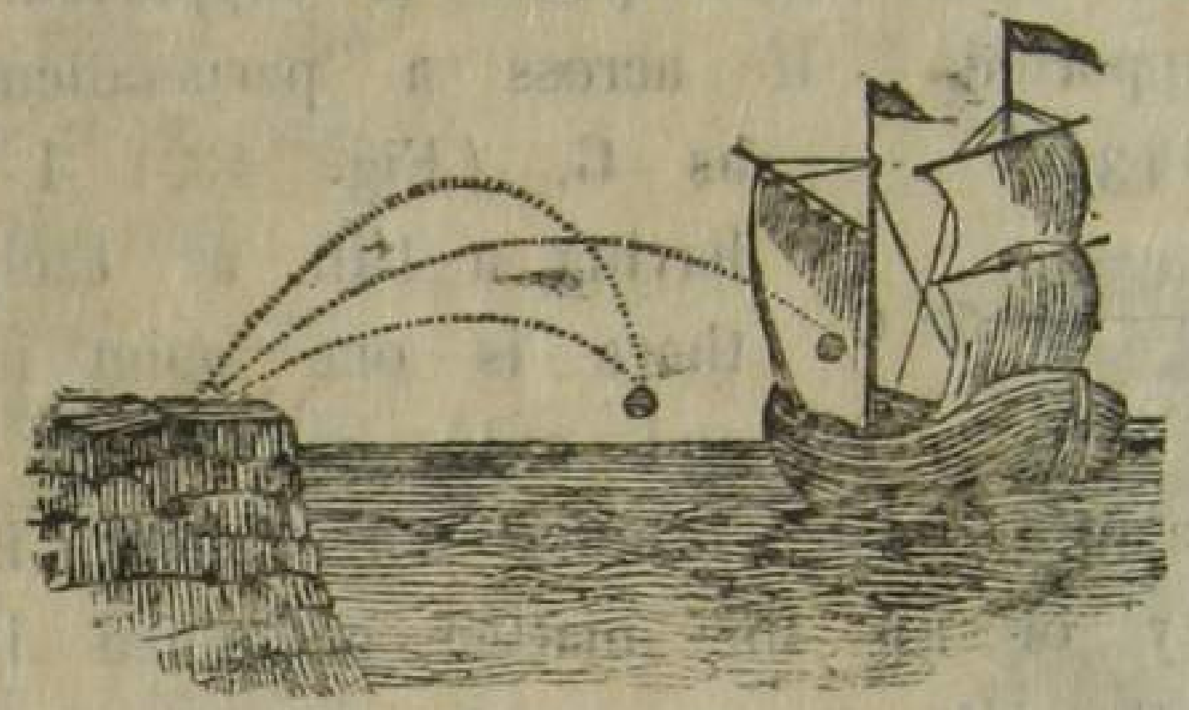


friction at the center of motion, the vibration would continue indefinitely.

37. It is the equality in the vibrations of a pendulum, which is the foundation of its use in *measuring time.* Time may be measured by any thing which divides duration into equal portions, as the pulsations of the wrist, or the period occupied by a portion of sand in running from one vessel to another, as in the hour-glass; but the pendulum can be made of such a length as to divide duration into seconds, an exact aliquot part of a day, and is therefore peculiarly useful for this purpose. Since, also, the pendulum which vibrates seconds at any given place, is always of the same invariable length, it forms the best *standard of measures* by which all others used by society can be adjusted and verified.

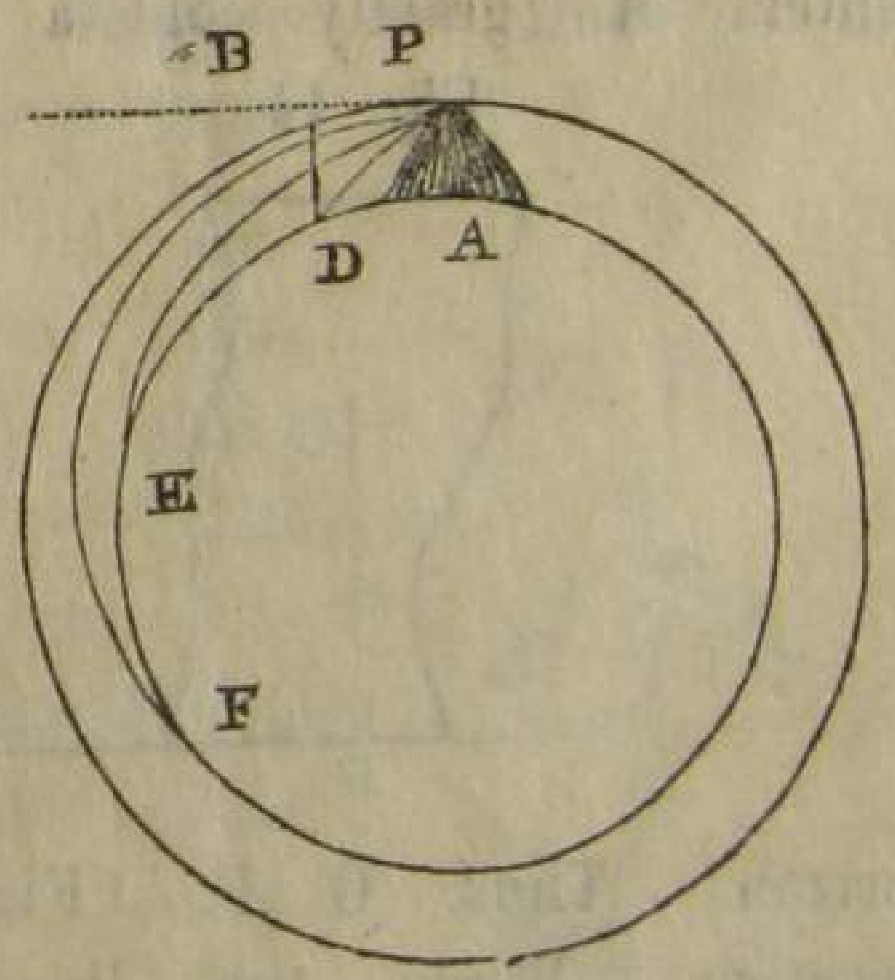
38. Projectile Motion. A body projected into the atmosphere, rises and falls in a curve line, as when a stone is thrown, or an arrow shot, or a cannon ball fired. The body itself is called a *projectile,* the curve it describes, the *path* of the projectile, and the horizontal distance between the points of ascent and descent, the *range.* When an arrow is shot, the impulse, if it were the only force concerned, would carry it forward uniformly in a straight line; but the gravity continually bends its course toward the earth and makes it describe a curve. An arrow, (or any missile,) will have the greatest range when shot at an angle of 45° with the horizon; and the range will be the same at any elevation above 45° as at the same number of degrees below 45°. A cannon ball shot at an elevation of 60° will fall at the same distance from the gun as when shot at an angle of 30°. Thus, in the annexed diagram, a ship is fired on from a fort, as she is attempting to pass it. The ball fired at an elevation of 45°, is the only one that reaches the ship: the others fall short, and equally when aimed above and below 45°.

Fig. 11.



39. If a cannon ball were fired horizontally from the top of a tower, in the direction of P B, the range would depend on the strength of the charge. With an ordinary charge, it would descend in the curve P D; with a stronger charge, it would move nearer to the horizontal line and descend in PE. We may conceive of the force being sufficient to carry the ball quite clear of the earth, and make it revolve around it in the circle.

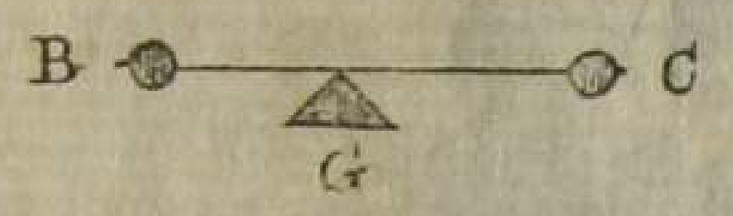
Fig. 12.



Sec. 3.—*Of the Center of Gravity.*

40. The center of gravity of a body is a certain point about which all parts of the body balance each other, so that when that point is supported, the whole body is supported. If across a perpendicular support, as G, (Fig. 13,) I lay a wire having a ball at each end, B C, there is one point in the wire, and only one, upon which the balls will balance each other. This point is the center of gravity of all the matter contained in the wire and both balls. It is as much nearer the larger, B, as the weight of this exceeds that of C. When two boys balance one another at the ends of a rail, the lighter boy will require his part of the rail to be as much longer as his weight is less. The center of gravity of a regular solid, as a cube, or a sphere, lies in the center of body, when the structure of the body is uniform throughout; but when one side is heavier than another, the center of gravity lies toward the heavier side.

Fig. 13.



41. *The line of direction* is a line drawn from the center of gravity of a body perpendicularly to the horizon. Thus, G F, (Fig. 14 or 15.) is the line of direction. When the line of direction falls within the *base,* (as in Fig. 14,) or part of the body on which it rests, the body will stand; when this line falls without the base, (as in Fig. 15,) the body will fall. At Pisa, in Italy, is a celebrated tower, called the *leaning tower.* It stands firm, although it looks as though it would fall every moment; and being very high, a view from the top is very exciting. Yet there is no danger of its falling, because the line of direction is far within the base. To effect this, the lower part of the tower is made broader than the upper parts, and of heavier materials. These two precautions carry the center of gravity low. Structures in the form of a pyramid, as the Egyptian pyramids, have great firmness, because the line of direcition passes so far within the base.

Fig. 14.

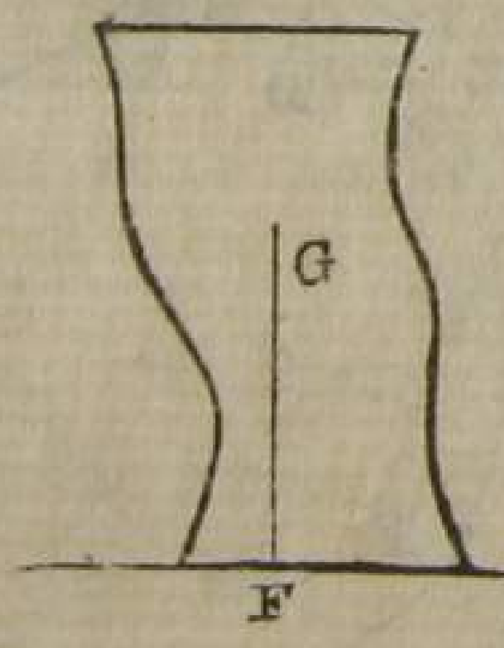


Fig. 15.

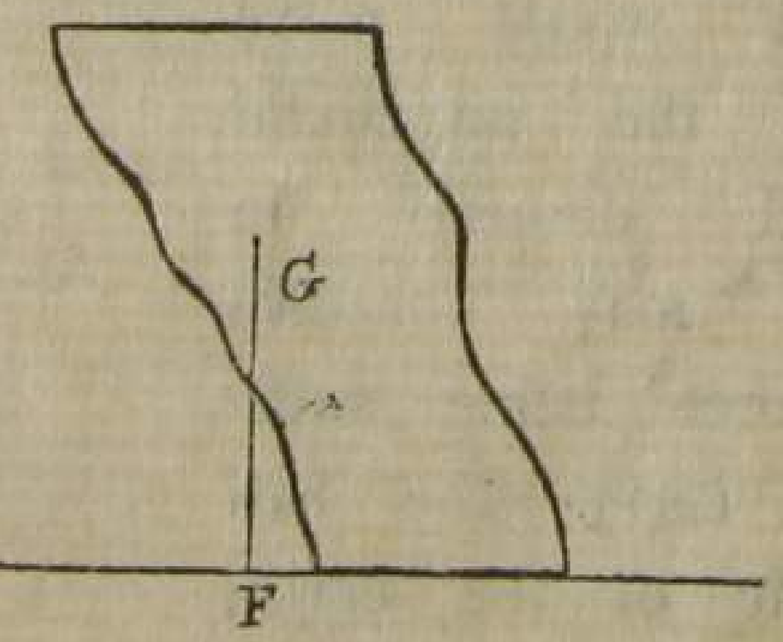
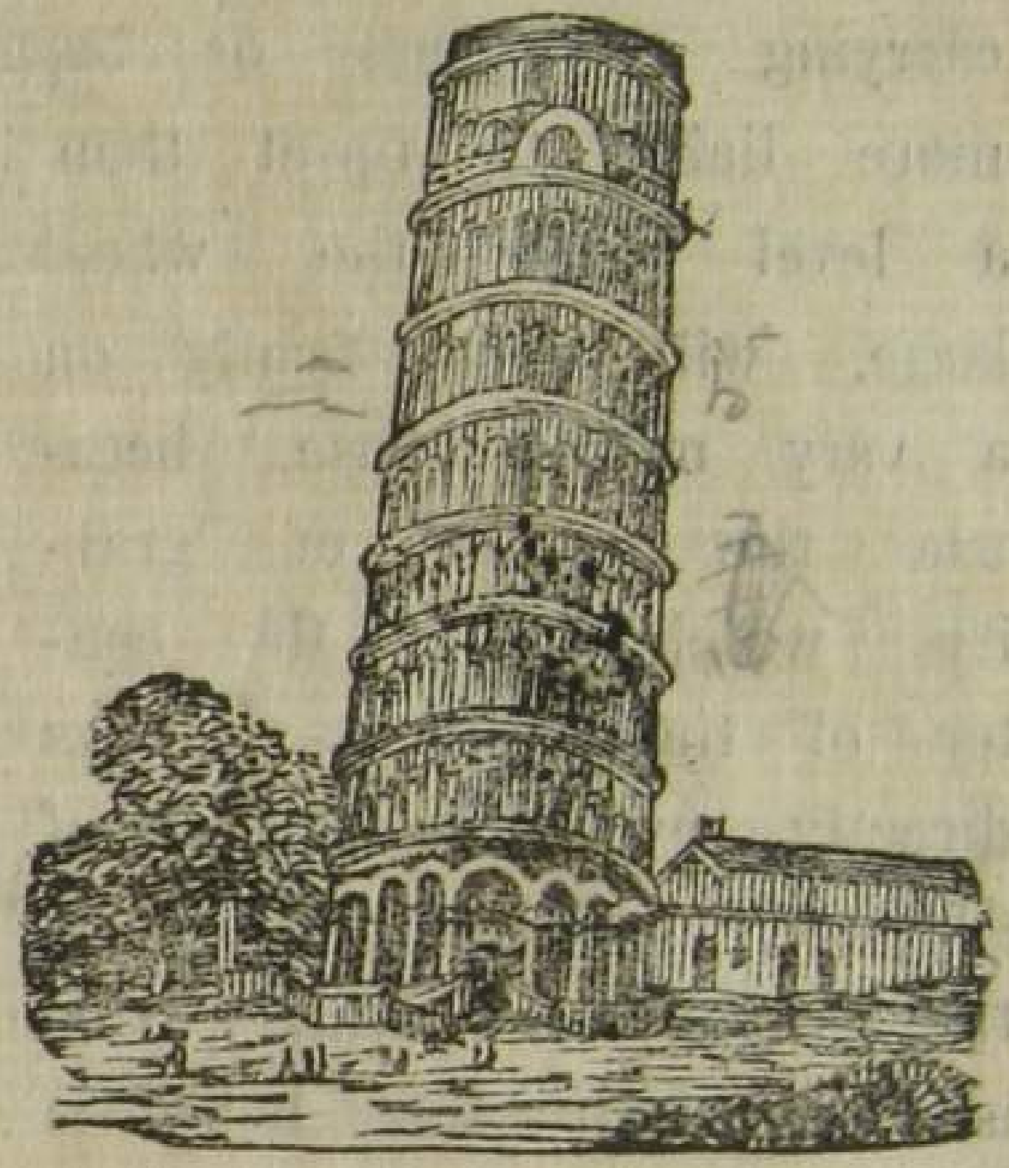


Fig. 16.



42. If we stick a couple of penknives in a small bit of wood, and poise them on the finger, or adjust them so that the center of gravity will fall in the line of a perpendicular pin, the point of the wood will rest firmly on the head of the pin, so that the knives may be made to vibrate on it up and down, or to revolve around it, with-

Fi. 17.

out falling off. A loaded ship is not easily overturned, because the center of gravity is so low, that the line of direction can hardly be made to fall without the base; but a cart loaded with hay or bales of cotton is, on the other hand, easily upset, because the center of gravity is so high. A stage coach carrying passengers or baggage on the top, is much more liable to upset than it is when the load is all on a level with the wheels. A round ball, however large, will rest firmly on a very narrow base, because the center of gravity (which is in the center of the ball) is always directly over the point of support; and, according to the definition, when this is supported, the body is supported. In the annexed diagram, a heavy ball, connected with the figure, bends under the table, and thus brings the center of gravity of the whole within the base, so that the animal rests firmly on his hind legs.

Fig. 18.

43. Animals with four legs walk sooner and more firmly than those with only two, because the line of direction is so much more easily kept within the base. Hence, children creep before they walk, and the art of walking, and even of standing firmly, requires so nice an adjustment of the center of gravity, (which must always be kept over the narrow base

within the feet,) that it is learned only after much experience. Children at school, also, are sometimes directed to turn out their toes when they walk, and to extend one foot from the other in taking a position to speak, because such attitudes, allowing a broader base for the line of direction, appear more firm and dignified.

44. A boy, promised another a cent, if he would pick it up from the floor, standing with his heels close against the wall. But in attempting to pick it up, he pitched upon his face. Performances on the slack rope, which often exhibit astonishing dexterity, depend upon a skilful adjustment of the center of gravity. The process is sometimes aided by holding in the hand a short stick loaded with lead, which is so flourished on one side or the other, as always to keep the center of gravity over the narrow base. Among the ancients, elephants were sometimes trained to walk a tight rope; a feat which was extremely difficult on account of the great weight of the animal.

45. Bodies subject to no other forces than their mutual attraction, and in a situation to approach each other freely, will meet in their common center of gravity. If the earth and moon were left to obey fully their attraction for each other, they would immediately begin to approach each other in a direct line, moving slowly at first, but swifter and swifter, until they would meet in their common center of gravity, which would have its situation as much nearer to the earth as the weight of the earth is greater than that of the moon. So all the planets and the sun, if abandoned to their mutual attraction, would rush together to a common point, which on account of the vast quantity of matter in the sun, lies within that body.

Indeed, were all the bodies in the universe abandoned to their mutual attraction, they would meet in their common center of gravity.

SECTION 4.—*Of the Principles of Machinery.*

46. The elements of all machines are found among the *Mechanical Powers*, which are six in number—the Lever, the Wheel and Axle, the Pulley, the Screw, the Inclined Plane, and the Wedge. That which gives motion is called the *power;* that which receives it, the *weight*. The first inquiry is, what power, in the given case, is required just to *balance* the weight. Any increase of power beyond this, would of course put the weight in motion. It is a general principle in Machines, that *the power balances the weight when it has just as much momentum.* Now we may give a small power as much momentum as a great weight, by making it move over as much greater space in the same time, as its quantity of matter is less. One ounce may balance a thousand ounces, if the two be connected together in such a way that the smaller mass, when they are put in motion, moves a thousand times as fast as the larger. If the momentum of the power be increased beyond that of the weight, as may be done by increasing its quantity of matter, then it will overcome the weight and make it move with any required velocity. Whatever strurcture connects the power and the weihgt is a machine.

47. THE LEVER. Figure 19 represents a lever of the simplest kind, where P is the *power*, W the *weight*, and

F the *fulcrum*, or point of support. Now P will just balance W when its weight is as much less as its distance from the fulcrum is greater. For example, if it is three times as far from the fulcrum as W, then one pound will balance three; three pounds will balance nine; and, universally, in an equilibrium, *the power multiplied into its distance from the fulcrum, will equal the weight multiplied into its distance.* In the present case, where the longer arm of the lever is three times the length of the shorter, a power of ten pounds will balance a weight of thirty.

Fig. 19.

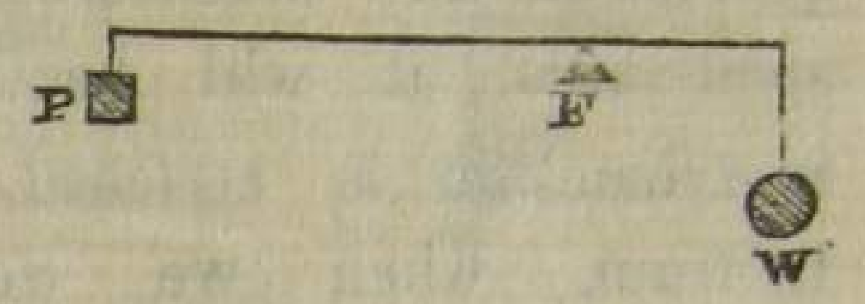
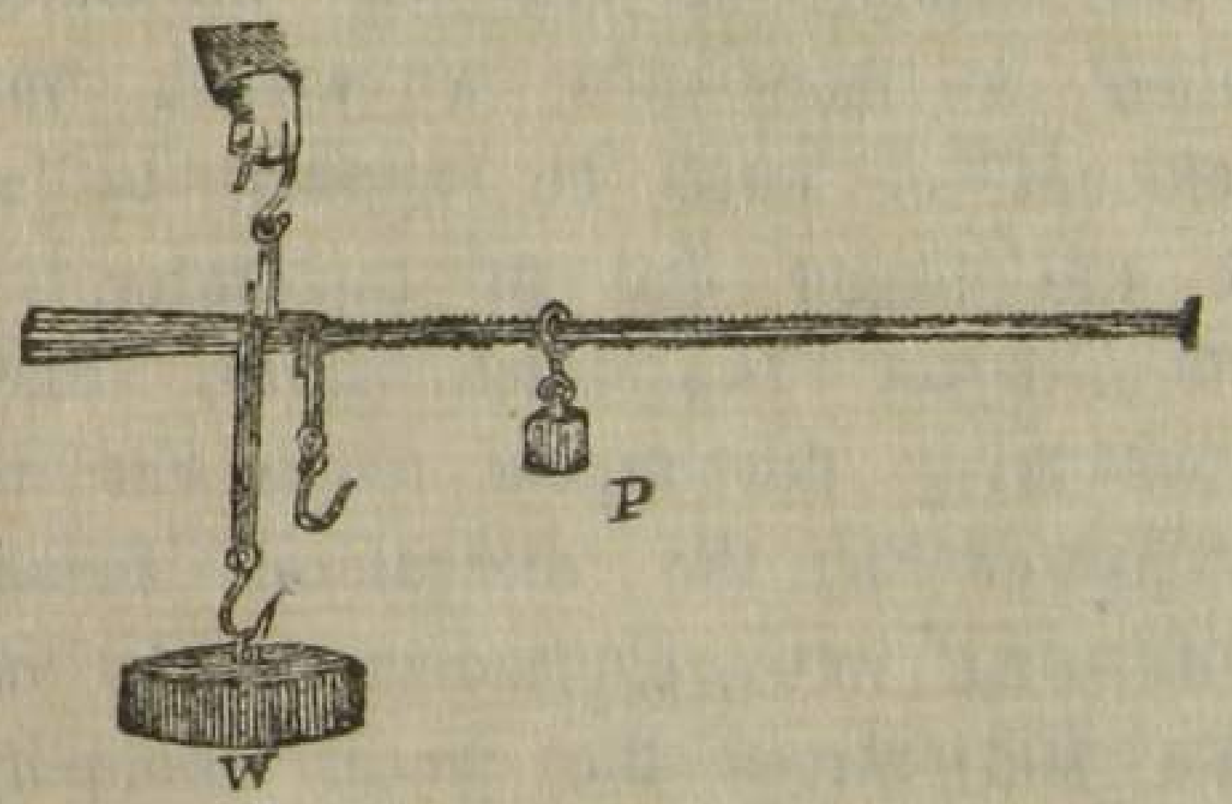


Fig. 20.



48. This principle is exemplified in a common pair of steel-yards. The same power is made to balance different weights of merchandise by attaching W to the shorter and P to the longer arm, and placing P in a notch that is as much farther from the fulcrum

as its weight is less than that of the merchandise, W. Steel-yards have commonly a smaller and a larger side; the former being ounce, and the latter quarter-pound notches. On examining such a pair of steel-yards, it will be seen that the hook to which the merchandise is attached, is four times as far from the fulcrum, when we weigh on the small, as when we weigh on the large side. Hence, we have to move the counterpoise over four notches on this side to gain as much power as we gain in one notch on the other. The spaces over which the power and weight move respectively, are in the same proportion. Thus, when the counterpoise is made to balance a weight ten times as large as itself, it will be seen, by making the arm of the steel-yards vibrate up and down, that the counterpoise moves ten times farther, in the same time, than the weight does, and of course with ten times the velocity. Hence the momenta of the power and the weight are the same. A crow-bar illustrates the same principle, when a man lifts a weight much heavier than the amount of force he applies, by making that force act at the longer end of the lever. A pair of shears is formed of two such levers combined; and the nearer we bring the article to be cut to the fulecrum, the greater is the mechanical advantage gained. Two boys differing in size, moving each other at the end of a pole laid across the fence, exemplify the same principle.

49. In the foregoing cases the weight and the power are on opposite sides of the fulcrum, and it is called a lever of the *first* kind. When the power and weight are on the same side of the fulcrum, but the weight nearer to it than the power, it is a lever of the *second* kind, as in the following figure. The mechanical advantage gained here is the same as in the first, for the power moves as much faster than the weight as it is more distant from the fulcrum.—When the power and weight are both on the same side of the fulcrum, but the power nearer to it than the weight, it constitutes a lever of the *third* kind, as in figure 22. A door moving on its hinges is a weight, the matter of which, for our present purpose, may be considered as all collected in the center of gravity, which, on account of the regular figure of the door, is the center of the door; and the effects of any force applied to a body are the same as though all the matter was concentrated in the center of gravity, and the force was applied to that point. Now if, in shutting the door, I place my hand on the edge, this point being farther from the fulcrum than the center of gravity, I gain a mechanical advantage, because the power moves faster than the weight; but if I apply my hand nearer the fulcrum than the center of gravity, then the power moves slower than the weight, and operates under a mechanical disadvantage; and as I approach nearer and nearer to the hinges, the door is shut with greater and greater difficulty. In the former case, the door exemplifies the principle of a lever of the second kind; in the latter, of the third. Suppose a ladder to lie on the ground, and it is required to raise it on one end by

Fig. 21.

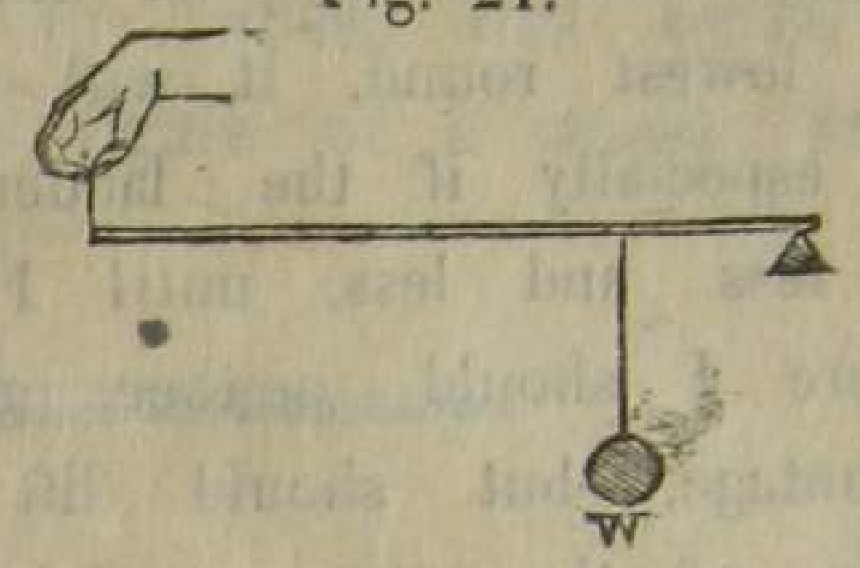
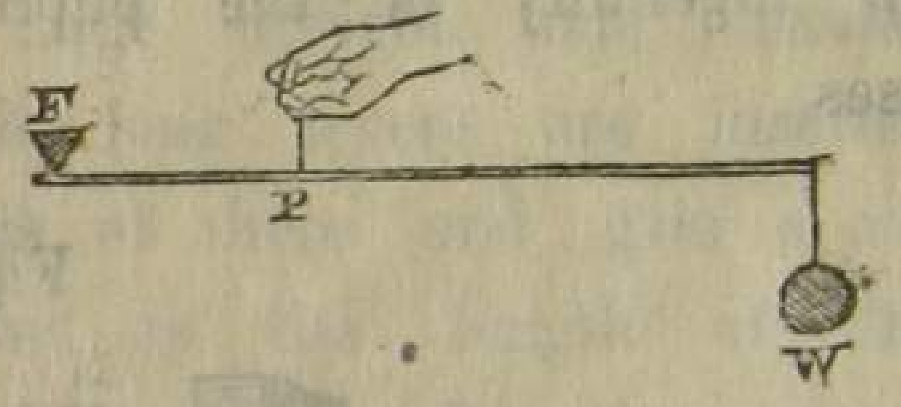
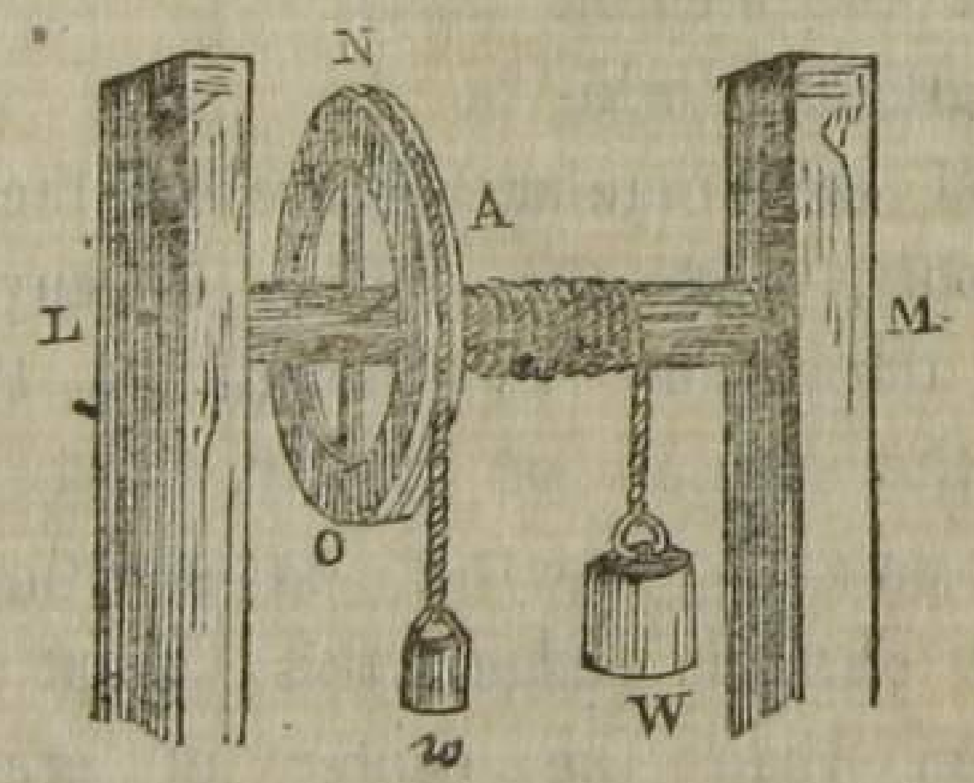


Fig. 22.



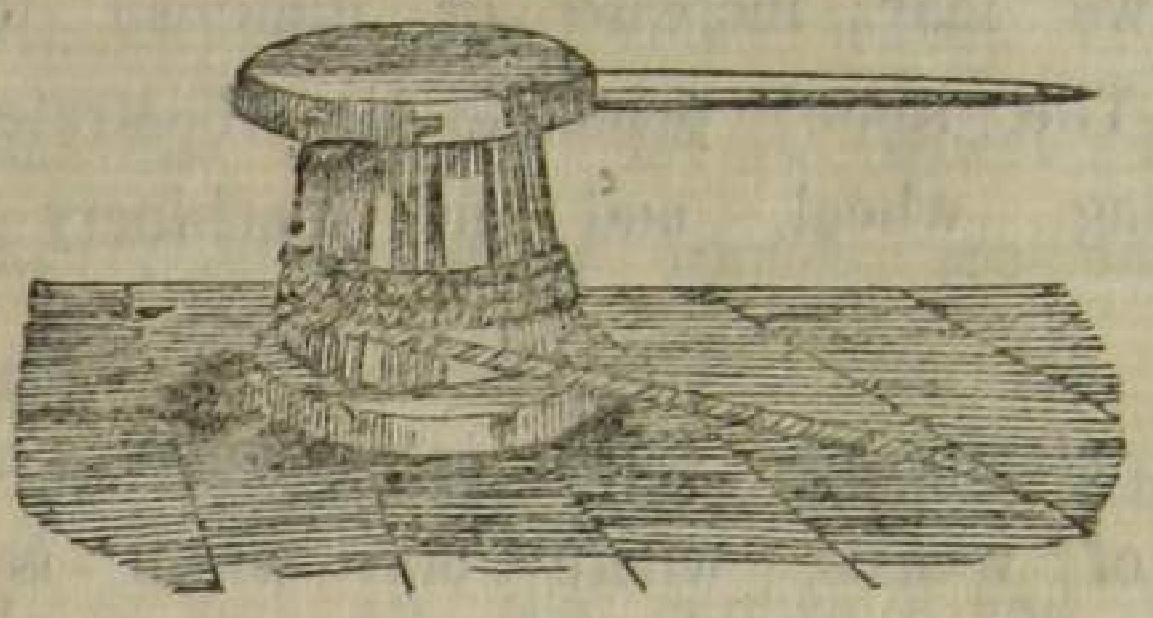
taking hold of one of the rounds. If I take hold of the lowest round, it will require a great effort to raise it, especially if the ladder is long. This effort will be less and less, until I come to the middle round, where I should neither gain nor lose any mechanical advantage, but should lift the ladder like any other body of the same weight, if raised directly from the ground by a string. If I apply my hand to any round beyond the middle, toward the farther end, I gain a mechanical advantage, and the greater as I approach nearer to the end of the ladder. We shall leave it to the ingenuity of the pupil to account for these several cases.

Fig. 23.



50. The Wheel and Axle.—The figure represents a wheel, A N O, and axis, L M, where a small power *w*, balances a greater weight, W. The power required to balance the weight is as much less than the weight as the diameter of the axle is less than that of the wheel. The wheel and axle has a great analogy to the lever, and is indeed little more than a revolving lever. For if the power were applied to the end of one of the spokes of the wheel, that spoke, as it revolved, would describe the figure of a wheel. Thus, the capstan of a ship is a large upright axle, having holes near the top into which long levers are inserted. The men press upon the ends of these and gain a mechanical advantage in proportion as the length of the lever exceeds the radius of the axle. By this means they draw up heavy anchors.

Fig. 24.

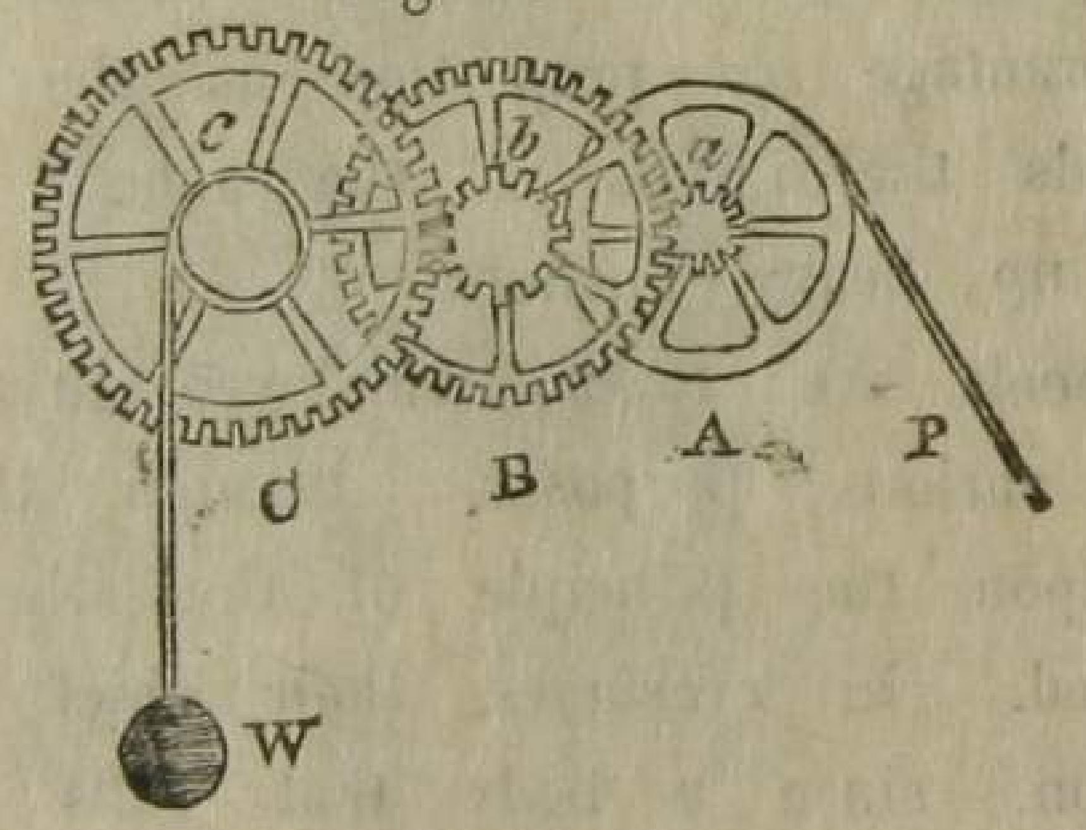


51. Wheels are much employed in machinery, and serve very various purposes, although they do not always act upon the principle of the wheel and axle, as just explained. In *carriages*, their chief use is to overcome friction, since a body that rolls on the ground meets with much less resistance than one that slides; and in lifting a wheel over an obstacle, as a stone; a mechanical advantage is gained in the same proportion as the radius of the wheel exceeds that of the axle. Large wheels, therefore, overcome obstacles better than small ones. Wheels are much employed also to *regulate velocity*. Just step into a mechanic's shop and see this use exemplified in the turner's lathe. By passing a band over a large wheel that turns with a steady motion, one may convey that motion to the small

wheel of a lathe, and the smaller wheel will revolve as much faster than the larger as its diameter is less. Now by using small wheels of different diameters on the lathe, we may increase or diminish the velocity at pleasure. The same principle is illustrated in a common spinning wheel, and in machinery for spinning cotton.

52. In *clock-work,* there is usually a combination of a number of wheels, where one wheel is connected to the axis of another by a small wheel fastened to the axis, called a *pinion.* Thus, the three wheels, A, B, C, are connected. The power is applied to the wheel A, on whose axis is the pinion *a*, the teeth of which (or *leaves*, as they are called) catch into the teeth of B, whose pinion *b* in like manner turns the wheel C. Here the motion of each succeeding wheel is less than the preceding; for if the pinion *a* have ten leaves, and the wheel B 100 teeth, the pinion in turning once would catch but ten teeth of the wheel, and must therefore turn ten times to turn B once. If the pinion *b* has

Fig. 25.



also 10 leaves, and the wheel C 100 teeth, then C turns ten times as slow as B and a hundred times as slow as A. By altering the proportions between the number of teeth in the wheel and leaves in the pinion, we may alter the velocity of a wheel at pleasure; and this is the way in which wheels are made to move faster or slower, at any required rate, in clocks and watches. If we apply the power at the other end and let the wheel C act on the pinion *b*, and the wheel B on the pinion *a*, then B will turn ten times as fast as C, and A ten times as fast as B, and a hundred times as fast as C; so that, when the wheels carry the pinions, the velocity is increased, but when the pinions carry the wheels, it is diminished.

53. The Pulley.—A pulley is a grooved wheel, around which a rope is passed, and is either fixed or movable. Figure 26 represents a *fixed* pulley; and

Fig. 26.

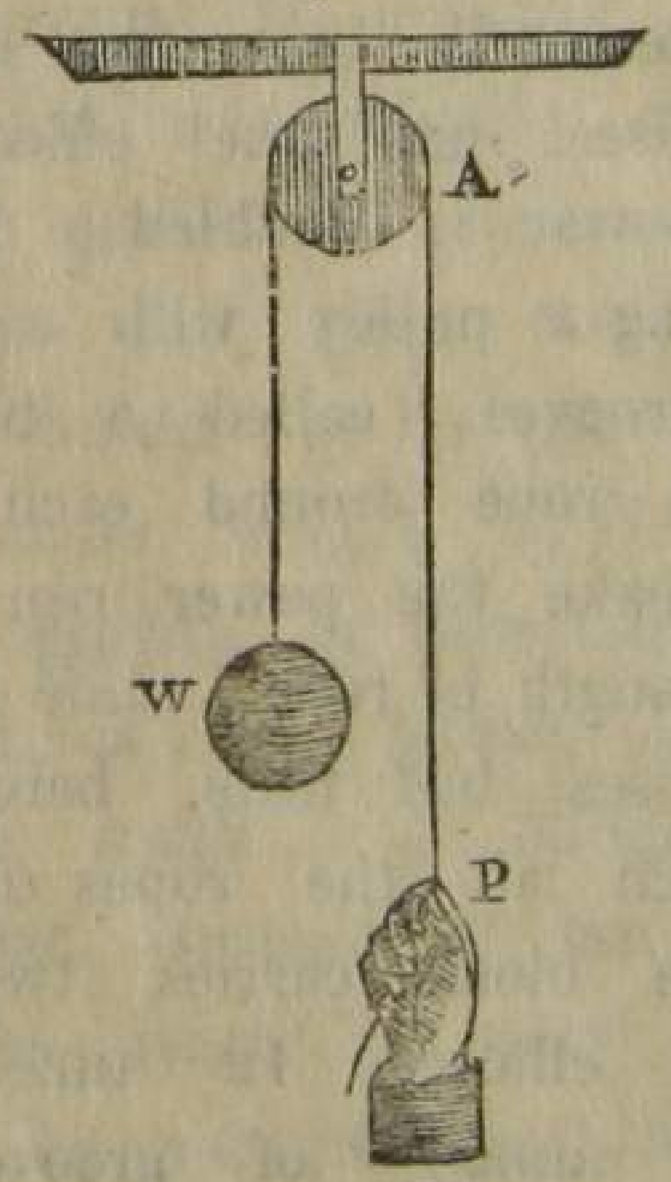


Fig. 27.

here no mechanical advantage is gained, since the power moves just as fast as the weight, and we must remember that it is only when the power moves faster than the weight, that any mechanical advantage is gained. The boy, however, in figure 27, draws himself up by lifting only half his weight, because the two ropes support equal portions of the weight. The principal use of the fixed pulley is to change the direction of the weight. Thus, in drawing a bucket out of a well, it is more convenient to pull downward by a rope passing over a pulley above the head, than upward by drawing directly at the bucket. By the *movable* pulley we gain a mechanical advantage, for by this we can give the weight a slower motion than the power has, and can proportionally increase the efficacy of the power. Thus, in figure 28, as both the ropes, A and E, are shortened as the weight ascends, the rope to which P is attached is lengthened by both, and therefore P descends twice as fast as W rises, and the efficacy of the power is doubled. By employing a pulley with a number of grooves (called a block) with a rope around each, we may make the power run off a great length of rope while the weight rises but little, being equal to the combined length by which all the ropes of the block are shortened. Thus, if the block carries twelve ropes, the power is increased in efficacy 12 times. Instead of a single block with a number of grooves, several pulleys with single grooves are combined upon a similar principle. By a block of pulleys, two men will lift a rock out of a quarry a thousand times as heavy as they could lift with their naked hands; but the rope at which they pull will run off a thousand times as fast as the weight rises.

Fig. 28.

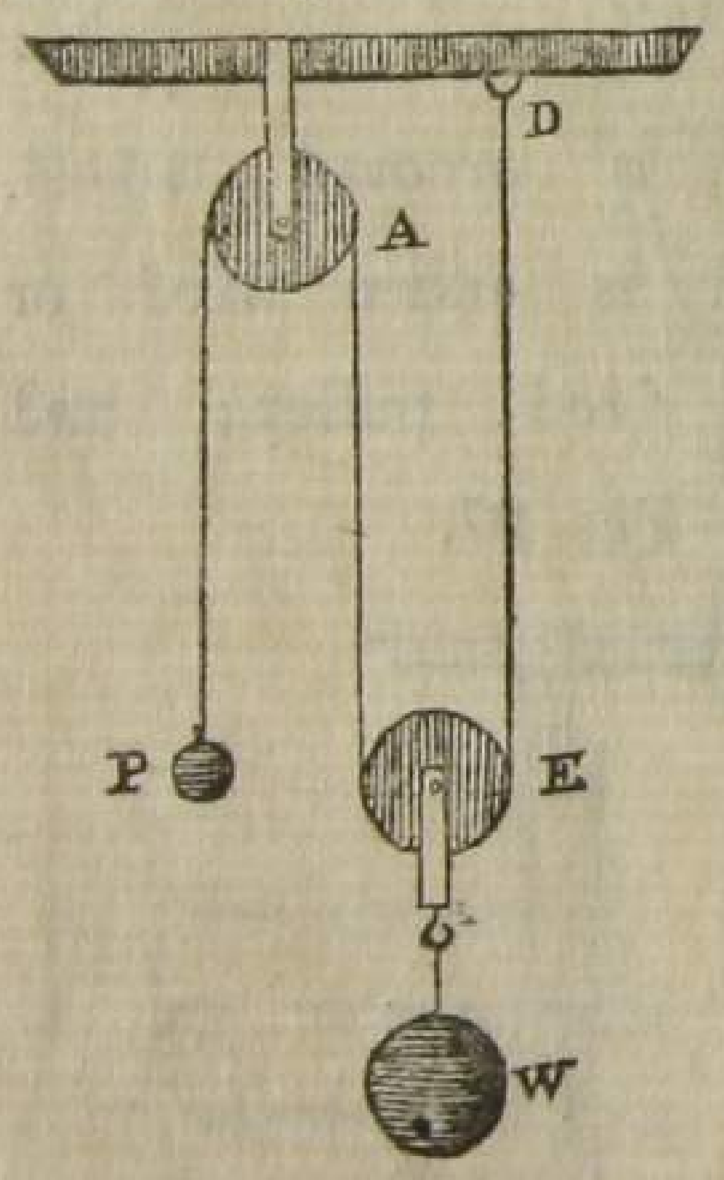
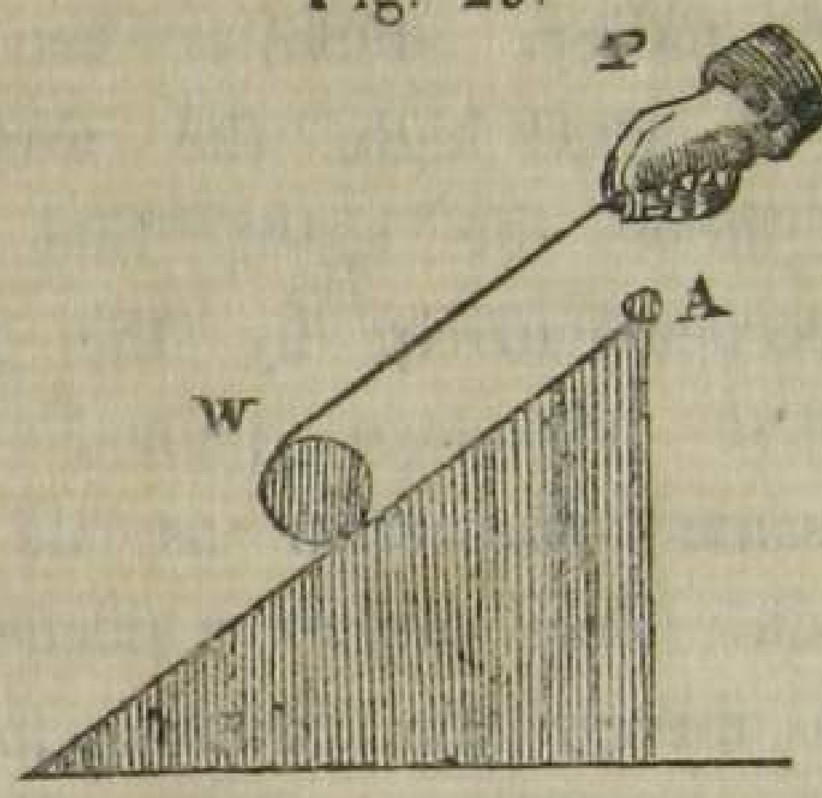


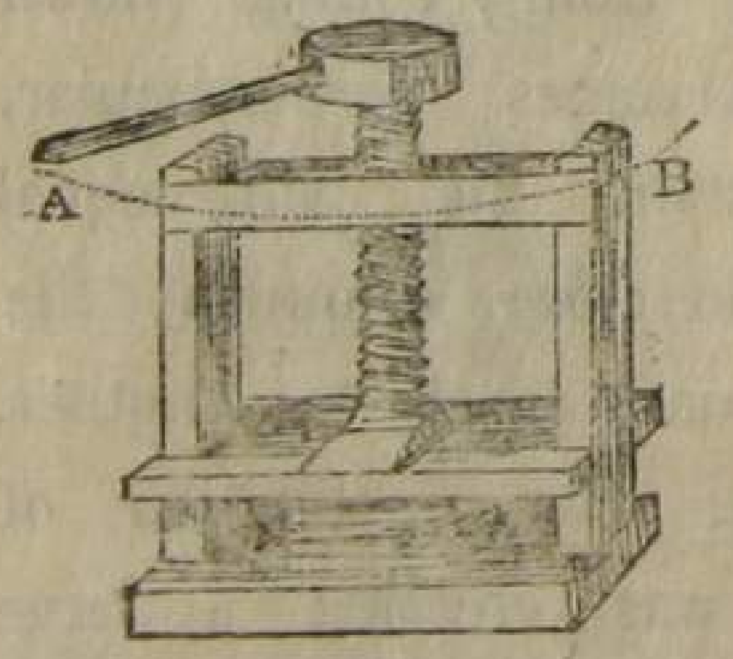
Fig. 29.



54. The Inclined Plane.—The Inclined Plane becomes a mechanical power in consequence of its supporting a part of the weight, and of course leaving only a part to be supported by the power. If a plank, for example, having on it a cannon ball, is laid flat on the ground, it supports the whole weight of the ball. If one end is gradually raised, more and more force must be applied to keep the ball from rolling down the plane: and when the plank becomes perpendicular, a force would be required to sustain the ball equal to its whole weight. We may therefore diminish the effect of gravity, in ascending from one level to another, as much as we please, by making the inclination of the plane small. A builder who was erecting a large edifice, had occasion at last to raise heavy masses of stone to the height of sixty feet. He might have hauled them up by pulleys; but this was inconvenient, and be-

sides, pulleys are subject to so much friction as to occasion a great loss of power. He therefore constructed of timbers and planks, an inclined plane six hundred feet long, and conveyed the blocks of stone up them on rollers. As the plane was ten times as long as it was high, it was as easy to roll 1000 pounds up the plane as it would have been to draw up 100 pounds by a fixed pulley. But as the plane was ten times as long as it was high, the weight would have to pass over ten times the space that it would if it had been raised perpendicularly by the pulley. In all cases, the mechanical advantage gained by the inclined plane is in the same proportion as its length exceeds its height. When a horse draws a loaded cart on level ground, he has merely the friction to overcome; but when he drags it up hill, he has, besides the friction, to lift a certain part of the load, which part will be greater in proportion as the hill is steeper. If the rise is one part in ten, then he would lift one tenth of the load continually.

Fig. 30.



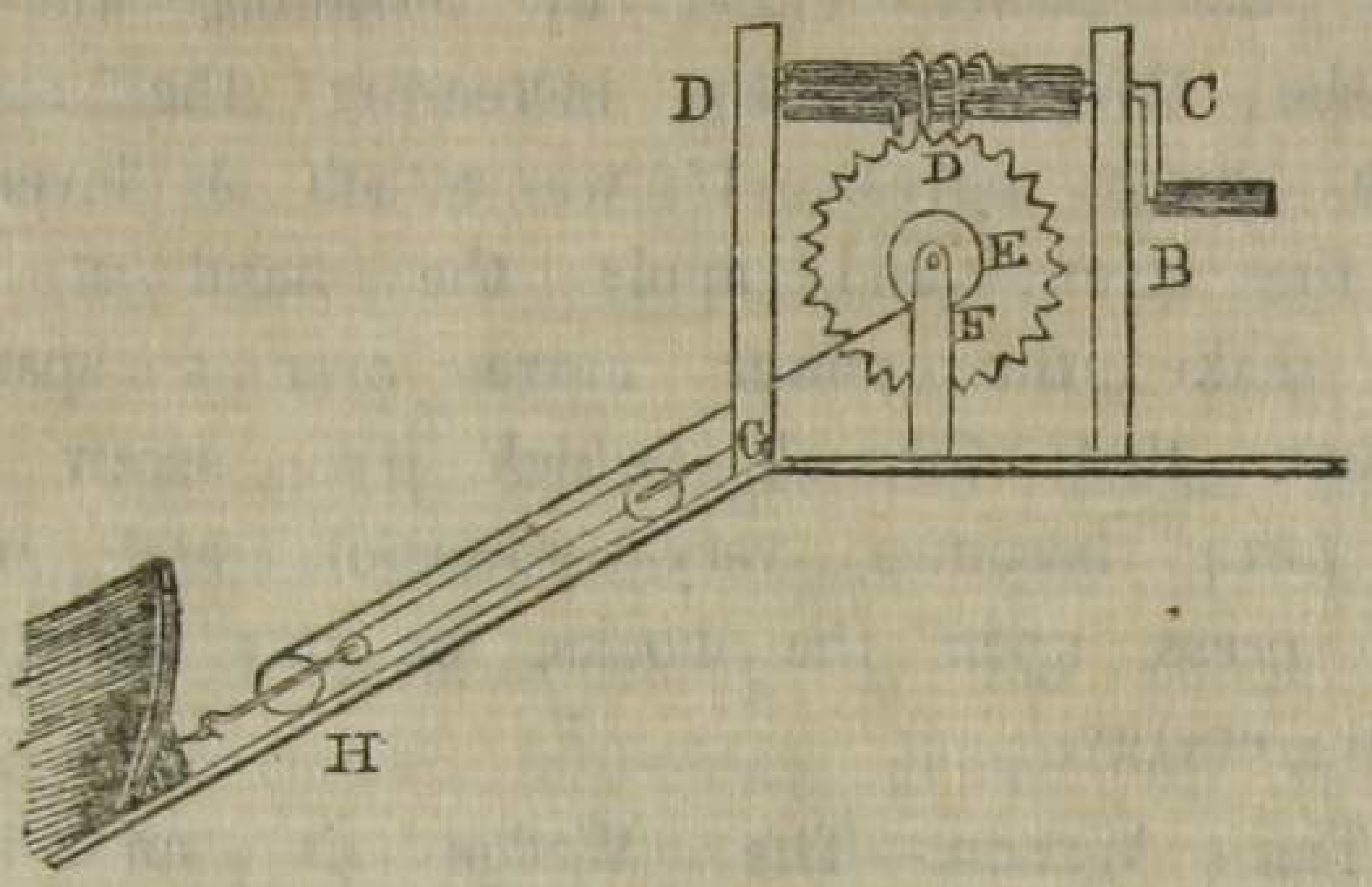
55. The Screw.—The screw is represented in the following diagram as acting upon a press, which is a very common use that is made of it. As the screw is turned, it advances lengthwise through a space just equal to the distance between the threads. Now if the power be applied directly to the head of the screw, then, in turning the screw once round, the power would move over as much more space than the screw advances, as the circumference of the head is greater than the distance between the threads. The mechanical advantage gained is in the same proportion; and we may increase the efficacy of the power either by lessening the distance between the threads, or by increasing the space over which the power moves. If we attach a lever to the head of the screw, and apply the hand at the end, then we make the power move over a space vastly greater than that through which the screw advances, and the force becomes very powerful, and will urge down the press upon the books, or any thing in press, with great energy.

56. The Wedge.—The Wedge is an instrument used for separating bodies, or the parts of bodies, from each other, as is seen in the common wedge used for splitting rocks or logs of wood. In the kind of wedge in ordinary use, the mechanical advantage gained is greater in proportion as the wedge is thinner. Accordingly, it requires but a small force to drive a thin wedge, but a greater force in proportion as the thickness increases. Cutlery instruments, as knives, axes, and the like, act on the principle of the wedge. When long and proportionally thin, the wedge becomes a mechanical power of great force, sufficient to raise ships from their beds.

57. Machines.—Machines are compounded of the mechanical powers variously united. We recognise, at one time, the union of the lever with the screw; at another, of the wheel and axle with the pulley; and, at another, of nearly all the mechanical powers together. The following figure represents a machine for hauling a vessel on the stocks, combining the wheel and axle, the screw, the inclined plane, and the pulley. Each contributes to increase the efficacy of the

force, and all together make a powerful machine. A man applies his hand at B, and turns a crank which acts on the principle of the lever upon the screw at D. If the space over which the hand moves in one revolution is a hundred times as great as the distance between the threads of the screw, then the mechanical advantage gained is in the same proportion, and the force with which the screw urges the teeth of the wheel, is a hundred times that applied by the hand to the crank. The diameter of the wheel is four times that of the axle; therefore, the force applied at E is four hundred times that at B. This acts on a combination of pulleys, which, having four ropes, multiply it again four times, and it becomes sixteen hundred. The inclined plane is twice as long as it is high, and therefore doubles the efficacy of the power, and it becomes three thousand and two hundred times what it was originally. So that the single force which a man can exert by means of such a machine is prodigious; and if the machine was so contrived (as it might easily be) that a pair of horses or a yoke of

Fig. 31.



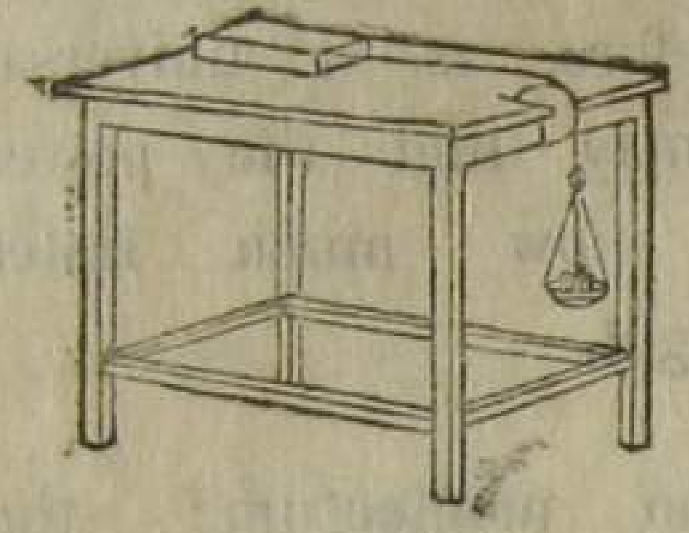
cattle, instead of the man, could turn the machine, the force would be adequate to move the largest ship. Such a machine, however, would move the body with extreme slowness. Its motion, in fact, would be diminished as much as the efficacy of the power was increased. This, as we have said before, is a universal principle in mechanics; so that we may find the power exerted by any machine, by seeing how much faster the moving force goes than the weight.

58. Machines, therefore, gain no momentum: the power multiplied into its velocity always equals the weight multiplied into *its* velocity. But although machines do not of themselves generate any force, they enable us to apply it to much greater advantage—to change its direction at pleasure—to regulate its velocity—and to bring in to the aid of the feeble powers of man the energies of the horse and the ox, of water, wind, and steam.

59. Friction.—The principles of machinery are first investigated, on the supposition that machines move without resistance from external causes. Then the separate influence of such accidental causes of irregularity, in any given case, is ascertaind and applied. The two most general impediments to machines are friction and resistance of the air, which occasion more or less destruction of force in all machines. Friction arises from the resistance which different surfaces meet with in moving on each other. Perfectly smooth surfaces adhere together by a certain force, opposing a corresponding resistance to the motion of the surfaces on one another; but the asperities which exist on most surfaces occasion a much greater resistance. An extreme case is when

one brush is slid across another, and the hairs interlace. By careful experiments on friction, the following are found to be its principal laws. First, the friction of a body, other things being equal, is proportioned to its *weight*. If a brick is laid on a table, with a string attached to it connected with a scale below, by placing weights in the scale we may ascertain just how much force it takes to drag it off from the table under different circumstances, and this will be the measure of the friction. We should suppose that the friction would be greater on its broad than on its narrow side; but experiments show that it is equal in the two cases, so that *extent of surface* makes no difference when the weight remains the same. We may let the same brick rest on either side, and load it with different weights, equal to its own weight, double, triple, and so on. In all cases, we shall find the friction increased in the same proportion as the weight. Secondly, friction is increased by bodies remaining some time *in contact* with each other; and when the contact is but momentary, as when a body is in very swift motion, the amount of friction is greatly diminished. Thus, when a carriage is in swift motion over a road, it encounters less resistance from friction in passing a given distance, than when it moves slowly. The same is strikingly the case in railway cars.

Fig. 32.



60. *Rolling* are subject to far less friction than *sliding* bodies. Thus, if a coach wheel be *locked*, that is, made to slide down hill instead of rolling, its

riction may be so much increased as to check the rapidity of descent in any required degree. Rollers are therefore employed in transporting heavy bodies, to diminish friction; and, for the same purpose, surfaces are made smooth by applying grease, or different pastes, or even water, all of which fill up the inequalities and thus diminish the asperities of the surface. Although friction presents a resistance to machines, yet it has its uses in mechanical operations. It is this which makes the screw and the wedge keep their places; and it is the friction of the surfaces of brick and stone against each other, which gives stability to buildings constructed of them. The wheels of a carriage advance by their friction against the ground. On perfectly smooth ice they would turn without advancing. We could not walk did not friction furnish us with a foothold; and it is for want of friction that walking is so difficult on smooth ice. So rail cars meet with great difficulty in proceeding when the rails have been recently rendered slippery by ice: the wheels turn without advancing. Friction is even employed as a mechanical force, as when a lathe is turned by the friction of a band. Air meets with greater resistance in passing over rough surfaces than water does; for water deposites a film of its own fluid upon the surface over which it moves, and thus lubricates it. Hence water flows in pipes with less resistance than air passes over the surfaces of a rough and sooty chimney.

61. The resistance which bodies meet with in passing through air or water, increases rapidly as the velocity is increased, being proportioned to the *square* of the velocity. Thus, if a steamboat doubles its

speed, it encounters not merely twice as much resistance from the water, but four times as much. This makes it much more expensive to move boats rapidly than slowly, for it would require nine times the force to triple the speed.

CHAPTER III.

HYDROSTATICS.

PRESSURE OF FLUIDS—SPECIFIC GRAVITY—MOTION OF FLUIDS—WONDERFUL PROPERTIES COMBINED IN WATER.

62. HYDROSTATICS *is that branch of Natural Philosophy, which treats of the pressure and motion of fluids in the form of water.*

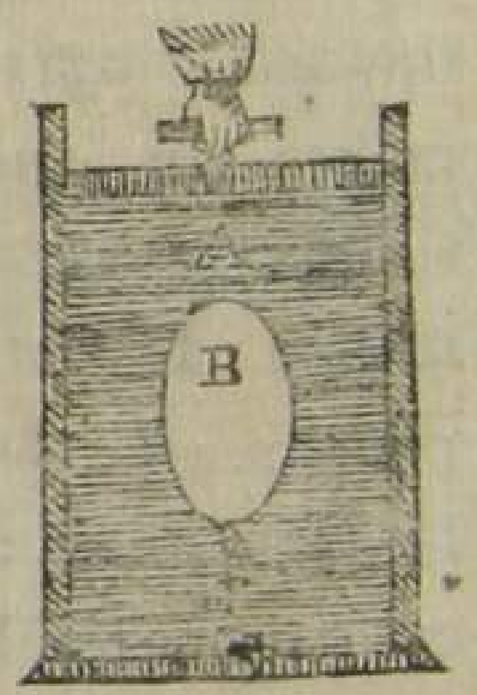
SEC. I. *Of the* PRESSURE *of Fluids.*

63. Water, on account of the mobility of its parts, may be easily *displaced*, but it is with great difficulty *compressed*. If we take a hollow ball of even so compact a metal as gold, fill it full of water, plug it close, and put it into a vise and compress it, the water will sooner force its way through the gold than yield to the pressure. This is an old experiment, and it led to the belief that water is wholly incompressible; but it is now found that its volume may be reduced to smaller dimensions by subjecting it to very great pressures. Thus, 30,000 pounds pressure to the inch will lessen its bulk one twelfth.

64. *A fluid when at rest, presses equally in all directions.* A point in a tumbler of water, for example, taken at any depth, exerts and sustains the same pressure in all directions, upward, downward, and sidewise. So that if I attach a string to a musket ball and let it down into water, the weight of the water which rests on its upper side is balanced by an equal pressure on its under side. This is the most remarkable property of fluids, and is what distinguishes them from solids, which press only downward, or in the direction of gravity.

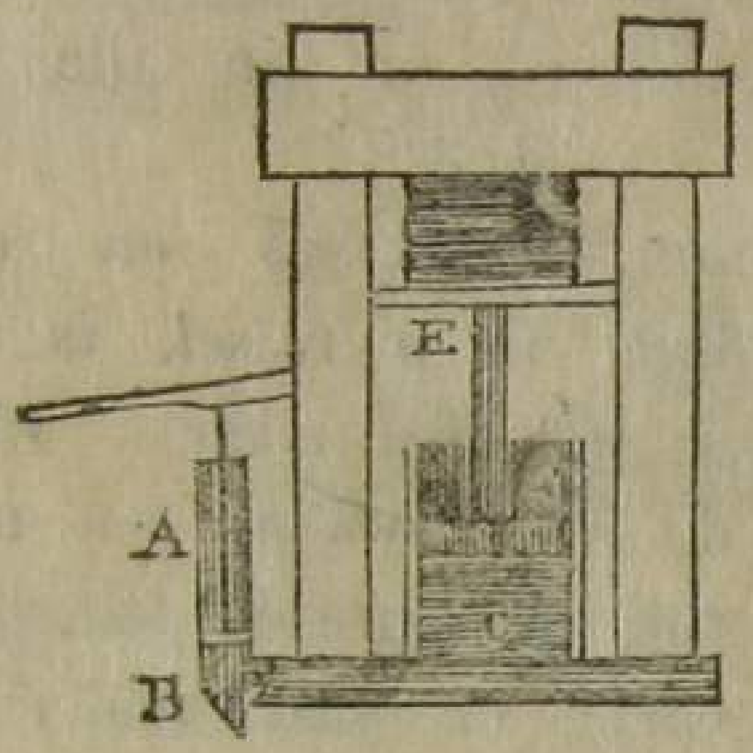
65. *A given pressure, or blow, impressed on any portion of a mass of water confined in a vessel, is distributed equally through all parts of the mass.* If I thrust a cork into a bottle filled with water, so near the top that the cork meets it, the pressure is felt, not merely in the direction of the cork, or just under it, but on all parts of the bottle alike; and the bottle is as likely to break in one part as another, if equally strong throughout, and if not equally strong, it will give way at its weakest point, wherever that is situated. If we insert into a large vessel of water a blown bladder, and then press upon the upper surface of the water with a lid that fits it close, as in figure 33, the bladder will indicate an equal pressure on all sides. A is the lid that fits the jar, water-tight, and is applied to the top of the fluid; B is a small blown bladder, kept in its place by a leaden weight resting on the bottom of the vessel. If a thin 72 glass ball is substituted for the bladder, on pressing down the lid, it will be broken into minute fragments, showing an equal pressure on all sides. The same effects would follow were the pressure applied at the side, or any other part of the vessel, instead of the top.

Fig. 33.



66. This principle operates with astonishing power in the *hydrostatic press*. Figure 34 represents a press

Fig. 34.



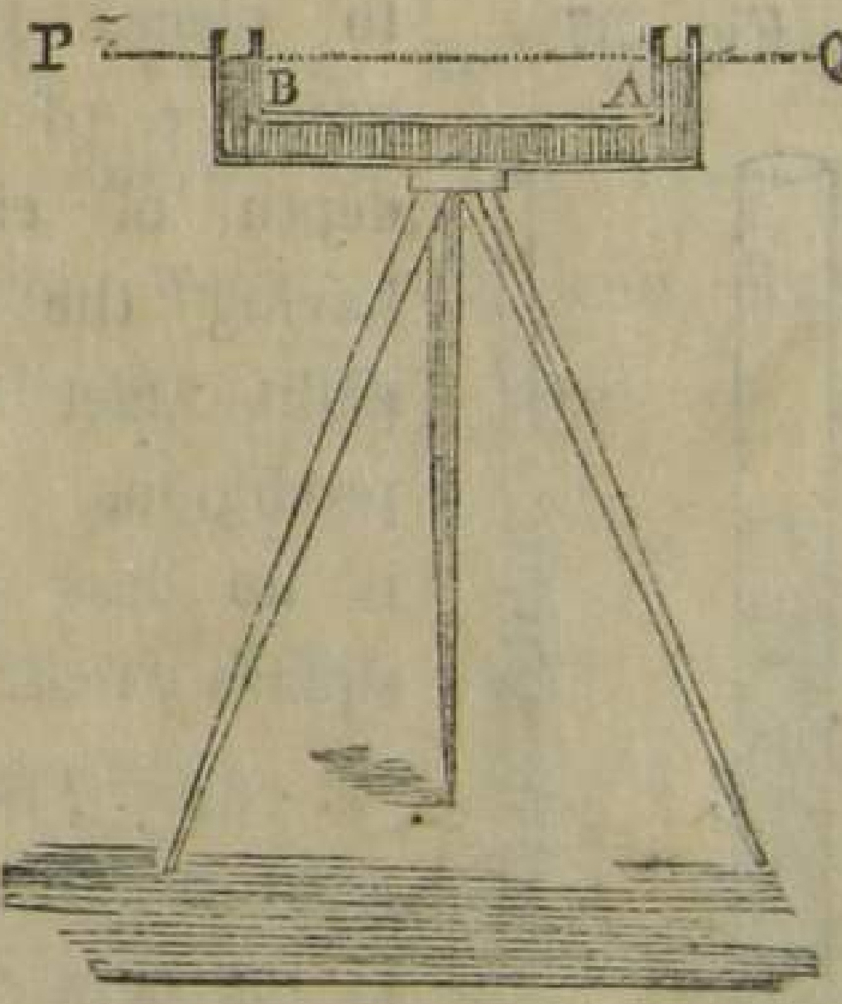
made of a strong frame of timbers, having a large cylinder, C D, full of water, and opening into a small cylinder, A B, in which a plug (called a *piston*) is moved up and down by the lever attached to it. At D is another piston, which when forced upward presses upon a *follower* at E, which communicates the force to a pile of books supposed in the process of binding. Now if I apply my hand to the lever and force down the piston in AB upon the surface of the water, with whatever force it presses upon the surface of the fluid in the small cylinder, the same is exerted on all parts of the water in the large cylinder, and consequently upon the piston D to push it upward against E. Suppose the number of square inches in the bottom of the piston E, is a thousand times as great as in that of the piston at B; then by urging B forward with a force equal to one hundred pounds, I should communicate to E a pressure of one hundred thousand pounds. The water in the small cylinder would descend a thousand times as much as that in the large cylinder rose, so that the space through which the accumulated force could act would be very small; still it would be sufficient for such articles as books, where the whole compression is but small. Since there is no loss from friction in this machine, a man can by means of it exert a greater power than by any other to which he can apply his own strength. He can by means of it crush rocks,

and cut in two the largest bars of iron. The hydrostatic press is much used as an oil press, as in extracting oil from flaxseed; and also for packing hay, cotton, and other light substances.

67. *The surface of a fluid at rest is horizontal.* This property is applied to the construction of the **FLUID LEVEL**, used by carpenters, masons, and other workmen. It usually consists of a flat rule, having a horizontal glass tube on the upper side, containing alcohol, (which is preferred to water because it never freezes.) The tube is not quite full of the fluid, so that when laid on its side a bubble of air floats on the upper surface. When this is exactly at a given mark near the middle, then the surface on which the rule is laid is level. Figure 36 represents a levelling staff much used in surveying and grading lands. The liquid in the two arms of the tube at A and B being precisely on a level, any two remote objects, P and Q, may be brought accurately to the same level by *sighting* P with the eye at A; that is, bringing it into the same horizontal line with the surfaces of A and B, and then sighting Q in the same manner.

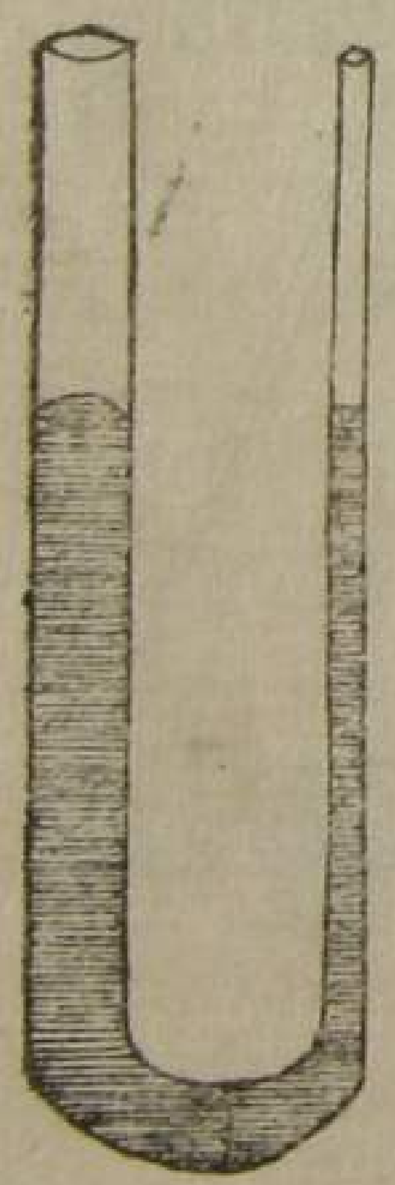
Fig. 35.

Fig. 36.



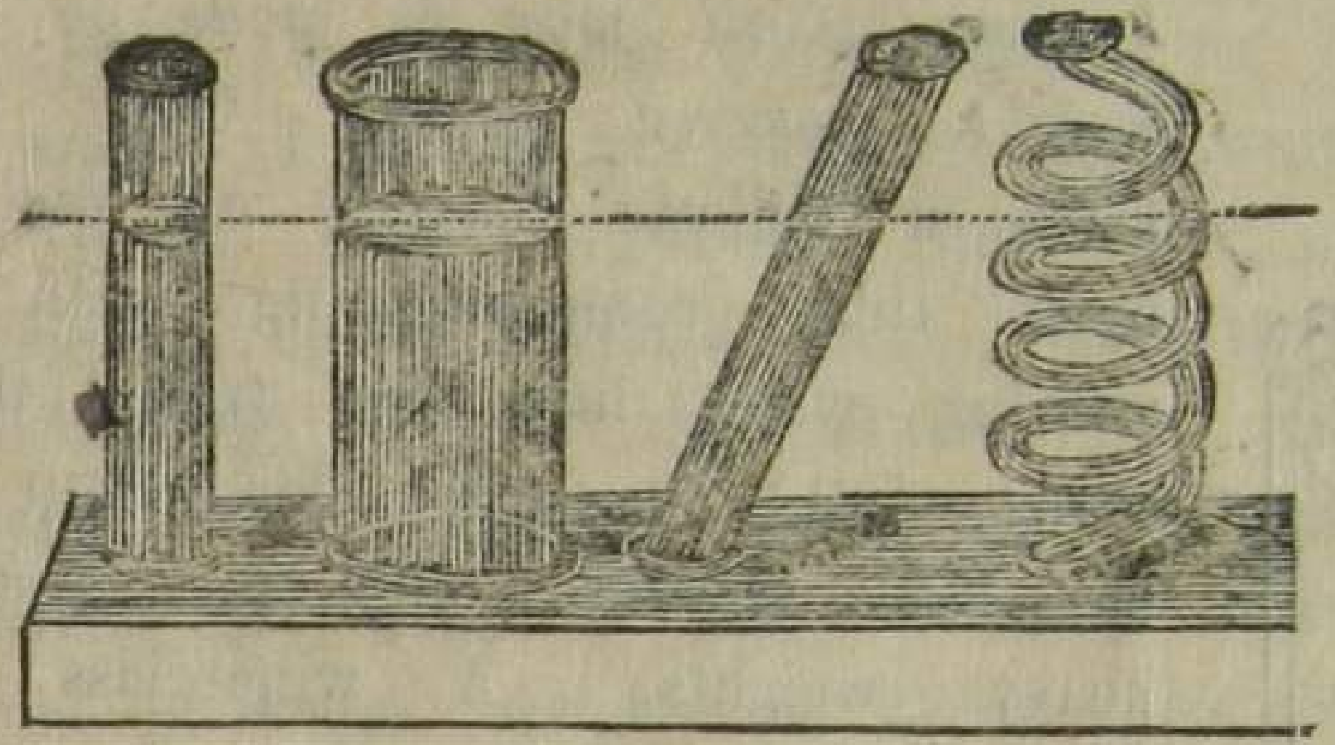
68. *The pressure upon any portion of a column of fluid, is proportioned to its depth below the surface.* If we let down a junk bottle into the sea, the pressure on all sides of it would continually increase as it descended, until it would be sufficient to crush it. Its great strength, however, would enable it to bear a prodigious pressure. When an empty bottle, corked closely, is let down to a great depth, on drawing it up, it is found full of salt water, and yet the cork undisturbed. At a certain depth, the pressure on the cork is such as to contract its dimensions, and yet, being equally pressed on all sides, it is not displaced. Its size being contracted, the water runs in at the sides; but on rising to the surface, the cork swells again to its former bulk. When the stopper does not admit of compression, the water sometimes is forced through its pores, and thus fills the bottle. Ships sunk at a great depth, have their wood rendered so heavy by the great quantity of water forced into it, that when they go to pieces their parts do not rise. The pressure of water on a square foot, at the depth of eight feet, is 500 pounds; and having the same amount added for every eight feet of descent, it soon becomes prodigious. At the depth of a mile, it is no less than 330,000 pounds upon the square foot.

Fig. 37.



69. *Fluids rise to the same level in the opposite arms of a bent tube.* Let Fig. 37 be a bent tube: if water be poured into either arm of the tube, it will rise to the same height in the other arm. Nor is it material what may be the shape, size, or inclination of the opposite arms. Figure 38 represents a variety of vessels and tubes open at top, but communicating with a common cistern of water below. If we pour water into any one of these, so as to fill it to any height, the water will be at the same height in each of the others. Hence, water conveyed in aqueducts, or running in natural confined channels, will rise just as high as its source, and no higher. Between the place of exit and the spring, the ground may rise into hills and descend into valleys, and the pipes which convey the water may follow all the irregularities of the country, and still the water will run freely, provided no pipe is laid higher than the level of the spring.

Fig. 38.



70. *The pressure of a column of water upon the bottom of a vessel, depends wholly upon the height of the column, without regard to its shape or size.* In Fig. 38 the pressure on the bottom of the cistern will be the same, whether one tube is attached, or the whole number, or the vessel itself is raised to the same height all the way of the same size as at the bottom.

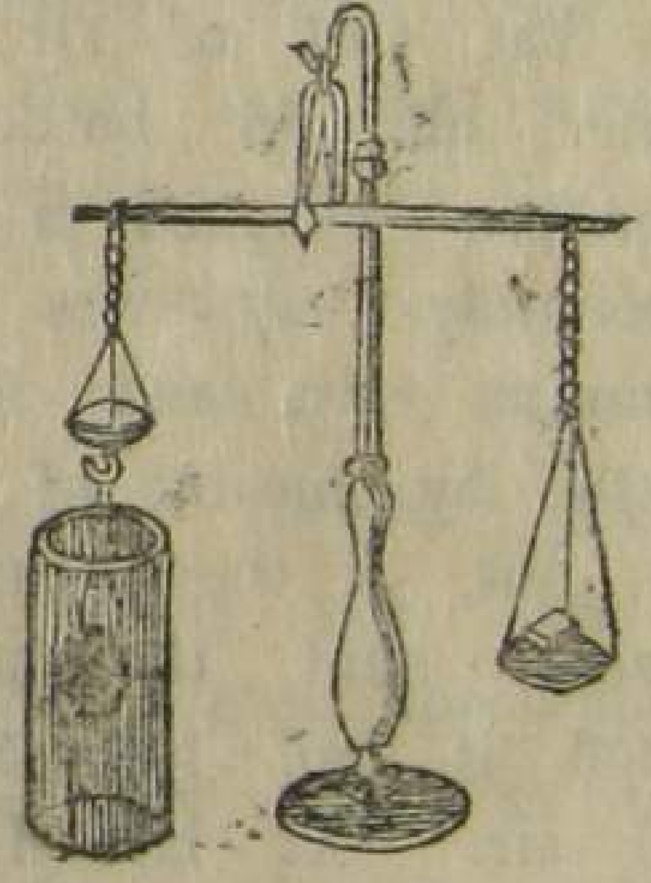
or even if swelled out like a funnel, so as to be much larger above than below. On this principle is founded the hydrostatic paradox—that *any quantity of water however small may be made to raise any weight however great.* Fig. 39 represents a bellows having on one side an open tube communicating with it. On pouring water into the tube (the bellows being full) it will force up the top of the bellows, although loaded with heavy weights. A wine-glass of water, for example, will raise the boys that stand on the bellows, and would sensibly lift a weight many hundred times as great. The principle is the same as in the hydrostatic press. Here the weight of the column of water affords the power that acts on the larger end of the bellows, as in the press the force of the piston in the small cylinder acts on that in the larger.

Fig. 39.

SEC. 2. *Of Specific Gravity.*

71. SPECIFIC GRAVITY *is the weight of a body compared with another of the same bulk, taken as a standard.* Water is the standard for solids and liquids; common air for gases. The specific gravity of a mineral, for example, or of alcohol, is its weight compared with that of a mass of water of exactly the same volume; the specific gravity of steam is its weight compared with that of the same volume of atmospheric air. We must know, then, what an equal volume of the standard would weigh. This is ascertained in the case of a solid, by finding how much less the body weighs in water than in air; and, in the case of a liquid or a gas, by weighing equal volumes of the body and of air. Wishing to know how much heavier a certain ore, which I suspected to be silver, was than water, I tried to compare its weight with that of an equal bulk of water; but the ore being of very irregular shape, I found great difficulty in measuring it accurately, to find the number of solid inches in it, so that I could weigh it against the same number of inches of water. But learning that a body when weighed in water weighs as much less than when weighed in air, as is just equal to the weight of the same volume of water, I attached a string to the ore, hung it to one arm of the balance, and found its weight to be 4.75 ounces; and then bringing a tumbler of water under the suspended ore so as to immerse it, I found it did not in this situation weigh as much as before, but I had to take out 1.25 ounces to restore the balance. This, then, was what the ore lost in water, and was the weight of an equal volume of water. Now I have found that the ore weighs four ounces and three quarters, while the same bulk of water weighs only one ounce and a quarter. I see, therefore, at once, that the ore is about four times as heavy as water; but to find the exact specific gravity, I see how many times the weight of the ore is greater than that of an equal volume of water, by dividing 4.75 by 1.25, which gives 3.8 as

Fig. 40.



the exact specific gravity of the ore. I conclude, therefore, that it cannot contain much silver, if any; otherwise it would be heavier. Again, desiring to find the specific gravity of some alcohol, (which is better in proportion as it is lighter,) I took a small vial, counterpoised it in a pair of delicate scales, and poured in water gradually till I had introduced exactly 1000 grains. I then set the vial on the table, and placing my eye accurately on a level with the surface of the water, I made a fine mark with a small file just round the water line. On emptying out the water and filling the vial to the same mark with the alcohol, I found the weight of it to be 815 grains I therefore inferred that its specific gravity was 815 water being 1000. Having now my vial ready, I filled it to the mark successively with half a dozen different liquors, some lighter and some heavier than water, and thus found the exact specific gravity of each. Finally, I had the curiosity to see which is the heaviest, common air, or that sort of air which sparkles so briskly in soda-water, and in bottled beer, called carbonic acid. I therefore weighed a light glass bottle, which, as we commonly say, was empty, but was really filled with common air, and then withdrawing the air from the bottle by means of a kind of syringe which sucked it all out, I then turned the stop-cock attached to the mouth, shut the bottle close, and weighing it again, found it had lost 40 grains, which was the weight of the air. At last I filled the bottle with carbonic acid instead of air, and weighiug again, found the vessel now weighed 60 grains more than before. This was the weight of the carbonic acid; and now having found hat when we take equal bulks of common air and carbonic acid, the latter weighs 60 grains, while the former weighs only 40, I infer that the carbonic acid is one half heavier than common air; that is, its specific gravity is 1.5. By a similar process, I found

that hydrogen gas, one of the elements of water, is more than thirteen times as light as air, being the lightest of all known bodies.

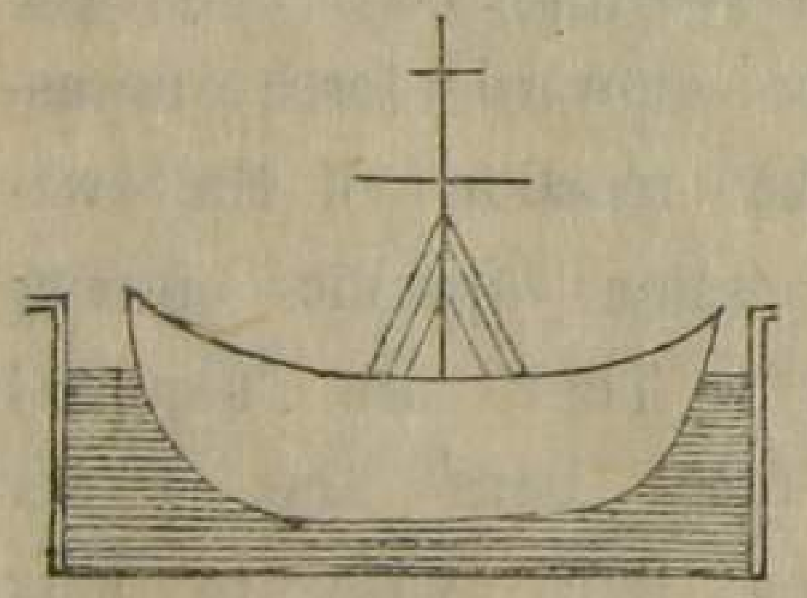
72. A body *floats in water at any depth,* when its specific gravity is just equal to that of water. The human system is a little heavier than water, and therefore tends to sink in it; but if we strike the water downward, its reaction will keep us up, acting as it does in a direction opposite to that of gravity. A very slight blow upon the water is sufficient to balance the downward tendency, and therefore *swimming* becomes an easy matter when skillfully practised. As we lose in water as much of our weight as the same bulk of water would weigh, and that is nearly the whole, it is only the slight excess of our weight which we have to sustain in swimming. Indeed, if we could keep our lungs constantly inflated, we should require no reaction to keep us up, but should float on the surface. Dr. Franklin when a boy swam across a river by the aid of his kite, which supplied the upward force necessary to sustain him, instead of the reaction of the water. Fishes are nearly of the same specific gravity as the water in which they live. They are supplied with a small air-bladder, which they have the power of compressing and dilating. When they wish to sink they compress this bladder, and their specific gravity is then greater than that of the water; and they easily rise again by suffering the bladder to dilate. Birds float in the atmosphere on similar principles. Being but little heavier, bulk for bulk, than the air, very slight blows with their wings create the reaction in an upward direction, which is necessary to sustain them; stronger blows cause the reaction to overbalance

the excess of their specific gravity over that of the air, and they rise with the difference.

73. When a body *floats on the surface of water*, it displaces as much weight of water as is equal to its own weight. Thus, if I place a wooden block weighing four ounces in a tumbler of water even full, just four ounces of the water will run over, as we may ascertain by collecting and weighing it. Upon this principle ships float on water. In proportion as we lade the ship, it sinks deeper and deeper, the weight of water displaced always being exactly equal to the weight of the ship and cargo. The actual weight of the ship and cargo may be easily ascertained on this principle; for if we float the ship into a dock of known size, containing a given quantity of water, the weight of the ship and cargo may be determined from the rise of the water in the dock. A boy wished to find the tonnage of his boat. He therefore loaded it as heavy as it would swim, and then transferred it to a small box which he had made, and of which he knew the exact dimensions. He then poured into the box a pound of water at a time, and when it had settled to a good level, he made a mark at the water line, and adding one pound of water at a time, he thus had marks at different heights, from one pound up to twenty. He found that four pounds of water were amply sufficient to float his boat, and when the boat was laid upon it, the water rose on the sides to the nineteenth mark. Consequently the boat had raised the water fifteen

marks, and its weight was of course fifteen pounds; for it weighed just as much as the water would have weighed which it would have taken to raise the level from the fourth to the nineteenth mark.

Fig. 41.



Sec. 3. *Of the* Motion *of Fluids.*

74. That part of hydrostatics which treats of the mechanical properties and agencies of running water, is called *Hydraulics*, and machines carried by water, or used for raising it, *Hydraulic machines*. It embraces what relates to water flowing in open channels, as rivers and canals; or in pipes, as aqueducts; or issuing from reservoirs in jets and fountains; or falling, as in dams and cascades; or oscillating in waves. A river or canal is water rolling down hill, and would be subject to the same law as other bodies descending inclined planes, were it not for the numerous impediments which oppose the full operation of the law. Now a body rolling down an inclined plane has its motion constantly accelerated, like a body falling perpendicularly, gaining the same speed in descending the plane that it would in falling through the perpendicular height of the plane. Hence when a body rolls down a long plane without obstruction, it soon acquires an immense velocity, as is seen in a rock rolling down a long hill. In the same manner, a body of water descending in a river constantly tends to run faster and faster, and would soon acquire a most destructive momentum, were it not retarded by numerous counteracting causes, the chief of which are the friction of the banks and bottom, and the resistance occasioned by its winding course, every turn opposing an impediment of more or less force. By such a circuitous route two benefits are gained—the rapidity of the

stream is checked, and its advantages are more widely distributed. A river flows faster in the channel, towards the middle, than near the banks, because it is less retarded by friction; and during a freshet the rapidity is greatly increased, because since the waters that are piled on the original bed are subject to little friction, they exhibit something of the accelerated motion of bodies rolling freely down inclined planes. A very slight fall is sufficient to give motion to water where the impediments are slight. The Croton Aqueduct, that waters the city of New York, falls but one foot in a mile. Three feet fall per mile makes a mountain torrent. Some rivers do not fall more than 500 feet in 1000 miles, or a foot in two miles, and require a number of days, or even weeks, to pass over this distance.

75. The Aqueducts which the ancient Romans and Carthaginians built for watering their cities, were among the greatest of their works, some of which have remained until the present day. Large streams were conducted for many miles sometimes not less than a hundred, in open canals, carried through mountains and led over deep valleys, on stupendous arches of masonry. Some have supposed that the ancients must have been unacquainted with the principle, that water flowing in pipes will rise as high as its source, since, had they known this, they might have conveyed water in pipes instead of such expensive structures; these might have ascended and descended, following all the inequalities of the face of the country, provided they were in no part higher than the head or spring. It is found, however, that they were acquainted with the principle, but preferred to construct their aqueducts of open channels rather than pipes. Suitable pipes, at that age, would have been very costly. They are apt also to become clogged; and although they might have followed the inequalities of hills and valleys, yet when they descended and ascended far from the general level, they would be obliged to encounter an enormous pressure, since, in a column of water, the pressure on any part is proportioned to the depth below the surface of the water, increasing five hundred pounds to the square foot for every eight feet of descent. A pipe, therefore, fifty-feet deep and full of water, would have to bear a pressure at the lower part of more than three thousand pounds to the square foot, and must be made proportionally strong, and would be apt to leak at the joints. Even at the present day, it is found more eligible to water cities by open aqueducts than by pipes, as is done in the new Croton Water Works for watering the city of New York. Here an artificial river of the purest water is conveyed from the county of Westchester, forty-one miles above the city, to a vast reservoir capable of holding 150,000,000 of gallons, where it has opportunity to deposit any sediment or impurities it may have taken up on its way, and to absorb air, which gives it life and briskness. From the reservoir it is distributed to all parts of the city in pipes, affording an ample suppy for domestic uses, for watering and washing the streets, and for extinguishing fires.

76. When a plug is removed from the top of one of the pipes of an aqueduct, the water spout upward in a jet; for, since water thus situated tends to rise as high as its source, it will spout to that height when unconfined. At least it would ascend to that height

were it not for the resistance of the air, which prevents its attaining that full height. It is on this principle that *fountains* are constructed. If we open a vent in the side of a water-pipe, so as to let the jet out obliquely, it will form the curve of a parabola; and by letting out the jet through different orifices, the curves may be varied, and beautiful and pleasing figures exhibited, as is shown at the Park Fountain in the city of New York.

77. In building tall or deep cisterns, we must remember, that the pressure on any part of the cistern increases with the depth, and hence that the lower parts require to be made stronger and closer than the upper, else they will either burst in pieces or leak. A philosopher wishing to provide a constant supply of water near his house, constructed a large cistern six feet high, and contrived to convey a small stream of water to the top which kept it always full and running over by a waste-pipe. In the side of the cistern he inserted two large stop-cocks of equal size, the first, one foot, and the other four feet from the top, supposing that he might, in a given time, draw off either one gallon or four gallons; but he was surprised to find that he could obtain from the lower stop-cock only *twice* as much as from the upper. How, thought he, is this consistent with the principle that the pressure is proportioned to the depth? If it presses against the side of the cistern at the lower level four times as much as at the upper, why do not four times as many gallons run out when the stopper is opened? On reflection, however, he perceived that the pressure on the side must be proportioned to the *momentum*, which depends on two things—the quantity of matter and the velocity; and of course that twice the quantity of water flowing with twice the velocity, would have just four times the momentum. Hence he learned the grand principle, that in a column of water kept constantly full, the quantity discharged from any orifice in the side, is proportioned to the *square root* of the depth below the surface of the fluid. So that, to draw off twice as much, we must make the opening four times as deep, and to draw off three times as much, we must make it nine times as deep.

78 The philosopher tried another experiment with his cistern. He turned off the run of water that supplied the cistern, and then opened the upper stop-cock, and found it took just five minutes to draw off the water to that depth. He then let in the run that supplied the cistern and kept it constantly full. Now opening the same orifice again, and drawing off for five minutes more, he found that he caught just twice as much water as before. From this he inferred, that if a vessel discharges a certain quantity of water in emptying itself to a certain level, it will discharge twice as much in the same time, when the vessel is kept constantly full.

79. Water issues from the bottom or side of a vessel with the same force that it would acquire by falling through the perpendicular height of the column. It would therefore seem to make no difference whether we let water fall upon a water-wheel from the top of a cistern, or whether we raise a gate at the bottom of the column, and let the water issue so as to strike the wheel there, since it would strike the wheel in both cases with the same velocity, except what might be lost in the falling column by the resistance

of the air. A waterfall like that of Niagara, where an immense body of water rolls first in *rapids* down a long inclined plane, and then descends perpendicularly from a great height, affords one of the greatest exhibitions of mechanical power ever seen. The Falls of Niagara contain power enough to turn all the mills and machinery in the world. They waste a greater amount of power every minute, than was expended in building the pyramids of Egypt; for, in that short space of time, millions of pounds of water go over the falls, and each pound, by the velocity it gains in falling first down the rapids, and then perpendicularly, acquires resistless energy. Water falling one hundred feet would strike on every square foot with a force of more than six thousand pounds.

80. Man imitates the power of the natural waterfall when he builds a dam across a stream, raising it above its natural level, and then turning aside more or less of it into a narrow channel, makes it acquire momentum while regaining its original level. When it has gained the requisite force, he turns it upon a water-wheel usually of great size, from which, by means of machinery, the force is distributed wherever it is wanted, and so applied as to do all sorts of work. When a run of water first strikes a wheel at rest, it strikes it with its full force; but as the wheel moves before it, the effect of the force is diminished, and if the wheel acquired the same velocity as the stream, the force would become nothing. The wheel is retarded by making it do more and more work, or carry a greater weight, until it acquires a uniform motion at a certain rate, which ought to be that at which the force of the stream produces the greatest effect. This is

in some cases when the wheel moves half as fast as the stream. That a current of water or of wind strikes an object with less force when the object is moving the same way, is a general principle. Thus, when a steamboat is moving directly before the wind, she would derive little aid from sails unless the wind were high, for she would "run away from the breeze;" that is, the wind would produce no effect any farther than its velocity exceeded that of the boat, and if it were just equal to that, the effect would be absolutely nothing. A man in a balloon, carried forward by a wind blowing a hundred miles an hour, would speedily acquire the same velocity with the wind, and therefore appear to himself to be all the while in a calm. Although the earth is constantly revolving round the sun with inconceivable rapidity, yet as we have the same velocity we seem to be at rest.

Sec. 4. *Of the Remarkable Properties combined in Water.*

81. Water combines in itself a variety of useful properties, all designed for the benefit of man. First, *Natural History* leads us to contemplate it in its various aspects. It covers about three fourths of the globe, and is distributed into oceans, seas, and lakes, rivers, springs, and atmospheric vapor. By the agency of heat, water is constantly rising in vapor on all parts of the ocean. This mingles with the air in an invisible elastic state, being separated in the process of evaporation from its salt and every other impurity. More or less of it is conveyed over the land by winds, and falls upon it in dew, and rain, and snow. A part of this filters through the sand, runs down in the

crevices of rocks, and collects in pure fountains not far below the surface, where it may be easily reached in almost every place, by digging wells. In various places it flows out by its own pressure, in springs and streamlets, which unite in rivulets, and these in rivers, which return the water to the sea. But rivers as they run are made to impart fertility, and to furnish an avenue by which vessels and steamboats may penetrate into the heart of every country, and convey to the remotest cities the riches of every clime. As rivers furnish an entrance into the interior of countries, so the ocean forms the great highway between nations, and unites all nations in the bands of commerce. Still further, to serve the grand cause of benevolence, the ocean is filled with living beings innumerable, which are not, like land animals, confined to the surface, but occupy the depth of at least six hundred feet, and thus enjoy a far more extensive domain than the part of the animal creation that inherits the land.

82. Secondly, *Chemistry* regards water with no less interest than Natural History. Its very *composition* is admirable, being constituted of two substances, oxygen and hydrogen, which, when united with heat, are separated in the gaseous form, and each possesses the most curious and wonderful properties. Oxygen is found as an element in nearly all bodies in nature; it is the part of atmospheric air which sustains all animal life and supports all fires; and it is the most active agent in producing all the changes of matter which take place both in nature and art. Hydrogen gas is the most combustible of all bodies, and is in fact what we see burning in nearly every sort of flame. As a *solvent*, water performs the most useful service to man, removing every impurity from his clothing or his person, dissolving and preparing his food, and entering largely into nearly all the processes of the arts. By the different *states* which water assumes, of ice and snow and vapor, it performs important offices in the economy of Nature, as well as in its native state of a liquid. These changes of state regulate the temperature of the atmosphere, and preserve it from dangerous excesses both of heat and cold. On the one hand, on the approach of winter in cold climates, water changes to ice and gives out a vast amount of heat that kept it in the liquid state; and on the approach of summer, to check the too rapid increase of temperature, the same heat which was given out when water was changed into ice, is now absorbed and withdrawn form the atmosphere, as ice is changed back to water. Moreover, during the heat of summer, the evaporation of water, a very cooling process, checks the tendency to excess of the heat of the sun, and guards us from all danger on that hand. Ice, by covering the rivers, keeps them from freezing except on the surface; and snow is a warm and downy covering thrown over the earth to protect the vegetable kingdom by confining the heat of the earth.

83. Thirdly, it is the province of *Physiology* to contemplate the relations of water to the vegetable and animal kingdoms. Water is the chief food of plants, which it nourishes, either by supplying a part of their elements, or by dissolving their nutriment, and thus preparing it for circulation; and hence water is indispensable to the life and growth of all vegetables. To animals and man, it furnishes the best and only necessary beverage; it is the medium by which our food is prepared; and it acts medicinally in various ways, both internally and externally.

84. Finally, the *Mechanical* relations of water, such as those we have been considering in the preceding pages, are hardly less remarkable and important than the rest. By its *mobility*, it maintains its own level and keeps itself within its prescribed bouuds; by its *buoyancy*, it furnishes a habitation for numerous tribes of fishes, and lays the foundation of the whole art of navigation; by its *pressure* in all directions, it gives the first indication of containing great mechanical energy, which is more fully developed in the immense force of running water, which may be regarded as a repository of power kept in readiness for the use of man; and, finally, by its property of being converted into ***steam***, it discloses a new and inexhaustible fountain of mechanical force, which man may employ in any degree of intensity to perform the humblest and the mightiest of his works.

CHAPTER IV.

PNEUMATICS.

PROPERTIES OF ELASTIC FLUIDS—AIR-PUMP—COMMON PUMP—SYPHON—BAROMETER—CONDENSER—FIRE ENGINE—STEAM AND ITS PROPERTIES—STEAM ENGINE.

85. PNEUMATICS *is that branch of Natural Philosophy which treats of the pressure and motion of elastic fluids.* Elastic fluids are those which are capable of contracting or dilating their volume under different degrees of pressure. They are of two kinds, *gases* and *vapors.* Gases constantly retain the elastic invisible state; vapors remain in this state only when heated to a certain degree, but return to the liquid state when cooled. Common air is a gas, steam a vapor. Although there are many different gases and vapors known to Chemistry, yet air and steam are the elastic fluids chiefly regarded in Natural Philosophy. Air and steam are both commonly invisible; but air, when we look through an extensive body of it, appears of a delicate blue or azure color, which habit leads us to refer to distant objects seen through it. It is not the distant mountain that is blue, but the air through which we see it. Air also sometimes becomes visible when ascending and descending currents mix, as over a pan of coals, or a hot chimney, when we see a wavy appearance, which is air itself. Vapors also exhibit naturally some variety of colors, as yellow and purple; but the vapor of water or steam is usually invisible. We must carefully distinguish between elastic vapor and the *mist* which issues from a tea-kettle. This is vapor *condensed*, or restored to the state of water, and it is only at the mouth of the tea-kettle, where it is hot, that it is in the state of steam, and there it is invisible.

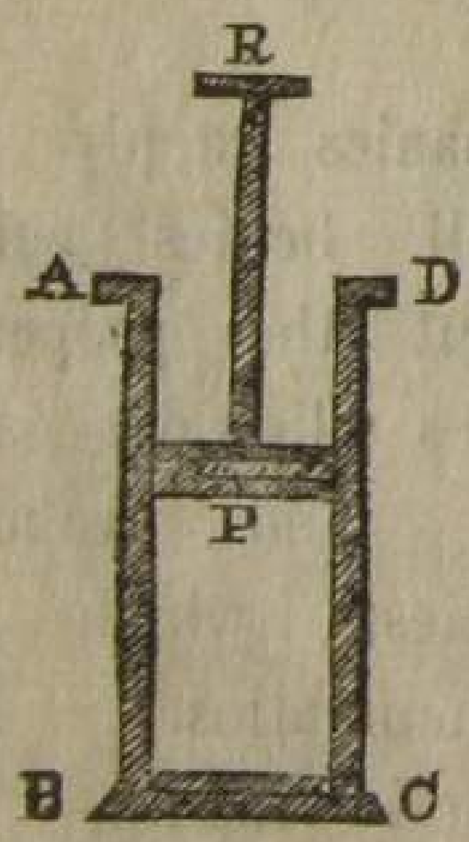
86. The general principles of mechanics apply to liquids and gases, as well as to solids, all bodies being subject alike to the laws of motion; but the property of *mobility of parts*, which characterizes liquids, and of *elasticity* which characterizes gases and vapors, gives them severally additional properties, which lay the foundation of hydrostatics and pneumatics. Although we do not usually *see* gases and vapors, yet we find in them properties of matter enough to prove their materiality. In common with solids, they have impenetrability, inertia, and weight; in common with liquids, they are subject to the law of equal pressure in all directions, and when confined they transmit the

effects of a pressure or blow upon any one part of the vessel, to all parts alike; but in their elasticity, they differ from both solids and liquids. Since air and steam are the elastic fluids with which Natural Philosophy is chiefly concerned, we shall consider each of these separately. 字合ハ

Sec. 1. *Of Atmospheric Air.*

87. We may readily verify upon atmospheric air, the various properties of an elastic fluid. Its impenetrability, or the property of excluding all other matter from the space it occupies, will be manifested if we invert a tall tumbler in water. It will permit the water to occupy more and more of the space as we depress it farther, but will never cease to exclude the water from a certain portion of the tumbler which it occupies. We may render this experiment more striking, by employing a glass cylinder and piston, as is represented in Fig. 42. Let A B C D represent a hollow cylinder, made perfectly smooth and regular on the inside, and P a short solid cylinder, called a *piston*, moving up and down in it air-tight, and R the piston-rod. Now when we insert the piston near the top of the cylinder, the space below it is filled with air. On depressing the piston, the air, on account of its elasticity, gives way, and we at first feel but little resistance; but as we thrust it down nearer to the bottom, the resistance increases, and finally becomes so great that we cannot depress it any farther by the strength of the hand. If we apply heavy weights, we may force it nearer and nearer to the bottom of the cylinder; but no power will bring it into contact with the bottom. This experiment may be so varied as to prove several things. First, it shows that air is impenetrable; secondly, that it may be indefinitely compressed—all the air of a large room might be reduced to a thimble-full, and on removing the pressure, it would immediately recover its original volume; thirdly, that the resistance increases the more it is compressed. We will graduate the cylinder into a thousand equal divisions, by horizontal marks numbered from the bottom upward from one to one thousand, and place on the pan at the top of the piston-rod a few grains, so as just to overcome the friction of the piston against the sides of the cylinder. We will now put on weights successively, until we have sunk the piston half way, when the air occupies five hundred instead of a thousand parts of the cylinder. If we double the weight, it will not carry the piston the same distance as before, that is to the bottom, but only through half the remaining space, so that the air now occupies one fourth of the capacity of the cylinder. If we double the present weight, it will again be compressed one half, so as to fill but an eighth part of the cylinder. We find, therefore, that a double force of compression, always reduces to half the former volume. This law is expressed by saying, that *the volume of a given weight of air is inversely as the compressing force.*

Fig. 42.



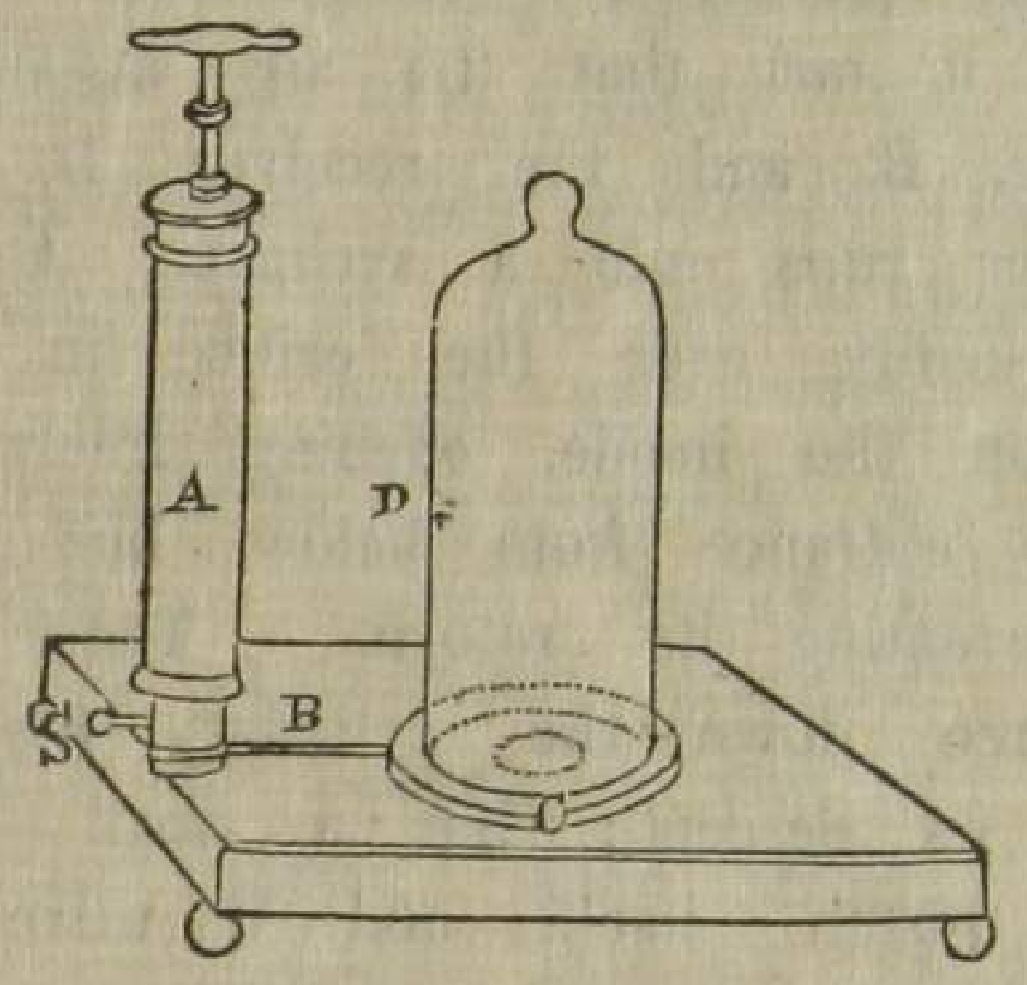
88. Air has the property of *inertia*. It remains at

rest unless put in motion by some force, and continues to move until some adequate force stops it. When put in motion by any moving body, it destroys just as much motion in that body as it receives from it; and it loses its motion only as it imparts the same amount to some other matter. A large body moving swiftly through the air meets with great resistance; but whatever motion it loses, it imparts to the air, which might be sufficient to produce a high wind. Air also has *weight*. If we balance a light bottle, containing a hundred cubic inches, in a delicate pair of scales, having just pumped out all the air from the bottle, and then open the stopper, and admit the air again, we find the vessel has gained in weight 30½ grains. We call air and all other gases and vapors *fluids*, because their particles move so easily among themselves. The particles of elastic fluids have no cohesion, but on the other hand, have a mutual repulsion, which causes them to fly off from each other as soon as the compressing force is removed or diminished.

89. The lower portions of air which lie next to the earth, are pressed by the whole weight of the atmosphere, which is found to amount to the enormous force of 15 pounds upon every square inch; or above 2,000 pounds upon a square foot. This force would be insupportable to man and animals, were it not equal in all directions, entering into the pores of bodies, and thus being everywhere nearly in a state of equilibrium. It is only when we withdraw the air from a given space, so as to leave the surrounding air unbalanced, that we see marks of this violent pressure.

90. THE AIR-PUMP.—Various properties of the air are exhibited by this beautiful and interesting apparatus. A simple form of the Air-Pump is shown in figure 43. A represents a cylinder having a piston moving up and down in it. The cylinder communicates by an open pipe, B, with the plate of the pump, C, opening into the receiver, D, which is a glass vessel ground at the bottom so as to fit the plate of the pump air-tight. At S is a small screw which opens or closes a passage into the pipe, B, by which air may be let into the receiver when it has been withdrawn by the pump.

Fig. 43.



In order to understand how the pump extracts the air from the receiver, or *exhausts* it, it is necessary first to learn the structure of a *valve*. A valve is any contrivance by which a fluid is permitted to flow one way, but prevented from flowing the opposite way. A common hand bellows affords an example of a valve, in the little clapper on the under side. When the bellows is opened, the clapper rises and the air runs in; and when the bellows is shut, the clapper closes upon the orifice, and as the air cannot escape by the same way it entered, it is forced out by the nozzle of the bellows. In the bottom of the cylinder, A, in figure 43, there is a small hole, like a pin hole. On drawing up the piston, the space below it would be a vacuum were it not that the air instantly rushes in from the pipe, B, and the receiver, D, and fills the space, as water runs into a syringe. A strip of oiled silk is tied firmly over the orifice in the bottom of the cylinder on the inside, opening freely upward when this air seeks entrance from below, but shutting downward and preventing its return. Then if we should attempt to force down the cylinder, the air below it would resist its descent; but a small hole is made through the piston itself, and a valve tied to the upper side opening upward; so that on depressing the piston, the air below makes its way through the valve and escapes into the open space above. We raise the piston, and the air in the receiver follows it through a valve in the bottom of the cylinder opening upward. The original air of the receiver being now expanded equally through the receiver, the cylinder, and the connecting-pipe, we thrust down the piston, and the portion of the air that is contained in the cylinder is forced out through the piston. We again raise the piston, and the remaining air of the receiver expands itself as before through the vacuum; we dedress the piston, and a second cylinder full of air is withdrawn. By continuing this process, we rarefy more and more the air of the receiver, every stroke of the piston leaving what remains more rare than before. Still, on account of the elasticity of air, what remains in the cylinder will always diffuse itself through the whole vessel, so that we cannot produce a complete vacuum by the air-pump.

91. Several experiments will illustrate the great *pressure of the atmosphere*, when no longer balanced by an equal and opposite force. We shall find the receiver, when exhausted by the foregoing process, held firmly to the plate of the pump so that we cannot remove it until we have opened the screw, S, and admitted the air; then the downward force of the air being counterbalanced by an equal force from within the vessel is easily taken off. The *Magdeburg Hemispheres*, represented in figure 44, afford a striking illustration of the force of atmospheric pressure. When they have air within as well as without they are easily, when joined, separated from each other; but let us now put them closely together and screw the ball thus formed upon the plate of the pump, exhaust the air, and close the stop-cock so as to prevent its return. We then unscrew the ball from the pump, and screw on the loose handle; the hemispheres are pressed so closely together that two men, taking hold by the opposite handles, can hardly pull them apart. Hemispheres four inches in diameter would be held together with a force equal to 188 pounds. Otto Guericke, of Magdeburg, in Germany, who invented the air-pump and contrived this experiment, had a pair of hemisphers constructed, so large that sixteen horses, eight on each side, were unable to draw them apart. A pair only two feet in diameter, would require to separate them a force equal to 6785 pounds. If our bodies were not so penetrated by air, that the external pressure is counterbalanced by an equal force from

Fig. 44.

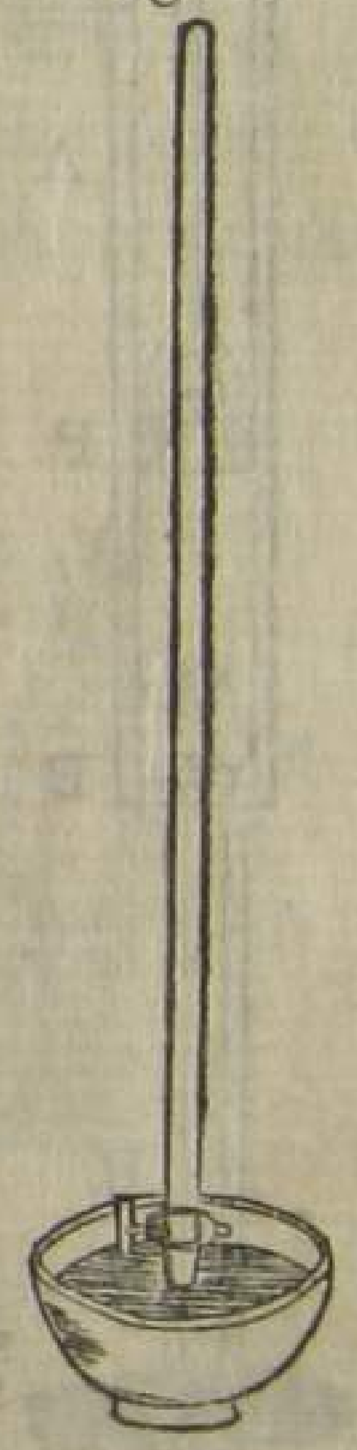
within, we should be crushed under the weight of the atmosphere; for a middle sized man would sustain a pressure of about 14 tons.

92. If we take a *square bottle*, fit a stop-cock to it, and exhaust the air, the pressure on the outside will crush it into small fragments, with a loud explosion. It is prudent to throw a towel or handkerchief loosely over it, to prevent injury from the fragments. A *square* bottle is preferred to a round one, because such a figure has less power of resistance. The *lap-stone* experiment may be tried without an air-pump, and affords a pleasing illustration of the force of atmospheric pressure. Cut out a circular piece of sole leather, five or six inches in diameter. Through a hole in the center draw a waxed thread to serve as a handle. Soak the leather in water until it is very soft and pliable; then, on applying this to any smooth, clean surface, as that of a lap-stone, a slab of marble, or a table, it will adhere with such force, that we cannot lift it off; but when we pull upward, the heavy body to which it is attached will be lifted with it. We may, however, *slide* it with ease, because no force acts upon it to prevent its motion in this direction, except simply the adhesion of the surfaces. Flies are said to ascend a pane of glass on this principle, by applying their broad feet firmly to the glass, which are held down by the pressure of the atmosphere. When we apply a sucker, and exhaust it with the mouth, the fluid rises because it is forced up by the pressure of the atmosphere on its surface. When we draw in the breath, the lungs are expanded like a pair of bellows. Thus the air runs from the sucker into the lungs, and forms a vacuum in the sucker. Immediately the pressure of the atmosphere on the surface of the fluid, not being balanced in the tube, forces the fluid up the tube and thence into the mouth.

Fig. 45.

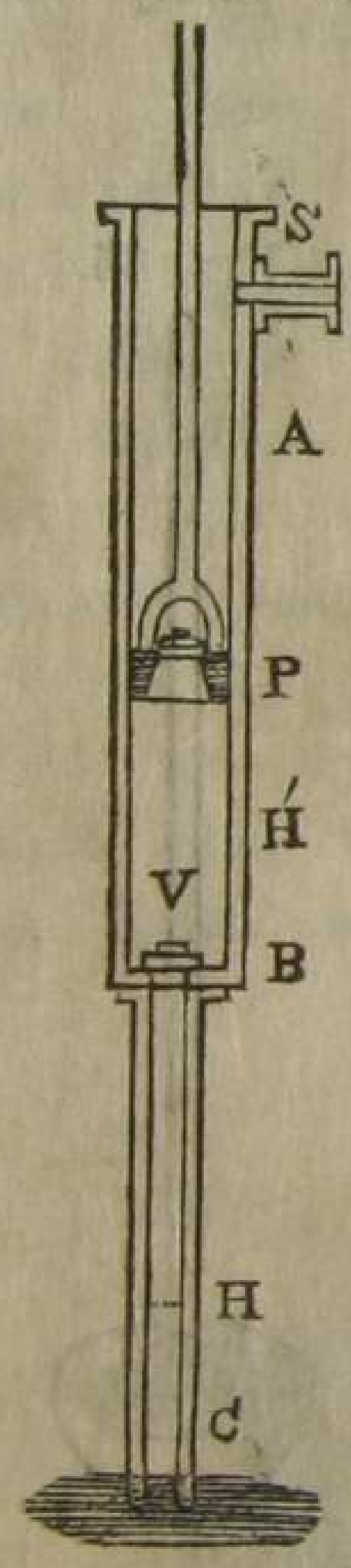
93. If we fill a vial with water, and, placing one thumb on the mouth, invert it in a tumbler partly full of water, the water will not run out of the vial, but will remain suspended, because there being no air at the top of the column to balance the pressure that acts at the mouth of the vial, the column cannot descend. If, however, instead of the vial, we should employ a pipe more than 33 feet long, on filling it and inverting it, as was done with the vial, the water would settle to about 33 feet, and there it would rest; for the pressure of the atmosphere is capable of sustaining a column of water only 33 feet high. Were it higher than this, it would be more than a counterpoise for that pressure, and would overcome it and sink; and were it lower than that, it would be overcome by that pressure, and rise until it exactly balanced the force of the atmosphere. Instead of filling the pipe with water, we will attach a stop-cock to the open end, screw it on the plate of the air-pump, and exhaust the air. We will now close the stop-cock, and removing the tube

Fig. 46.



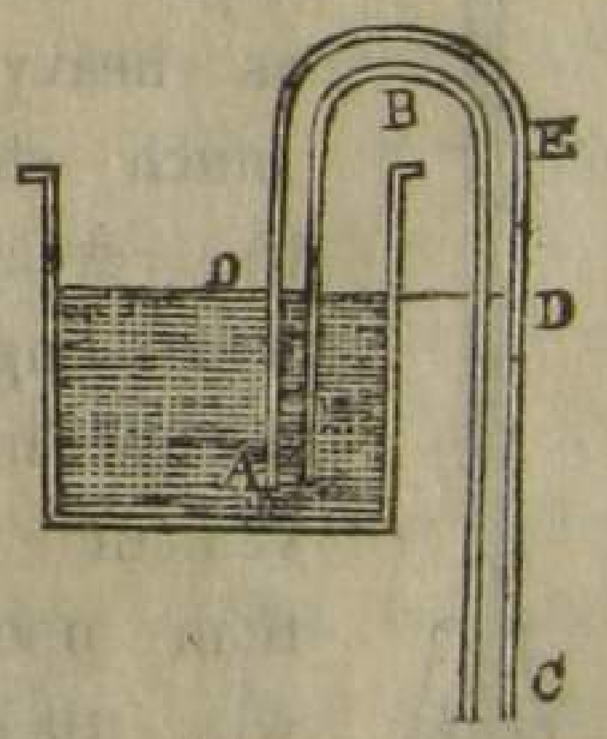
from the pump, will place the lower end of the pipe in a bowl of water. On opening the stop-cock the water will rush into the pipe, and rise to about the same height as before, namely, about 33 feet, where it will rest. In both cases, there is an empty space or vacum in the upper part of the pipe above the column of water.

Fig. 47.



94. This experiment illustrates the principle of the *common pump*, of the *syphon*, and of the *barometer*. Let us first see how water is raised by the pump. This apparatus usually consists of two pipes—a larger, A B, above, and a smaller, H C, below. The piston moves in the larger pipe, and the smaller pipe descends into the well. On the top of the latter, where it enters the former, is a valve, V, opening upward. Suppose the piston, P, is down close to this valve. On raising it, the air from the lower pipe diffuses itself into the empty space below the piston, becomes rarefied, and no longer balances the pressure of the atmosphere on the surface of the well. Consequently, the water is forced up until the weight of the column, together * with the weight of the rarefied air, restores the equilibrium. Suppose by the piston being drawn up to P, the water rises to H; then the column, H C, and the rarefied air in both pipes together, first counterbalance the weight of the atmosphere. On raising the piston still higher, the water rises above H, but would not probably reach the valve, V, by a single elevation of the piston. We therefore thrust down the piston to repeat the operation. The air between V and P is prevented from returning into the lower pipe, by the valve, V, which shuts downward; but the enclosed air, when compressed by the descending piston, lifts a valve in the piston, as in the air-pump, and escapes above. On drawing up the piston a second time, suppose that the water rises into the upper pipe above the valve, V, then on depressing the piston again, this water, pressed on by the piston, lifts its valve, and gets above it. Finally, on drawing up the piston again, this same water is lifted up to the level of the spout, S, where it runs off. We exert just as much force in exhausting the air, as the pressure of the atmosphere exerts in raising the water. It requires, therefore, just as much force to raise a given quantity of water by the pump, as to draw it up in a bucket; and the only question is, which is the most convenient mode of applying the force.

Fig. 48.



95. The *Syphon* is a bent tube, having one leg longer than the other, as in Fig. 48. If we dip the shorter leg into water and suck out the air from the tube, the water will rise, pass over the bend, flow out at the open end, and continue to run until all the water in the vessel is drawn off. Here the pressure of the atmosphere on both mouths of the tube is the same; but in each arm, that pressure is resisted by the weight of the column of water above it, and more by the longer than by the shorter column. This is the same thing as though the pressure were less upon the outer

than upon the inner mouth; and it is easy to see that if the water in a tube is pressed one way more than the other, it will flow in the direction in which the pressure is greatest. The syphon is used in drawing off liquors; and the water in aqueducts is sometimes conveyed over hills on the principle of the syphon. But we must remember, that water could not be raised by it more than 33 feet; for when the bend is 33 feet above the level of the fountain, then the column in the shorter arm balances the pressure of the atmosphere at the mouth of the tube in the well, and leaves no force to drive forward the column into the descending arm.

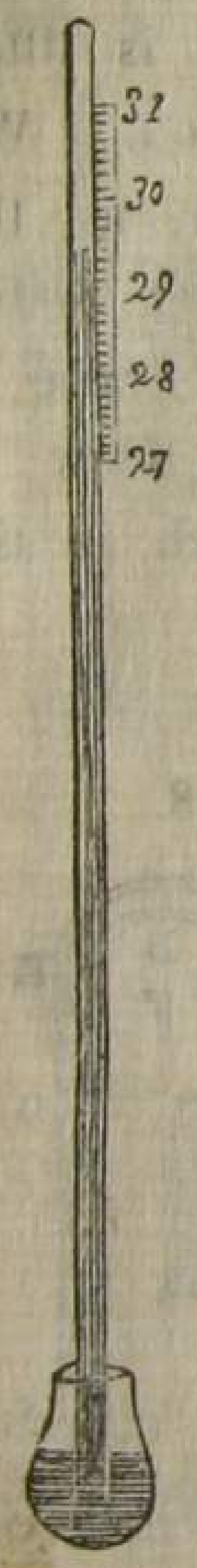


Fig. 49.

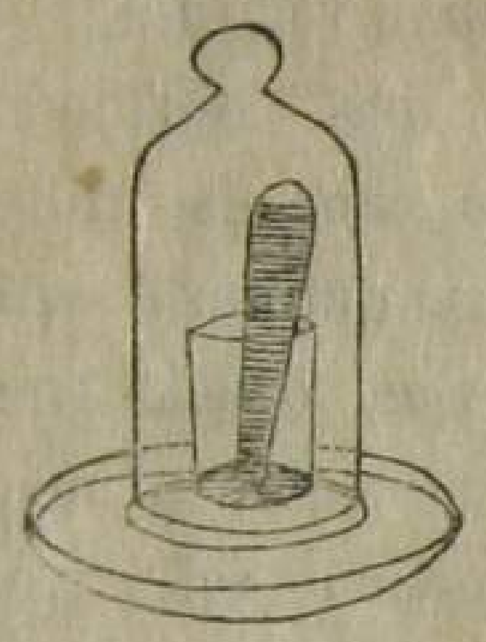
96. The *Barometer* is an instrument for measuring the pressure of the atmosphere. If the atmosphere be conceived to be divided into perpendicular columns, the barometer measures the weight of one of these by the height of a column of quicksilver which it takes to balance it. Quicksilver is 13½ times as heavy as water, and therefore a column so much shorter than one of water, will balance the weight of an atmospheric column. This will imply a column about 2½ feet, or 30 inches high; and it will be much more convenient to experiment upon such a column, than upon one of water 33 feet high. We will therefore take a glass tube about three feet long, closed at one end and open at the other, fill it with quicksilver, and placing the finger firmly on the open mouth, we will insert this below the surface of the fluid in the small cistern, as represented in the figure.

On withdrawing the finger, the quicksilver in the tube will settle to the height of about thirty inches, where it will rest, being sustained by the pressure of the atmosphere on the surface of the fluid in the cistern, to which force its weight is exactly equal. The space above the quicksilver, is the best vacuum we are able to form. It is called the *Torricellian* vacuum, from Torricelli, an Italian philosopher, who first formed it. The weight of a column of atmospheric air is different in different states of weather, and its variations will be indicated by the rising and falling of the quicksilver in the barometer. Any increase of weight in the air will make the fluid rise; any diminution of weight will make it fall. Hence, these variations in the height of the barometric column, show us the comparative weight and pressure of the atmosphere at any given time. By applying to the upper part of the tube a scale divided into inches and tenths of an inch, we can read off the exact height of the quicksilver at any given time. Thus, the fluid, as represented in the figure, stands at 29.4 inches.

97. The barometer is one of the most useful and instructive of philosophical instruments. By observing it from time to time, we may find how its changes are connected with the changes of weather, and thus it frequently enables us to foretell such changes. If, for example, we should observe a sudden and extraordinary fall of the barometer, we should know that a high wind was near, possibly a violent gale. To seafaring men, the barometer is a most valuable instrument, since it enables them to foresee the approach of a gale, and provide against it. As a general fact, the rising of the barometer indicates *fair*, and its falling, *foul* weather.

98. The foregoing considerations relate to the weight and pressure of the atmosphere; but the air-pump also affords us interesting illustrations of the *elasticity* of air. We will fill a vial with water, and invert it in a tumbler partly filled with the same fluid. We will now place the tumbler and vial on the plate of the air-pump, and cover it with a receiver, and exhaust the air. Soon after we begin to work the pump, we shall see minute bubbles of air making their appearance in the water, which will rise and collect in a bubble at the top of the column. The bubble thus formed, will expand more and more as the exhaustion proceeds, until it expels the water, and occupies the whole interior of the vial. This will happen much sooner if we let in a bubble of air at first, and do not wait for it to be extricated from the water; but this extrication of air from the water, is itself an instructive part of the experiment, as it shows us that water contains a large quantity of air, held in combination with it by the pressure of the atmosphere on the surface, which pressure pervades all parts of the fluid alike. But on withdrawing this pressure gradually from the surface of the water, the particles of air imprisoned in the pores of the water escape, and collect on the top. The bubble thus formed, will expand more and more as the pressure is still farther removed, until it drives down the water and fills the whole vial. If we turn the screw S of the pump (Fig. 43) and let in the air, the pressure on the surface of the water in the tumbler being restored,

Fig. 50.



the water will be forced up the vial again, and the air will be reduced to its original bubble. If we place any porous substance, as a piece of brick, or a crust of bread, in a tumbler, and fill the tumbler with water, (attaching a small weight to the bread to keep it under) we shall see, in like manner, an unexpected amount of air extricated when we place it under the receiver, and remove the atmospheric pressure from it, so as to permit it to assume the elastic state. Liquids boil at a much lower temperature than usual, when the pressure of the atmosphere is removed from them. Thus, if we take a tumbler half full of water, no more than blood-warm, set it under the receiver, and exhaust the air, it will boil violently.

99. Air is the medium of *combustion*, of *respiration*, and of *sound*. If we place a lighted candle under the receiver of an air-pump, and exhaust the air, the light will immediately go out, showing that bodies cannot burn without the presence of air. Nor without this can animals breathe. A small bird placed beneath the receiver, will cease to breathe as soon as the air is exhausted. If a bell, also, is made to ring under a receiver, the sound will grow fainter and fainter as the air is withdrawn, and finally be scarcely heard at all. The *buoyancy* of air, like that of water, enables it to support light bodies. In a vacuum, the heaviest and lightest bodies descend to the earth with the same velocity. If we suspend a guinea and a feather from the top of a tall receiver, exhaust the air, and let them fall at the same instant, the feather will keep pace with the guinea, and reach the plate of the pump at the same instant.

100. THE CONDENSER.—A piston and cylinder may be so contrived as to pump air into a vessel instead of

pumping it out. Figure 51 represents a condensing syringe, screwed to a box partly filled with water. When the piston is drawn up to the top, above an orifice E in the side, the air runs in at E, which on depressing the piston, is driven forward into the box through a valve, V, which opens inward, but closes outward, and prevents the return of the air. By repeated blows of the piston, more and more air is forced into the box, constantly increasing the pressure on the surface of the water. D is a tube opening and closing by a stop-cock, having its lower end in the water. When the air is strongly condensed, on opening the stop-cock, the water issues from the tube with violence. *Soda Water Fountains* are constructed on this principle. A great quantity of carbonic acid, or fixed air, is forced into a strong metallic vessel, containing a solution of soda, and therefore is subjected to a powerful pressure. A tube connects this vessel to the counter where the liquor is to be drawn, which issues with violence, as soon as vent is given to it, and foams, in consequence of the carbonic acid expanding by the removal of the pressure by which it had been confined. The condenser employed for this purpose, is called a *forcing pump*, and differs from the condensing syringe, represented in figure 51, chiefly in being worked by a lever attached to the pision, instead of the naked hand.

Fig 51.

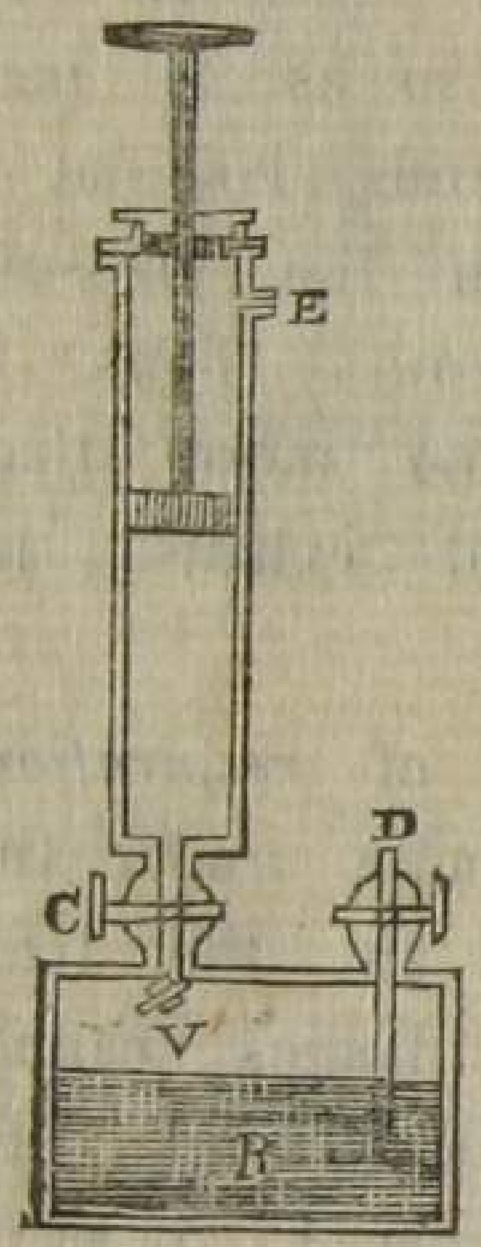
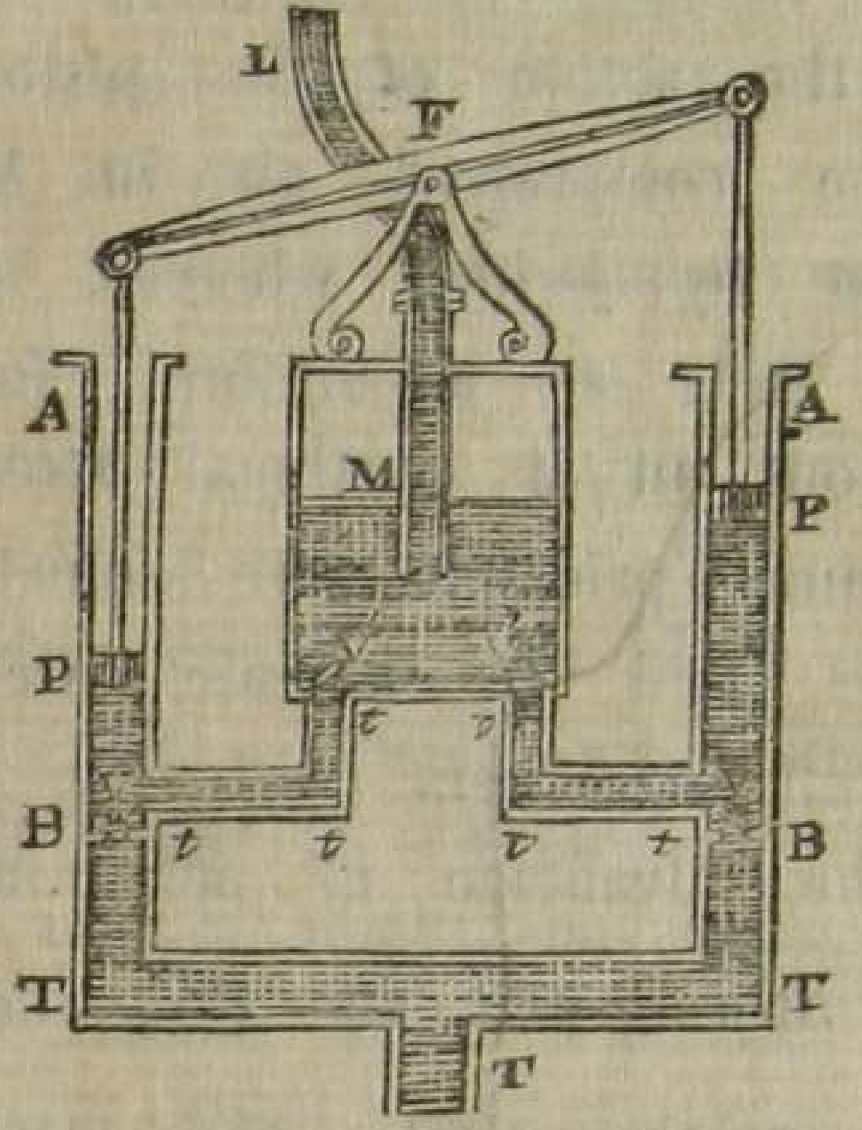


Fig. 52.



101. The *Fire-Engine* throws water by means of two forcing pumps, one on each side, which are worked by the firemen. T represents the hose, or leathern pipe, which leads off to some well or cistern of water, whence the supply is drawn. F is the working beam, to each end of which is attached a piston moving in the cylinder A B. Suppose at the commencement of the process, the left hand piston is down close to the valve V; as it rises, the water follows it from the hose, lifting the valve V, and entering P B below the piston. When the piston descends, it forces the water through a valve into the air-vessel, M. As the water is thrown in by successive descents of the piston, it rises in M, and condenses the air of the vessel into a small space at the top. A second hose, F, dips into the water, and terminates in the farther end in a pipe, which the fireman directs upon any required point, sending the water in a continual stream. The stream might indeed be propelled directly by the action of the pistons, without the intervention of the compressed air in M; but in that case it would go by jerks; whereas, the elasticity of the confined air acts as a uniform force, and makes the water flow out in a continual stream. *Air-springs*, acting on the same principle, are sometimes attached to coaches, and are said to operate well. *Beds* have been filled by inflating them with air instead of feathers, and have the advantage of being always made up.

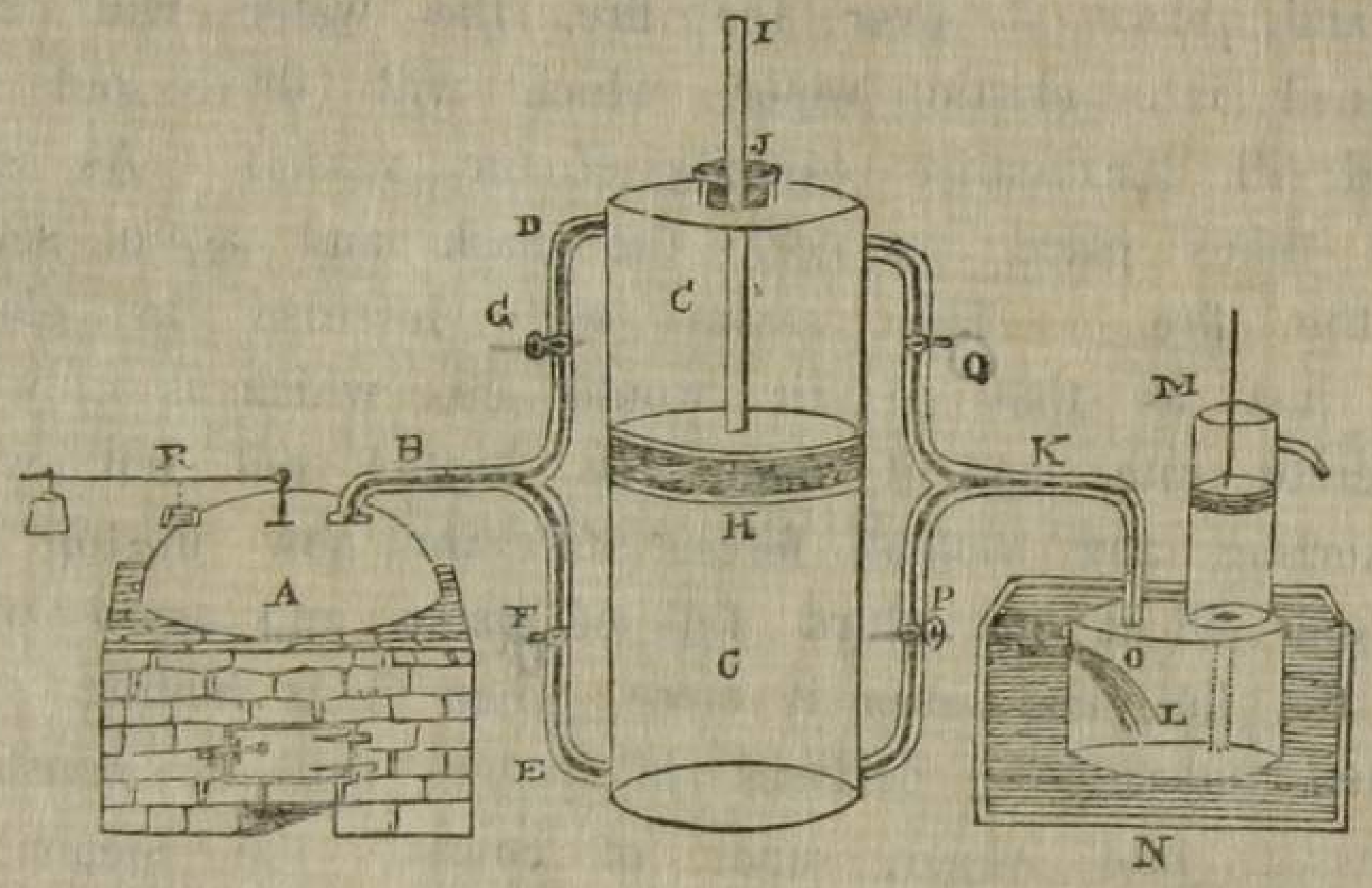
SEC. 2. *Of Steam and its Properties.*

102. Steam, or the elastic fluid which is produced by heating water, owes its mechanical efficacy to its power of suddenly acquiring by heat a powerful elasticity, and then losing it as suddenly, by cold; in the former case, expanding rapidly, and expelling every thing else from the space it occupies; and, in the latter case, shrinking instantly to its original dimensions in the state of water, and thus forming a vacuum. By this means, an alternate motion is given to a piston, which being communicated to machinery, supplies a force capable of performing every sort of labor, and being easily endued with any required degree of energy, is at once the most efficient and the most manageable of all the forces of nature. Thus, if steam be admitted below the piston, in figure 53, when its force accumulates sufficiently to overcome the resistance of the piston, it raises it; and if it then be let in above the piston, it depresses it. When the piston rises, it may be made to turn a crank half round, and the other half when it falls, and thus a

main wheel may be made to revolve, from which motion may be conveyed to all sorts of machinery. The degree of force which steam exerts, depends on the *temperature* and *density* conjointly. If we put a spoonful of water into a convenient vessel, as an oil-flask, and place it over the fire, the water will soon be turned into elastic vapor, which will drive out the air and fill the entire capacity of the vessel. As soon as this takes place, we cork the flask and again set it over the fire. The steam will increase in elastic power, just as that of air would do, which is only at a moderate rate, and it might be heated red hot without exerting any violent force. If we now unstop the flask and fill it one third full of water, and again place it on the fire, and stop it close when it is boiling freely, then successive portions of water will be constantly passing into vapor, and, of course, the steam in the upper part of the vessel will be constantly growing more and more dense. It is important to remember, therefore, that when steam is heated by itself, and not in contact with water, its elasticity increases slowly, and never becomes very great; but when it is heated in a close vessel containing water, which makes to it constant additions of vapor, thus increasing its density, it rapidly acquires elastic force, and the faster the longer the heat is continued, so as shortly to reach an energy which nothing can resist. Such an accumulation of force sometimes takes place by accident in a steam boiler, and produces, as is well known, terrible explosions.

103. If the foregoing principles are well understood, it will be easy to learn the construction and operation of the *Steam Engine*. For the sake of simplicity, we will leave out numerous appendages which

Fig. 53.



usually accompany this apparatus, but are not essential to the main principle. In figure 53, A represents the *boiler*, C the *cylinder*, in which the piston H moves, L the *condenser*, and M the *air-pump*. B is the *steampipe*, branching into two arms, communicating respectively with the top and bottom of the cylinder, and K is the *eduction-pipe*, formed of the two branches which proceed from the top and bottom of the cylinder on the other side, and communicate between the cylinder and the condenser, which is immersed in a well or cistern of cold water. Each branch of the pipe has its own valve, as F, G, P, Q, which may be opened or closed as occasion requires. R is a safety valve, closed by a plate, which is held down by a weight attached to a lever, and sliding on it, so as to increase or diminish the force at pleasure. When the force of the steam exceeds this, it will lift the valve and escape, thus preventing the danger of explosion.

104. Suppose, first, that all the valves are open, and that steam is issuing freely from the boiler. It is easy to see, that the steam would circulate freely through all parts of the engine, expelling the air, which would escape through the valve in the piston of the air-pump, and thus the interior spaces would be all filled with steam. This process is called *blowing off*; it is heard when a steamboat is about leaving the wharf. Next the valves, F and Q, are closed, G and P remaining open. The steam now pressing on the cylinder, forces it down, and the instant when it begins to descend, the stop-cock O is opened, through which cold water meets the steam as it rushes from the cylinder and condenses it, leaving no force below the piston to oppose its descent. Lastly, G and P being closed, F and Q are opened, the steam flows in from the boiler below the piston, and rushes from above into the condenser, by which means the piston is forced up again with the same power as that by which it descended. Meanwhile, the air-pump is playing, and removing the water and air from the condenser, and pouring the water into a reservoir, whence it is conveyed to the boiler to renew the same circuit.

105. In *High Pressure* engines, the steam is not condensed, but discharges itself directly into the atmosphere. The *puffing* heard in locomotives, arises from this cause. High pressure engines are those in which steam of great density, and high elastic power, is used. By this means, a more concentrated force is produced, and the engine may be smaller and more compact;

but unless it is made proportionally stronger, it is more liable to explode, and when it gives way it explodes with great violence.

CHAPTER V.

METEOROLOGY.

GENERAL OBJECTS OF THE SCIENCE—EXTENT, DENSITY, AND TEMPERATURE OF THE ATMOSPHERE—ITS RELATIONS TO WATER—RELATIONS TO HEAT—RELATIONS TO FIERY METEORS.

106. Meteorology *is that branch of Natural Philosophy which treats of the Atmosphere.* In Pneumatics, we learn the properties of elastic fluids in general, on a small scale, and by experiment rather than by observation; but in Meteorology, we extend our views to one of the great departments of nature, and we reason, from the known properties of air and vapor, upon the phenomena and laws of the entire body of the air, or the atmosphere. Meteorology leads us to consider, first, the *description* of the atmosphere itself, including its extent, condition at different heights, and the several elements that compose it; secondly, the relations of the atmosphere to *water*, including the manner in which vapor is raised into the atmosphere, the mode in which it exists there, and the various ways in which it is precipitated in the form of dew, fog, clouds, rain, snow, and hail; thirdly, the relations of the atmosphere to *heat*, embracing the motions of the atmosphere as exhibited on a small scale, in artificial draughts and ventilation; and on a large scale, in winds, hurricanes, and tornadoes;

finally, in the relations of the atmosphere to *fiery meteors*, as thunder and lightning, aurora borealis, and shooting stars.

Sec. 1. *Of the Extent, Density, and Temperature of the Atmosphere.*

107. The atmosphere is a thin transparent veil, enveloping the earth, and extending to an uncertain height, but probably not less than one hundred miles above it. Since air is elastic, and the lower portions next to the earth sustain the weight of the whole body of air above them, they are compressed by the load, as air would be under any other weight. As we ascend above the earth, the air grows thinner and thinner very fast, so that if we could rise to the height of seven miles in a balloon, we should find the air four times as rare there as at the surface of the earth. The air is, indeed, much more rare on the tops of high mountains than at the level of the sea; and at a height much greater than that of the highest mountains on the globe, man could not breathe, nor birds fly. The upper regions of the atmosphere are also very *cold*. As we ascend high mountains, even in the torrid zone, the cold increases, until we finally reach a point where water freezes. This is called the *term of congelation.* At the equator, it is about three miles high; but in the latitude of 40, it is less than two miles, and in the latitude of 80, it is only one hundred and twenty feet high. Above the term of congelation, the cold continues to increase till it becomes exceedingly intense. The clouds generally float below the term of congelation. Mountains, when very high, are usually covered with snow all the year round, even in the

warmest countries, merely because they are above this boundary.

SEC. 2. *Of the Relations of the Atmosphere to Water.*

108. Besides common air, the atmosphere always contains more or less watery vapor, a minute portion of fixed air, or carbonic acid, and various exhalations, which are generally too subtile to be collected in a separate state. By the heat of the sun, the waters on the surface of the earth are daily sending into the atmosphere vast quantities of watery vapor, which rises not only from seas and lakes, but even from the land, wherever there is any moisture. The vapor thus raised, either mixes with the air and remains invisible, or it rises to the higher and colder regions, and is condensed into clouds. Sometimes accidental causes operate to cool it near the surface of the earth, and then it forms fogs. It returns to the earth in the forms of dew, and rain, and snow, and hail.

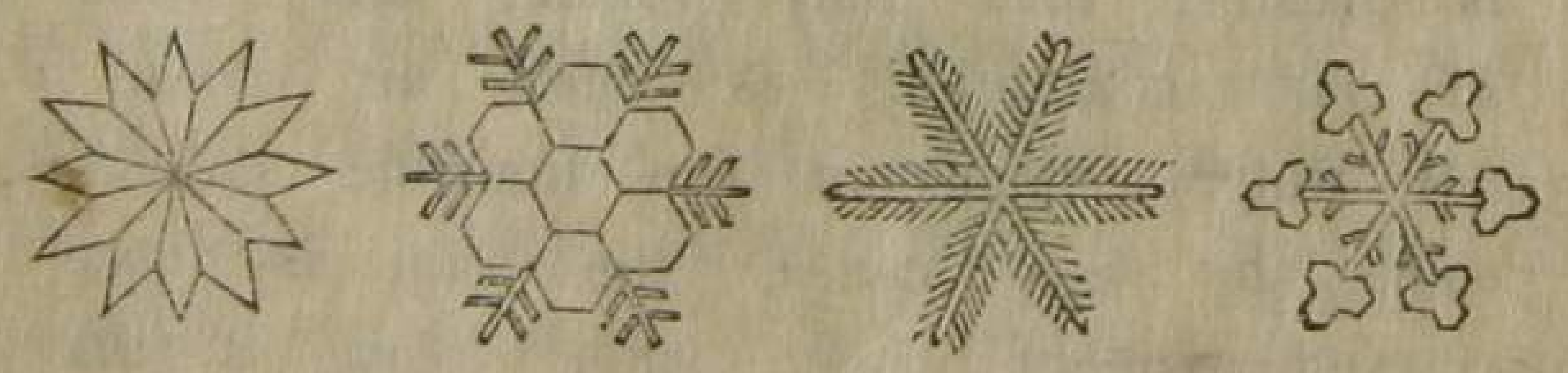
109. *Dew* does not fall from the sky, but is deposited from the air on cold surfaces, just as the film of moisture is, which we observe on a tumbler of cold water in a sultry day. Here, the air coming in contact with a surface colder than itself, has a portion of the invisible vapor contained in it condensed into water. In the same manner, on clear and still nights, which are peculiarly favorable to the formation of dew, the ground becomes colder than the air, and the latter circulating over it, deposits on it and on all things near it, a portion of its moisture. Dew does not form on all substances alike that are equally exposed to it. Some substances on the surface of the earth are found to grow colder than others, and these receive the greatest deposit of dew. Deep water, as that of the ocean, does not grow at all colder in a single night, and therefore receives no dew; and the naked skins of animals, being warmer than the air, receive none; although the moisture which is constantly exhaled from the animal system itself, as soon as it comes into contact with the colder air that surrounds the person, may be condensed, and moisten the skin or the clothes in such a way as to give the appearance of dew. In this manner, also, frost (which is nothing more than frozen dew) collects, in cold weather, on the bodies of domestic animals. By a beautiful provision of Providence, dew is always guided with a frugal hand to those objects which are most benefited by it. Green vegetables receive much more than naked sand equally exposed, and none is squandered on the ocean.

110. *Rain* is formed in the atmosphere at some distance above the earth, where warm air becomes cooled. If it is only cooled a few degrees, the moisture may merely be condensed into cloud; but if the cooling is greater, rain may result; and when a hot portion of air, containing, as such air does, a great quantity of watery vapor in the invisible state, is suddenly cooled by any cause, the rain is more abundant, or even violent. In such cases, it may have been cooled by meeting with a portion of colder air, as when a warm southwesterly wind meets a cold northwester, or by rising into the upper regions near the term of congelation. In some parts of the earth, as in Egypt, and in a part of Chili and Peru, it seldom or never rains, for there the winds usually blow

steadily in one direction, and encounter none of those mixtures with colder air which form rain. In some other countries, as the northeastern part of South America, the rains are excessive; and in others, as most tropical countries, the rains are periodical, being very copious at particular periods called the rainy seasons, while little or none falls during the other parts of the year.

111. *Snow* is formed from vapor crystallized by cold instead of uniting in drops. By this means it is converted into a light downy substance, which falls gently upon the earth, and forms a covering that confines the heat of the earth, and furnishes an admirable defence of the vegetable kingdom, during winter, in severe climates. In cold climates, flakes of snow consist of regular crystals, presenting many curious figures, which, when closely inspected, appear very beautiful. Nearly a hundred distinct forms of these crystals have been particularly described by voyagers in the polar seas, specimens of which, as they appear under the magnifier, are exhibited in the following diagram.

Fig. 54.



When a body of hot air becomes suddenly and intensely cooled, the watery vapor is frozen and forms *hail*. The most violent hailstorms are formed by whirlwinds, which carry up bodies of hot air far beyond the term of congelation, where the drops of

rain are frozen into hailstones, and these being sustained for some time by the upward force of the whirlwind, accumulate occasionally to a very large size. Hailstorms are chiefly confined to the temperate zones, and seldom occur either in the torrid or the frigid zone. In the equatorial regions, the term of congelation is so high, that the hot air of the surface, if raised by a whirlwind, would seldom rise beyond it; and in the polar regions, the air does not become so hot as is required to form a hailstorm.

Sec. 3. *Of the Relations of the Atmosphere to Heat.*

112. It is chiefly by the agency of heat, that air is put in motion. If a portion of air is heated more than the surrounding portions, it becomes lighter, rises, and the surrounding air flows in to restore the equilibrium; or if one part be cooled more than another, it contracts in volume, becomes heavier, and flows off on all sides until the equilibrium is restored. Thus the air is set in motion by every change of temperature; and as such changes are constantly taking place, in greater or less degrees, the atmosphere is seldom at rest at any one place, and never throughout any great extent. The most familiar example we have of the effects of heat in setting air in motion, is in the *draught of a chimney*. When we kindle a fire in a fireplace, or stove, it rarefies the air of the chimney, and the denser air from without rushes in to supply the equilibrium carrying the smoke along with it. Smoke, when cooled, is heavier than air, and tends to descend, and does descend unless borne up by a current of heated air. A

hot current of air in a chimney is cooled much more rapidly when the materials of the chimney are damp than when they are dry, and therefore it will cool much faster in a wet than in a dry atmosphere. Hence, chimneys are apt to smoke in wet weather. It is essential to a good draught, that the inside of a chimney should be smooth, for air meets with great resistance in passing over rough surfaces. Burning a chimney improves the draught, principally by lessening the friction occasioned by the soot. In stoves for burning anthracite coal, it is important to the draught, that no air should get into the chimney except what goes through the fire. On account of the great resistance which a thick mass of anthracite opposes to air, this will not work its way through the coal if it can get into the chimney by any easier route. Hence the pipes which conduct the heated air from a stove to the chimney, should be close, especially the joint where the pipe enters the chimney; and care should be taken, that there should be no open fireplace, or other means of communication, between the external air and the flue with which the stove is connected.

113. It is important to health, that the apartments of a dwelling-house should be well *ventilated*. This is especially the case with crowded rooms, such as churches and schoolhouses. Of the method of ventilating churches, a beautiful specimen is afforded in the Centre Church, in New Haven. In the middle of the ceiling, over the body of the church, is an opening through the plastering, which presents to the eye nothing but a large circular ornament in stucco. Over this, in the garret of the building, a circular enclosure of wood is constructed, on the top of which is built a large wooden chimney, leading off, at a small rise, to the end of the building, where it enters the steeple. An upper window of the steeple being open, in warm weather, the current sets upward from the church into the chimney, and thence into the tower, and completely ventilates the apartment below. A door, so hung as to be easily raised or lowered by a string, leading to a convenient place at the entrance of the church, can be opened or closed at pleasure. In cold weather, it will generally be found expedient to keep it closed, to cut off cold air, opening it only occasionally. A schoolhouse may easily be ventilated by a similar contrivance connected with a belfry over the center, as is done in several schoolhouses recently built in New England.

114. Nature, however, produces movements of the atmosphere on a far grander scale, in the form of *Winds*. These are exhibited in the various forms of breezes, high winds, hurricanes, gales, and tornadoes; varieties depending chiefly on the different velocities with which the wind blows. A velocity of twelve miles an hour makes a strong breeze; sixty miles, a high wind, one hundred miles, a hurricane. In some extreme cases, the velocity has been estimated as high as three hundred miles an hour. The force of the wind is proportioned to the square of the velocity; a speed ten times as great increases the force a hundred times. Hence, the power of violent gales is irresistible. Air, when set in motion, either on a small or on a great scale, has a strong tendency to a whirling motion, and seldom moves forward in a straight line. The great gales of the ocean, and the small

tornadoes of the land, often, if not always, exhibit more or less of a rotary motion, and sometimes appear to spin like a top around a perpendicular axis, at the same time that they advance forward in some great circuit.

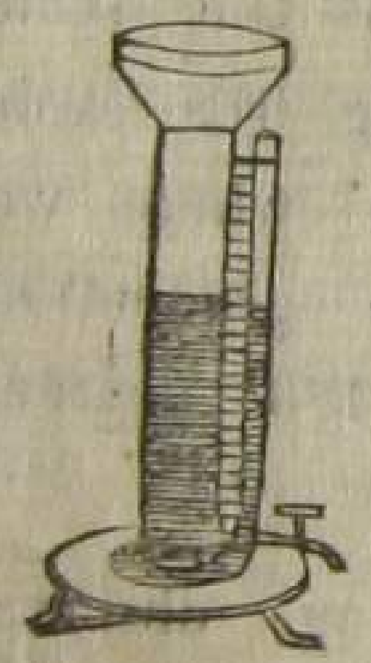
115. METEOROLOGICAL INSTRUMENTS.—The principal of these are the Thermometer, the Barometer, and the Rain Gage. The principle, construction, and uses of the *Barometer*, have already been pointed out, (Arts. 96 and 97.) Since it informs us of the changes that take place in the weight and pressure of the atmosphere, at any given place, on which depend most of the changes of weather, it becomes of great aid in the study of Meteorology and has, in fact, led to the knowledge of most of the laws of atmospheric phenomena hitherto established. We should, in purchasing, be careful to select an instrument of good workmanship, for no other is worthy of confidence. We should suspend it in some place where there is a free circulation of air—as in an open hall, having an outside door—and we should take the exact height of the mercury at the times directed below for recording the thermometrical observations. In case the barometer is falling, or rising with unusual rapidity, observations should be recorded every hour, or even oftener, as such observations afford valuable means of comparison of the states of the atmosphere at different places.

116. The *Thermometer* is an instrument used for measuring variations of temperature by its effects on the height of a column of fluid. As heat expands and cold contracts all bodies, the amount of expansion or contraction in any given case, is made a criterion of the change of temperature. Fahrenheit's thermometer, the one in common use, consists of a small glass tube, called the stem, with a bulb at one end, and a scale at the side. The bulb and a certain part of the stem are filled with mercury. The scale is divided into degrees and aliquot parts of a degree. If we dip the thermometer into boiling water, the mercury will expand and rise in the stem to a certain height, and there remain stationary. We will, therefore, mark that point on the stem, and then transfer the thermometer to a vessel where water is freezing. The mercury now descends to a certain level, and remains there stationary, as before. We mark this point, and we thus obtain the two most important fixed points on the scale, namely, the freezing and boiling points of water. We will now apply the scale, and transfer these marks from the stem to the scale, and divide the part of the scale between them into 180 equal parts, continuing the same divisions below the freezing point 32 degrees, where we make the zero point, and there begin the graduation from 0 to 32, the *freezing* point, and so on 180 degrees more, to 212, the *boiling* point.

The best times for making and recording observations, are when the mercury is lowest, which occurs about sunrise, and when it is highest, which is near two o'clock in winter, and three in summer. The sum of these observations, divided by two, gives the average, or *mean*, for the twenty-four hours; the sum of the daily means for the days of a month, gives the mean for that month; and the monthly averages, divided by twelve, give the annual mean. By such observations, any one may determine the temperature of the place where he resides.

117. The climate of the United States is very variable, and the annual range of the thermometer is greater than in most other countries. It embraces 140°, extending from 40° below zero, (usually marked —40°,) to 100° above. In the southern part of New England, the mercury seldom rises above 90°, and descends but a few times in the winter below zero. From 70° to 80° is a moderate summer heat. Although the equatorial regions of the earth are, in general, hotter than places either north or south, yet we have seen that the temperature of a place depends on various other circumstances, as well as on the latitude. (Arts. 82 and 107.)

Fig. 55.



118. The *Rain Gage* is an instrument employed for ascertaining the amount of water that falls from the sky, in the various forms of rain, snow, and hail. The simplest form is a tall tin cylinder, with a funnel-shaped top, having a graduated glass tube communicating with the bottom, and rising on the side. The water will stand at the same level in the tube and in the cylinder, and the divisions of the tube may be such as to indicate minute parts of an inch, and thus determine the depth of rain that falls on the area of the funnel, suppose a square foot. After the rain is over, the water may be removed by means of the stop-cock, and the apparatus will be ready for a new observation. It is useful to know the amount of rain that falls annually at any given place, not only in reference to a knowledge of the climate, but also for many practical purposes to which water is applied, such as feeding canals, turning machinery, or irrigating land.

Sec. 4. *Of the Relations of the Atmosphere to Fiery Meteors.*

119. The luminous phenomena which go under the general name of "fiery meteors," are Thunder Storms, Aurora Borealis, and Shooting Stars. Sudden and violent showers of rain, in hot weather, are usually accompanied by thunder and lightning. The lightning is owing to the sudden discharge of electricity, and the thunder is ascribed to the rushing together of the opposite portion of air, that are divided by the passage of the electric current. The snapping of a whip depends on the same principle as a clap of thunder. The lash divides the air, and the forcible meeting of the opposite parts to restore the equilibrium, produces the sound. Whenever hot vapor is rapidly condensed, a great amount of electricity is extricated. This accumulates in the cloud, until it acquires force enough to leap from that to some other cloud, or to the earth, or to some object near it, and thus the explosion takes place.

120. The *Aurora Borealis*, or *Northern Lights*, are most remarkable in the polar regions, and are seldom or never seen in the torrid zone. They sometimes present merely the appearance of a *twilight* in the north; sometimes they shoot up in *streamers*, or exhibit a flickering light, called *Merry Dancers;* sometimes they span the sky with luminous *arches*, or *bands;* and more rarely they form a circle with stream-

ers radiating on all sides of it, a little southeast of the zenith, called the *corona*. The aurora borealis is not equally prevalent in all ages, but has particular periods of visitation, after intervals of many years. It is more prevalent in the autumnal months than the other parts of the year, and usually is most striking in the earlier parts of the night, frequently kindling up with great splendor about 11 o'clock. From 1827 to 1842, inclusive, was a remarkable period of auroras. The cause of this phenomenon is not known; it has been erroneously ascribed to electricity, or magnetism; but it is probably derived from matter found in the planetary spaces, with which the earth falls in while it is revolving around the sun.

121. *Shooting Stars* are fire-balls which fall from the sky, appearing suddenly, moving with prodigious velocity, and as suddenly disappearing, sometimes leaving after them a long train of light. They are occasionally observed in great numbers, forming what are called *Meteoric Showers*. Two periods of the year are particularly remarkable for these displays, namely, the 9th or 10th of August, and the 13th or 14th of November. The most celebrated of these showers occurred on the morning of the 13th of November, 1833, when meteors of various sizes and degrees of splendor, descended with such frequency as to give the impression that the stars were all falling from the firmament. The exhibition was nearly equally brilliant in all parts of North America, and lasted from about 11 o'clock in the evening till sunrise. This phenomenon began to appear in some parts of the world, as early as November, 1830, and increased in splendor at the same period of the year, every year, until 1833, when it reached its greatest height. It was repeated on a smaller scale, every year, until 1838, since which time nothing remarkable has been observed at this period. The meteoric shower of August still (1858) continues. Meteoric showers appear to rise from portions of a body resembling a comet, which revolves about the sun, and sometimes comes so near the earth that portions of it are attracted down to the earth, and are set on fire as they pass through the atmosphere.

CHAPTER VI.

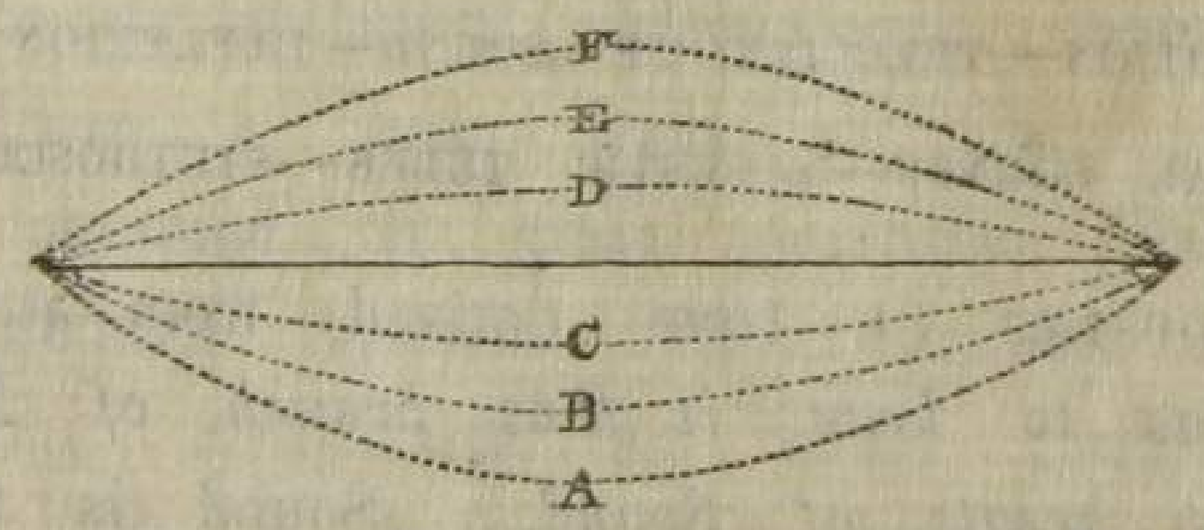
ACOUSTICS.

VIBRATORY MOTION—VELOCITY OF SOUND—REFLEXION OF SOUND—MUSICAL SOUNDS—ACOUSTIC TUBES—STETHOSCOPE.

122. ACOUSTICS (a term derived from a Greek word which signifies *to hear*) *is that branch of Natural Philosophy which treats of Sound.* Sound is produced by the vibrations of the particles of a sounding body. These vibrations are communicated to the air, and by that to the ear, which is furnished with a curious apparatus specially adapted to receive them and convey them to the brain, and thus is excited the sensation of hearing. Vibration consists in a motion of the particles of a body, *backward and forward*, through an exceedingly minute space. The particles of air in contact with the body, receive a corresponding motion, each particle impels one before it, and re-

bounds, and thus the motion is propagated from particle to particle, from the sounding body to the ear. Such a vibratory motion of the medium, does not imply any current or progressive motion in the medium itself, but each particle recovers its original situation when the impulse that produced its vibration ceases. Elastic bodies being most susceptible of this vibratory motion, are those which are usually concerned in the production of sound. Such are thin pieces of board, as in the violin; a steel spring, as in the Jewsharp; a glass vessel, and cords closely stretched; or a column of confined air, as in wind instruments. If we stretch a fine string between two fixed points, and draw it out of a straight line to A, and then let it go, it will proceed to nearly the same distance on the other side, to E, whence it will return to B, and thus continue to vibrate through smaller and smaller spaces, until it comes to a state of rest. When we throw a stone upon a smooth surface of water, a circle is raised immediately around the stone; that raises another circle next to it, and this another beyond it, and thus the original impulse is transmitted on every side. This example may give some idea of the manner in which sound is propagated through the air in all directions from the sounding body.

Fig. 56.



123. Although air is the usual medium of sound, yet it is not the only medium. Solids and liquids, when they form a direct communication between the sounding body and the ear, conduct sound far better than air. When a tea-kettle is near boiling, if we apply one end of an iron poker to the kettle, and put the other end to the ear, we may perceive when the water begins to boil, long before it gives the usual signs. If we attach a string to the head of a fire-shovel, and winding the ends around the fore-fingers of both hands, apply them to the ear, and then ding the shovel against an andiron, or any similar object, a sound will be heard like that of a heavy bell. The ticking of a watch may be heard at the remote end of a long pole, or beam, when the ear is applied to the other end; and if the watch is let down into water, its beats are distinctly heard by an ear placed at the surface. A bell struck beneath the water of a lake, has been heard at the distance of nine miles. Air is a better conductor of sound when moist than when dry. Thus, we hear a distant bell or a waterfall with unusual distinctness just before a rain, and better by night than by day. Air conducts sound better when condensed, and worse when rarefied. On the tops of some of the high mountains of the Alps, where the air is much rarefied, the sound of a pistol is like that of a pop-gun.

124. The *velocity* of sound in air is 1130 feet in a second, or a little more than a mile in five seconds. On this principle, we may estimate the distance of a thunder-cloud, by the interval between the flash and the report. For example, an interval of five seconds, gives $1130 \times 5 = 5650$ feet, or a little more than a mile. A feeble sound moves just as fast as a loud one. Its velocity is not altered by a high wind in a direction at right angles to the course of the wind; but in the same direction, the comparatively small velocity of the wind is to be added, and in the opposite direction to be subtracted. In water, the velocity of sound is about four times as great as in air, being 4709 feet per second; and in cast iron its velocity is more than ten times as great as in air, being no less than 11,895 feet per second.

125. Sound is capable of being *reflected*, and is thus sometimes returned to the ear, forming an *echo*. Thus, the sound of the human voice is sometimes returned to the speaker, or other persons near him, in a repetition usually somewhat feebler than the original sound; but it may be louder than that, if several reflected waves are unitedly conveyed to the ear. When one stands in the centre of a hollow sphere or dome, numerous waves being reflected from the concave surface so as to meet in the centre, a sound originally feeble becomes so augmented as to be astounding. A cannon discharged among hills or mountains, reverberates in consequence of the repeated reflexions of the sound.

126. A sound becomes *musical* when the vibrations are performed with a certain degree of frequency. The slow flapping of the wings of a domestic fowl has nothing musical; but the rapid vibration of the wings of a humming-bird, produces a pleasant note. The slow falling of trees before a high wind, is attended with a disagreeable crash; the rapid prostration of the trees of a forest by a tornado, with a sublime roar. A string stretched between two points, and made to

vibrate very slowly, has nothing musical; but when the tension is increased, and the vibrations quickened, the note grows melodious. The strings of a violin give different sounds in consequence of affording vibrations more or less rapid. The larger strings, having slower vibrations, afford graver notes. The screws enable us to alter the degree of tension, and thus to increase or diminish the number of vibrations at pleasure; and by applying the fingers to the strings, we can shorten them more or less, producing sounds more or less acute, by increasing the number of vibrations in a given time. In wind instruments, as the flute, the vibrating body which produces the musical tone is the column of air included within. This, by the impulse given by the mouth, is made to vibrate with the requisite frequency, which is varied by opening or closing the stops with the fingers. The shorter the column, the more rapid is the vibration, and the more acute the sound; and the length of the vibrating column is determined by the place of the stop that is opened, the higher stops giving sharper sounds because the vibrating columns are shorter. The pipes of an organ sound on a similar principle, the wind being supplied by a bellows instead of the breath. In certain instruments, as the clarinet and hautboy, the vibrations are first communicated from the lips of the performer to a reed, and from that to the column of air.

127. Sounds differing from each other by certain intervals, constitute musical *notes*. The singing of birds affords sweet sounds but no music, being uttered continuously and not at intervals. Man only, among animals, has the power of uttering sounds in this man-

ner; and his voice alone, therefore, is endued with the power of music. Music becomes a branch of mathematical science, in consequence of the relation between musical notes, and the *number of vibrations* that produce them respectively. Although we cannot say that one sound is larger than another, yet we can say that the vibrations necessary to produce one sound are twice or thrice, or any number of times, more frequent than those of another; and the number of vibrations necessary to produce one note has a fixed ratio to the number which produces another note. Thus, if we diminish the length of a musical string one half, we double the number of vibrations in a given time, and it gives a sound eight notes higher in the scale than that given by the whole string, and is called an octave. Hence, these sounds are said to be to each other in the ratio of 2 to 1, because this is the ratio of the numbers of vibrations which produce them. A succession of single musical sounds constitutes *melody;* the combination of such sounds, at proper intervals, forms *chords;* and a succession of chords, produces *harmony.* Two notes formed by an equal number of vibrations in a given time, and of course giving the same sound, are said to be in *unison.* The relation between a note and its octave is, next after that of the unison, the most perfect in nature; and when the two notes are sounded at the same time, they almost entirely unite. Chords are produced by frequent *coincidences of vibration,* while in discords such coincidences are more rare. Thus, in the unison, the vibrations are exactly coincident; in the octave, the two coincide at the end of every vibration of the longer string, the shorter meanwhile performing just two vibrations; but in the second, the vibrations of the two

strings coincide only after eight of one string and nine of the other, and the result is a harsh discord.

128. When an impulse is given to air contained in an open tube, the vibrations coalesce, and are propagated farther than when similar impulses are made on the open air. Hence the increase of sound effected by horns and trumpets, and especially by the speaking trumpet. Alexander the Great is said to have had a horn, by means of which he could give orders to his whole army at once. *Acoustic Tubes* are employed for communicating between different parts of a large establishment, as a hotel, or manufactory, by the aid of which, whatever is spoken at one extremity is heard distinctly at the other, however remote. They are usually made of tin, being trumpet-shaped at each end. They act on the same principle as the speaking trumpet. The *Stethoscope* is an instrument used by physicians, to detect and examine diseases of the lungs and the heart. It consists of a small pipe ef wood or ivory with funnel-shaped mouths, one of which is applied firmly to the part affected and the other to the ear. By this means the processes that are going on in the organs of respiration, and in the large blood-vessels about the heart, may be distinctly heard.

CHAPTER VII.

ELECTRICITY.[*]

DEFINITIONS—CONDUCTORS AND NON-CONDUCTORS—ATTRACTIONS AND REPULSIONS—ELECTRICAL MACHINES—LEYDEN JAR—ELECTRICAL LIGHT AND HEAT—THUNDER STORMS—LIGHTNING RODS—EFFECTS OF ELECTRICITY ON ANIMALS.

129. MORE than two thousand years ago, Theophrastus, a Greek naturalist, wrote of a substance we call amber, which, when rubbed, has the property of attracting light bodies. The Greek name of amber was *electron*, (ηλεκτρον,) whence the science was denominated ELECTRICITY. The inconsiderable experiment mentioned by Theophrastus, was nearly all that the ancients knew of this mysterious agent, but for two or three centuries past, new properties have been successively discovered, and new modes of accumulating it devised, until it has become one of the most important and interesting departments of natural science. It is common to call this power, whatever it is, the electric fluid, although it is of too subtile a nature for us to show it, as we do air, and prove that it possesses the properties of ordinary matter. But as it is more like an elastic fluid of extreme rarity, than like any thing else we are acquainted with, it is convenient to denominate it a fluid, although we know very little of its nature.

130. Some bodies permit the electric fluid to pass freely through them, and are hence called *conductors;* others hardly permit it to pass through them at all, and are therefore called *non-conductors.* Metals are the best conductors; next, water and all moist substances; and next, the bodies of animals. Glass, resinous substances, as amber, varnish, and sealing wax; air, silk, wool, cotton, hair, and feathers, are *non-conductors.* Wood, stones, and earth, hold an intermediate place: they are bad conductors when dry, but much better when moist; and air itself has its non-conducting power greatly impaired by the presence of moisture. Electricity is *excited* by friction. If I rub the side of a dry glass tumbler, or a lamp chimney, on my coat sleeve, the electricity excited will manifest itself by attracting such light substances as bits of paper, cotton, or down. A stick of sealing-wax, when rubbed, exhibits similar effects. When an electrified body is supported by non-conductors so that its electricity cannot escape, it is said to be *insulated.* Thus, a lock of cotton suspended by a silk thread is insulated, because if electricity be imparted to the cotton, it remains, since it cannot make its escape either through the thread, or through the air, both being non-conductors. A brass ball supported by a pillar of glass is insulated; but when supported on a pillar of iron or any other metal, it is *uninsulated*, since the electricity does not remain in the ball, but readily makes its escape through the metallic support. By knowing how to avail ourselves of the conducting properties of some substances, and the non-conducting properties of other substances, we can either confine, or convey off the electric fluid at pleasure.

131. There are a number of different classes of phenomena which electricity exhibits; as attraction and repulsion—heat and light—shocks of the animal system—and mechanical violence. These will suc-

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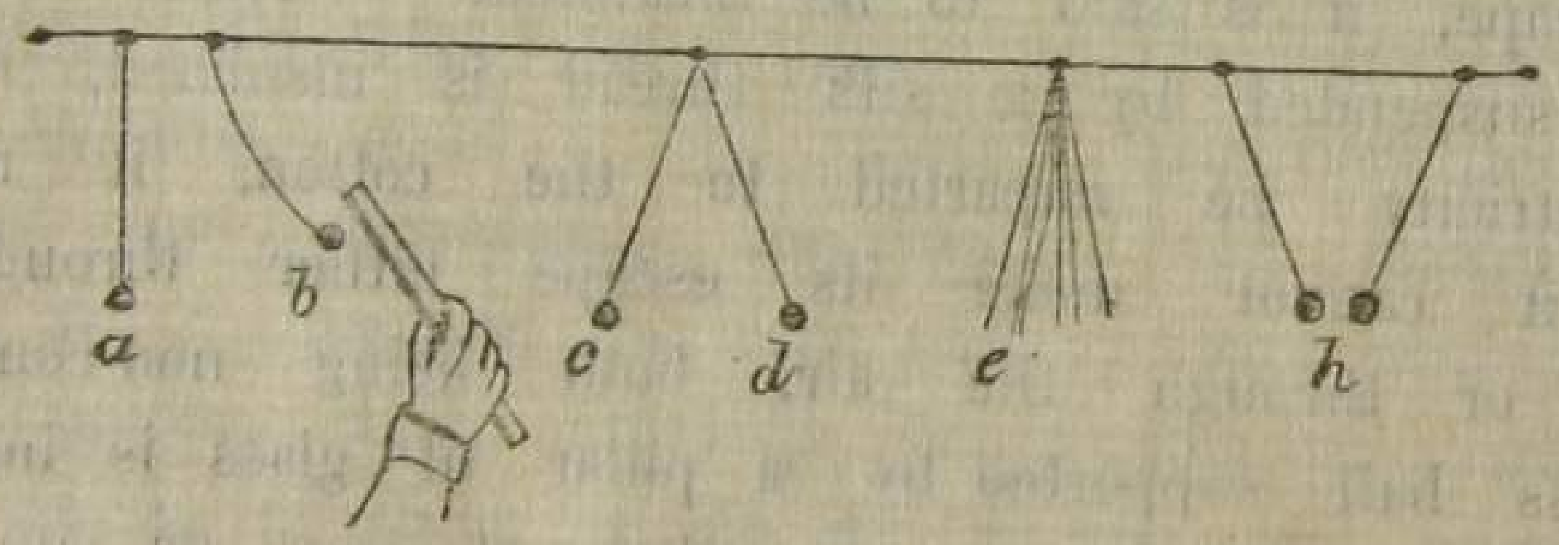
[*] The experiments in this chapter are so simple, and require so little apparatus, that it is hoped the learner will generally have the advantage of witnessing them, which will add much more than mere description to his improvement and gratification.

cessively claim our attention; but as the properties of electricity were first discovered by experiment, so it is by experiments, chiefly, that they are still to be learned. We will therefore describe, first, a few such experiments as every one may perform for himself, and afterwards such as require the aid of an electrical machine.

Sec. 1. *Of Electrical Attractions and Repulsions.*

132. For a few simple experiments, we will stretch a wire horizontally between the opposite walls of a room, or between any two convenient points, as represented in figure 57. This will afford a convenient support for *electroscopes*, as those contrivances are called, which are used for detecting the presence and examining the properties of electricity. A downy feather, a lock of cotton, or pith-balls,* are severally conveninent substances for electroscopes. To one of these, say a pith-ball, we will tie a fine linen thread, about nine inches long, and suspend it from the wire, as at *a*. By slightly wetting the thumb and finger and drawing the thread through them, it becomes a good conductor, and the electroscope is therefore uninsulated. We will now take a thick glass tube and rub it with a piece of silk, (or a dry silk handkerchief,) by which means the tube will be excited, and on approaching it towards the electroscope, the pith-ball will be attracted towards it, as at *b*, and may be led in any direction by shifting the position of the tube; or if the tube be brought nearer, the ball will stick fast to it. We will next suspend two other balls, *c* and *d*, by silk threads, in which case they will be insulated. If we now approach the excited tube, the balls will first be attracted to it, but as soon as they touch it, they will fly off, and the tube when again brought towards them will no longer attract but will repel them, and they will mutually repel each other as in the figure; and if the lock of threads, *e*, be electrified, they will also repel each other. A stick of sealing-wax excited and applied to the electroscopes will produce similar effects. But if we first electrify the ball with glass, and then bring near it the sealing-wax, previously excited, it will not repel the ball, as the excited tube does, but will first attract it as though it were unelectrified, and then repel it; and now the excited glass tube will attract it. Hence it appears that the glass and the sealing-wax, when excited, produce opposite effects: what one attracts the other repels. Each repels its own, but attracts the opposite. Glass repels a body electrified by itself, but attracts a body electrified by sealing-wax; and sealing-wax repels a body electrified by itself, but attracts a body electrified by glass. In the figure, *h* represents two balls differently electrified, one by glass and the other by sealing-wax, and therefore attracting each other. This fact has led to the conclusion, that

Fig. 57.



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*The pith of elder, of corn stalk, or of dry stalks of the artichoke, is suitable for this purpose.

there are *two kinds of electricity;* one excited by glass and a number of bodies of the same class, called the *vitreous* electricity, and the other excited by sealing-wax and other bodies equally numerous, of the same class with it, called the *resinous* electricity. Vitreous electricity is sometimes called *positive*, and resinous electricity *negative*.

133. The foregoing cases of electrical attractions and repulsions constitute important laws of electrical action, and are to be treasured up in the memory in the following propositions:

First. An electrified body *attracts* all unelectrified matter.

Secondly. Bodies electrified similarly, that is, both positively or both negatively, *repel* each other.

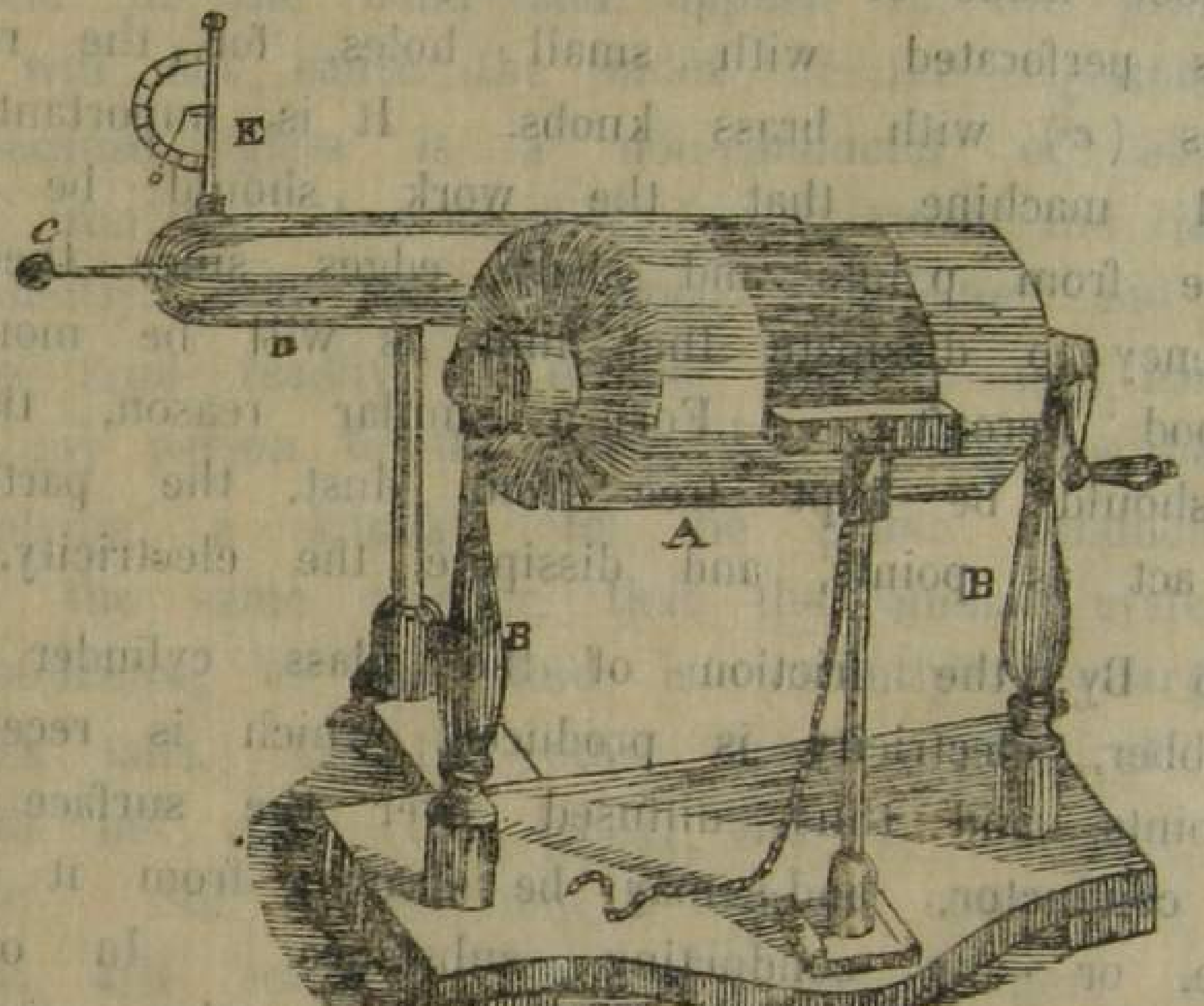
Thirdly. Bodies electrified differently, that is, one positively and the other negatively, *attract* each other.

Fourthly. The force of attraction or repulsion is *inversely as the square of the distance;* that is, when two balls are electrified, the one positively and the other negatively, the force of attraction increases rapidly as they draw near to each other, being four times as great when twice as near, and a hundred times as great when ten times as near. Repulsion follows the same law; that is, when two balls are similarly electrified, it requires four times the force to bring them twice as near to each other, and a hundred times the force to bring them ten times as near as before.

Sec. 2. *Of Electrical Apparatus.*

134. Electrical machines afford the means of accumulating the electric fluid, so as to render its effects far more striking and powerful than they appear in the simple experiments already recited. The *cylinder* machine is represented in Fig. 58. Its principal parts are the cylinder, the frame, the rubber, and the prime conductor. The *cylinder* (A) is of glass, from eight to twelve inches in diameter, and from twelve to eighteen inches long. The *frame* (B B) is made of hard wood, dried and varnished. The rubber (C) consists of a leathern cushion, stuffed with hair like the pad of a saddle. This is covered with a black silk cloth, having a flap, which extends from the cushion over the top of the cylinder to the distance of an inch from the points of the prime conductor, to be mentioned presently. The rubber is coated with an *amalgam*, composed of quicksilver, zinc, and tin, which preparation has been found by experience to produce

Fig. 58.



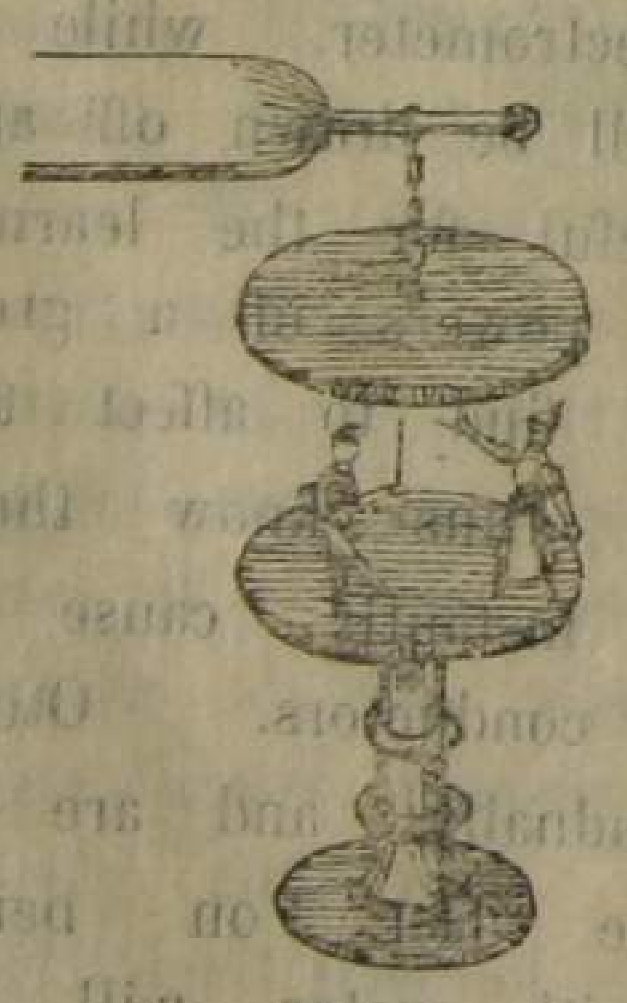
a high degree of electrical excitement, when subjected to the friction of glass. The *prime conductor* (D) is usually a hollow cylinder of brass or tin, with rounded ends. It is mounted on a solid glass pillar, (a junk-bottle with a long neck will answer,) with a broad and heavy foot made of wood to keep it steady. The cylinder is perforated with small holes, for the reception of wires (*c*) with brass knobs. It is important in an electrical machine, that the work should be smooth and free from points and sharp edges, since these have a tendency to dissipate the fluid, as will be more fully understood hereafter. For a similar reason, the machine should be kept free from dust, the particles of which act as points, and dissipate the electricity.

135 By the friction of the glass cylinder against the rubber, electricity is produced, which is received by the points, and thus diffused over the surface of the prime conductor, and may be drawn from it by the knuckle, or any conducting substance. In order to indicate the degree of excitement in the prime conductor, the *Quadrant Electrometer* is attached to it, as is represented at E, Fig. 58. This electrometer is formed of a semicircle, usually of ivory, divided into degrees and minutes, from 0 to 180. The index consitsts of a straw, moving on the center of the disk, and carrying at the other extremity a small pith-ball. The perpendicular support is a pillar of brass, or some conducting substance. When this instrument is in a perpendicular position, and not electrified, the index hangs by the side of the pillar, perpendicularly to the horizon; but when the prime conductor is electrified, it imparts the same kind of electricity to the index, repels it, and causes it to rise on the scale towards an angle of 90 degrees, which point indicates a full charge.

136. Let us now try a few experiments. If we turn the machine one or two rounds, the prime conductor will be charged, and the quadrant electrometer will remain fixed at 90 degrees. We will first examine the conducting powers of different bodies. A glass tube held in the hand and applied to the prime conductor will not cause the index of the electrometer to fall, because glass is a non-conductor of electricity; but an iron rod thus applied, will cause the index to fall instantly, iron being a good conductor, and permitting the fluid readily to escape first to my hand, and through my person to the floor, and finally to the earth. On applying a knuckle to the prime conductor, we find, in the same manner, that the animal system is a good conductor, as the fluid is instantly discharged and the index falls. On the other hand, a piece of sealing-wax will not affect the index, and is therefore a non-conductor. So, if we hold a lock of cotton by a silk thread it will scarcely affect the electrometer, while if held by a linen thread, the fluid will be drawn off and the index will fall. It is very useful for the learner to try in this way the conducting powers of a great variety of bodies. Some he will find to affect the electrometer very little, and he will thus know them to be non-conductors; others will instantly cause it to fall, and are known as good conductors. Other will cause the index to descend gradually, and are of course imperfect conductors. These last, on being moistened with the breath or wet with water, will indicate an increase of conducting power. A *long* stick of wood, as a broom-handle, will be found to conduct with less power than a *short* stick of the same, and a large thread will conduct better than a small one.

Thus all the different circumstances affecting the conducting power, may be ascertained; and upon the knowledge of these relative powers, depends the art of managing the electric fluid, whether in the form of common electricity or in that of lightning.

Fig. 59.



137. The laws of *attraction* and *repulsion* may be verified by the aid of an electrical machine, much more strikingly than by the simple apparatus mentioned in Articles 132 and 133. If we hang a lock of hair to the prime conductor, on turning the machine the hairs will recede violently from each other, because bodies similarly electrified repel each other. By placing light bodies, as paper images, locks of cotton, or light feathers, between one plate connected with the prime conductor and another which is uninsulated, as is represented in figure 59, (the upper plate being hung to the prime conductor,) the *electrical dance* may be performed. The images will first be attracted to the upper plate, but instantly imbibing the same electricity, they will be repelled by the upper and attracted by the lower plate; on descending to the latter, they will give up their charge and return again to the upper plate to repeat the process, thus performing a kind of dance, which when performed by little images of men and women, is often very amusing. Most electrical machines are furnished with a variety of apparatus for illustrating the principles of electrical attractions and repulsions, such as a chime of bells, the electrical horse-race, the electrical wind-mill, and

the like; but these must be seen in order to be fully understood, and therefore their exhibition is left to the instructor.

138. The *Leyden Jar* is a piece of apparatus used for accumulating a large quantity of electricity. It consists of a glass jar coated on both sides with tin foil, except a space on the upper end, within two or three inches of the top, which is either left bare, or is covered with a coating of varnish, or a thin layer of sealing wax. To the mouth of the jar is fitted a cover of hard baked wood, through the center of which passes a perpendicular wire, terminating above in a knob, and below in a fine chain that rests on the bottom of the jar. On presenting the knob of the jar near the prime conductor of an electrical machine, while the latter is in operation, a series of sparks pass between the conductor and the jar, which will gradually become more and more feeble, until they cease altogether. The jar is then said to be *charged*. If we now take the *discharging rod*, (which is a bent wire, armed at both ends with knobs, and insulated by a glass handle, as in figure 61,) and apply one of the knobs to the outer coating and bring the other to the knob of the jar, a flash of intense brightness, accompanied by a loud report, immediately ensues. If, instead of the discharging rod, we apply one hand to the outside of the charged jar, and bring a knuckle of the other hand to the knob of the jar, a sudden and surprising *shock* is felt, convul-

Fig. 60.

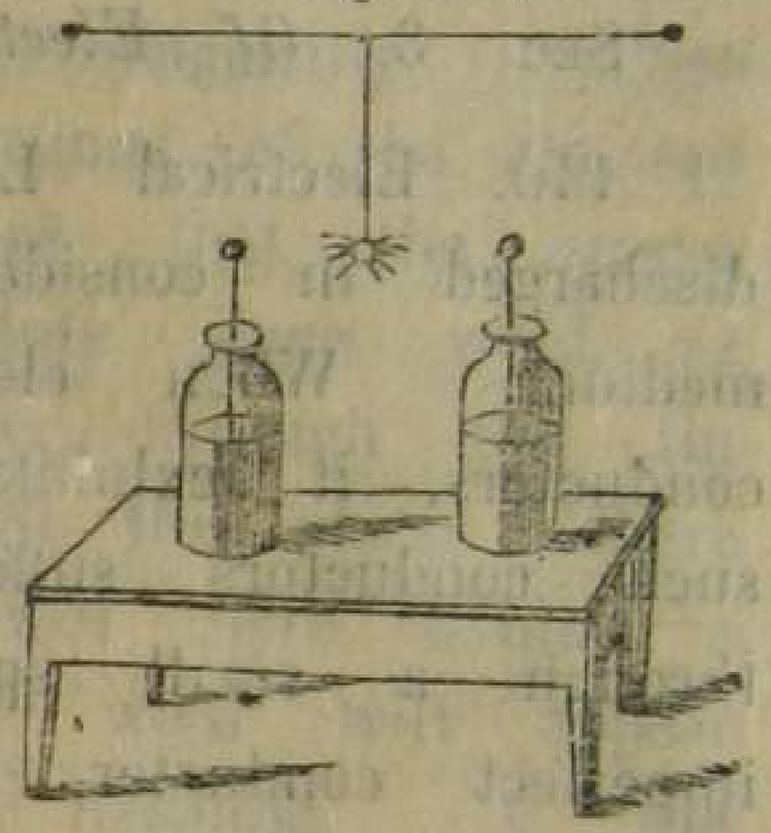
Fig. 61.

sing the arms, and when sufficiently powerful, passing through the breast.

139. The outside and the inside of a Leyden Jar are always found in opposite states; that is, if to the knob connected with the inside we have imparted positive electricity, (as in the mode of charging already described,) then the outside will be electrified in the same degree with negative or resinous electricity. Every spark of one sort of fluid that enters into the jar, drives off a spark of the same kind from the outside, and leaves that in the opposite state. And if the jar, is insulated, (as when it stands on a glass support,) so that the electricity cannot pass from the outer coating then it will take no charge. We may charge a jar negatively instead of positively, by grasping hold of the knob and presenting the outside to the prime conductor. The positive electricity that enters the outer coating, drives off an equal quantity of the same kind from the inside, which escapes through the body of the operator and leaves the inner coating negative. When the jar is thus charged, we must be careful to set it down on a *glass* support before withdrawing the hand; for, if we place it on the table, which is a conductor, the electricity will immediately rush from the outside to the inside, through the table, floor, and body of the operator, and he will receive a shock. But if he sets the jar on a non-conducting support, no such communication will be formed between the two sides of the jar, and consequently it will not discharge itself.

The *Electrical Spider* forms a pleasing illustration of the different states of two jars, one charged positively and the other negatively. It is contrived as follows: Take a bit of cork and form a small ball of the size of a pea, for the body of the spider. With a needle, pass a fine black thread backward and forward through the sides of the cork, letting the threads project from it half or three fourths of an inch on the opposite sides, to form the legs. Now suspend it from the center of the body by a fine silk thread, between two jars, one charged positively and the other negatively, and placed on a table, as is represented in figure 62. The spider will first be attracted to the knob of the nearest jar, will imbibe the same electricity, be repelled, and attracted to the knob of the other jar, from which again it will be repelled, and so will continue to vibrate back and forth between the two jars, until it has restored the equilibrium between them by slowly conveying to the inside of each jar the electricity of the inner coating of the other.

Fig. 62.



Pointed conductors have a remarkable power of drawing off and dissipating the electric fluid when it has accumulated. If we apply one hand to the outer coating of a charged jar, and with the other bring a needle towards the knob, it will silently draw off all the charge, without giving any shock. And if, while we are charging a jar with the machine, we direct a pointed wire or a needle towards the machine, even at a much greater distance from it than the knob of the jar, the fluid will

Fig. 63.

pass into the needle in preference to the jar. All apparatus, therefore, for confining electricity, requires to be free from sharp lines and points, and to terminate in round smooth surfaces.

Sec. 3. *Of Electrical Light and Heat.*

140. Electrical Light appears whenever the fluid is discharged in considerable quantities through a resisting medium. When electricity flows freely through good conductors, it exhibits neither light nor heat; but if such conductors suffer any interruption, as in passing through a small space of air, or even through an imperfect conductor, then light becomes manifest. We will suppose the experiment to be performed in a dark room, or in the evening, in a room very feebly lighted. A glass tube, rubbed with black silk, coated with a little electrical amalgam, will afford numerous sparks, with a slight crackling noise. A chain, hung to the prime conductor of a machine, will show a bright spark at every link. If we attach one end of the chain to the prime conductor, and hold the other end suspended by a glass tube, brushes or pencils of light will issue from various points along the chain. The spark seen in discharging the Leyden Jar, as in Article 138, is very intense and dazzling.

Fig. 64.

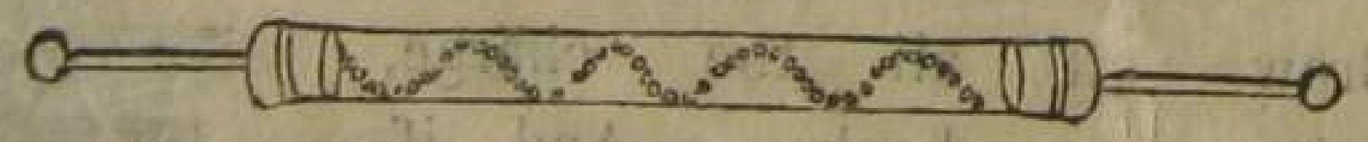


Figure 64 represents a glass cylinder, armed at each end with brass balls, and wound round, spirally, with a narrow strip of tin foil. At short intervals, small portions of the tin foil are cut out, so as to interrupt the circuit. Whenever a spark is passed through this apparatus, it appears beautifully luminous at every interruption in the tin foil. Words or figures of any kind may be very finely exhibited by coating a plate of glass with a strip of tin foil in a zigzag line, from one corner to the opposite corner, diagonally. Then with the point of a knife, small portions of the tin foil are nicked out in such a manner that the spaces thus left bare shall together constitute some word, as Washington. The spark, in passing through the tin foil, will meet with resistance at all the places where the metal has been removed, and will there exhibit a bright light. Thus an illuminated word will appear at every spark received from the machine. If the machine is not sufficiently powerful to afford a spark strong enough to overcome the resistance occasioned by so many non-conducting spaces, then the illuminated word may be made to appear with great splendor, by making the plate form a part of the circuit between the inside and the outside of a charged Leyden Jar.

141. By means of the *Battery*, far more brilliant experiments may be performed than with a single jar. The Battery consists of a number of jars, twelve, for instance, so combined that the whole may be either charged or discharged at once. Large Leyden Jars, placed side by side in a box, standing on tin foil, which forms a conducting communication between the outer coatings, while the inner coatings are also in communication by a system of wires and knobs, answer the same purpose as a single jar of enormous size, and are far more convenient. When the battery is charged, and a chain is made to form a part of the circuit between the outside and inside, on discharging it, the whole chain is most brilliantly illuminated. Rough

lightning rods sometimes present a similar appearance when struck during a thunder storm. Batteries are sometimes made of sufficient power to kill small animals, and even men.

142. *Heat*, as well as light, attends the electric spark, although, except when the discharge is very powerful, as in the case of the battery, or of lightning, it is but feeble, sufficient to set on fire only the most inflammable substances. Alcohol and ether, two very inflammable liquids, may be fired by the spark, a candle may be lighted, and gunpowder exploded. It is, however, difficult to set powder on fire by electricity, unless the spark is very strong.

143. The electric spark passes much more easily through *rarefied* air, than through air in its ordinary state. Thus, a spark which would not strike through the air more than four or five inches, will pass through an exhausted glass tube, four feet or more in length, filling all the interior with a soft and flickering light, somewhat resembling the Aurora Borealis. Hence, that phenomenon has been ascribed by some to electricity, though this is probably not its true explanation.

144. In *Thunder Storms*, we see electricity exhibited in a state of accumulation far beyond what we can create by our machines, and producing effects proportionally more energetic. A cloud presents a conductor insulated by the surrounding air, in which, in hot weather, electricity collects and accumulates as it would upon a prime conductor of immense size. By sending up a kite armed with points, electricity may be drawn from such clouds, and made to descend by a wire wound ronnd the string of the kite. We

may easily direct it upon a prime conductor, or charge a Leyden Jar with it, and examine its properties as we should do in the case of ordinary electricity. By such experiments, it is found that the clouds are sometimes positively and sometimes negatively electrified. In thunder storms, the lightning is usually nothing more than the electric spark passing from one cloud to another differently electrified, as it passes between the outer and inner coating of the Leyden Jar. The flash appears in the form of a line, because it passes so swiftly, just as a stick, lighted at the end and whirled in the air, forms a circle of light. The motion of the electric fluid is, to all appearance, instantaneous. Thunder is the report occasioned by the rushing together of the air, after it has been divided by the passage of the lightning. The cracking of a whip, as already mentioned, is ascribed to the same cause. The lash divides the air into two parts, which forcibly rush together and occasion the sound. When a thunderclap is very near us, the report follows the flash almost instantly, and such claps are dangerous. In all cases, the lightning and the thunder actually occur at the same moment, but when the discharge is at some distance from us, the report is not heard till some time after the flash; for the light reaches the eye instantaneously, but the sound travels with comparative slowness, moving only about a mile in five seconds. We may, therefore, always know nearly how distant a thunder cloud is, by counting the number of seconds between the flash and the report, and allowing the fifth of a mile (or, more accurately, 1,130 feet) to a second. (See Art. 124.)

145. Sometimes lightning, instead of passing from

cloud to cloud, discharges itself into the earth, and then strikes objects that come in its route, as houses, trees, animals, and sometimes man. As electricity always selects, in its passage, the best conductors, Dr. Franklin first suggested the idea of protecting our dwellings by means of *Lightning Rods*. If these are properly constructed, the lightning will always take its passage through them in preference to any part of the house, and thus they will afford complete protection to the family. Sharp metallic points were observed by Dr. Franklin to have great power to discharge electricity from either a prime conductor or a Leyden Jar, and this suggested their use in lightning-rods. Metals, also, being the best conductors of electricity, would obviously afford the most proper material for the body of the rod.

There are three or four conditions in the construction and application of a lightning-rod, which are essential to insure complete protection. The rod must not be less than three-fourths of an inch in diameter—it must be continuous throughout, and not interrupted by loose joints—it must terminate above in one or more sharp points of some metal, as silver, gold, or platina, not liable to rust—it must enter the ground to the depth of permanent moisture, which will be different in different soils, but usually not less than six feet. A rod thus constructed will generally protect a space every way equal to twice its height above the ridge of the house. Thus, if it rises fifteen feet above the ridge, it will protect a space every way from it of thirty feet. It is usually best to apply the rod to the chimney of the house; or, if there are several chimneys, it is best to select one as central as possible. The kitchen

chimney, being usually the only one in which fires are maintained during the season of thunder storms, requires to be specially protected, since a column of smoke rising from a chimney is apt to determine the course of the lightning in that direction. If, therefore, the lightning-rod is attached to some other chimney of the house, either a branch should proceed from it up the kitchen chimney, or this should have a separate rod. As lightning, in its passage from a cloud to the earth, selects tall pointed objects, it often strikes trees, and it is, therefore, never safe to take shelter under trees during a thunder storm. Persons struck down by lightning are sometimes recovered by dashing on repeated buckets of water.

SEC. 4. *Of the Effects of Electricity on Animals.*

Fig 65.

146. When we apply a knuckle to the prime conductor of an electrical machine, and receive the spark, a sharp and somewhat painful sensation is felt. If we receive the charge of a Leyden Jar, a *shock* is experienced which is more or less severe, according to the size and power of the jar. A battery gives a shock still more severe, and it may be even dangerous. Lightning, it is well known, sometimes prostrates and kills men and animals. A convenient method of taking the *shock*, is to charge a

quart jar, place it on a table, and grasping in each hand a metallic rod, apply one rod to the outside of the jar, and touch the other to the knob connected with the inside. If the charge is feeble, it will be felt only in the arms; if it is stronger, it will be felt in the breast; and it may be sufficiently powerful to convulse the whole frame. Any number of persons may, by taking hold of hands, all receive the shock at the same instant. The first must touch the outside, and the last the knob of the jar. Whole regiments have been electrified at once in this way.

Fig. 66.

147. Electricity is sometimes employed *medicinally*, and is thought to afford relief in various diseases. It may be applied either to the whole system at once, or to any individual part, by making that part form a portion of the communication between the inside and the outside of a jar. Or the fluid may be taken in a milder form by means of the *Electrical Stool*. This is a small stool, resting on glass feet. The patient stands or sits on the stool, and holds a chain connected with the prime conductor, while the machine is turned. This produces an agreeable excitement over the whole system: the hair stands on end; sparks may be taken from all parts of the person, as from a prime conductor; and the patient may communicate a slight

shock to any one that comes near him, or may set on fire ether and other inflammable substances, by merely touching them with a rod, or pointing toward them.

148. Several *fishes* have remarkable electrical powers. Such are the Torpedo, the Gymnotus, and the Silurus. The Gymnotus, or Surinam eel, is found in the rivers of South America. Its ordinary length is from three to four feet; but it is said to be sometimes twenty feet long, and to give a shock that is instantly fatal. Thus, it paralyzes fishes, which serve as its food, and in the same manner it disables its enemies and escapes from them. By successive efforts, electrical fishes exhaust themselves. In South America, the natives have a method of taking them, by driving wild horses into a lake where they abound. [For the subject of Electro-Magnetism, and a description of the Electric Telegraph, I must, for want of room, refer the reader to my "School Philosophy," p. 303.]

CHAPTER VIII.

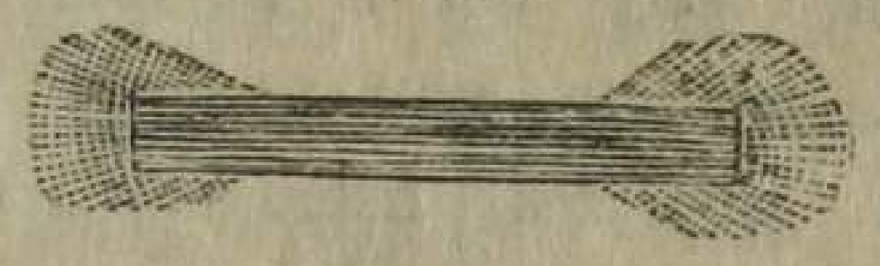
MAGNETISM

DEFINITIONS—ATTRACTIVE PROPERTIES—DIRECTIVE PROPERTIES—VARIATION OF THE NEEDLE—DIP—MODES OF MAKING MAGNETS.

149. Among the ores of iron, there is found an ore of a peculiar kind, which has the power of attracting iron filings, and other forms of metallic iron, and is called the *loadstone*. This power can be imparted to bars of steel, which are denominated *magnets*. The unknown power which produces the peculiar effects of the magnet, is called *magnetism*. This name is

also applied, as at the head of this chapter, to that branch of Natural Philosophy which treats of the magnet. ***Magnetic bars*** are thick plates of iron or steel, commonly about six inches long. If a magnetic bar be placed among iron filings, they will arrange themselves around a point at each end, forming tufts,

Fig. 67.



as is shown in figure 67. These two points are called the *poles*, and the straight line that joins them, the *axis* of the magnet. If we suspend, by a fine thread, a small needle, and approach toward it either pole of a metallic bar, the needle will rush toward it and attach itself strongly to the pole. By rubbing the needle on one of the poles of the magnet it will itself imbibe the same power of attracting iron, and become a magnet, having its poles. If we now bring first one pole of the magnetic bar toward the needle, and then the other pole, we shall find that one attracts, and the other repels the needle. Figure 68 represents two large sewing needles, magnetized, and suspended by fine threads. On approaching the north pole of a magnetic bar to the north poles of the needles, they are forcibly repelled; but on applying the south pole of a bar, as in figure 69, the north poles of the needles are attracted toward it.

Fig. 68.

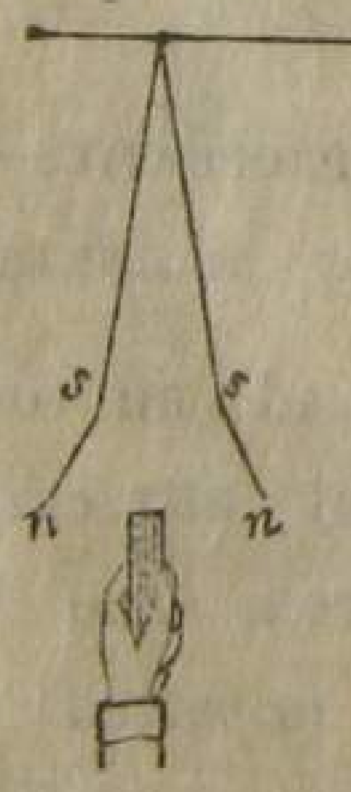
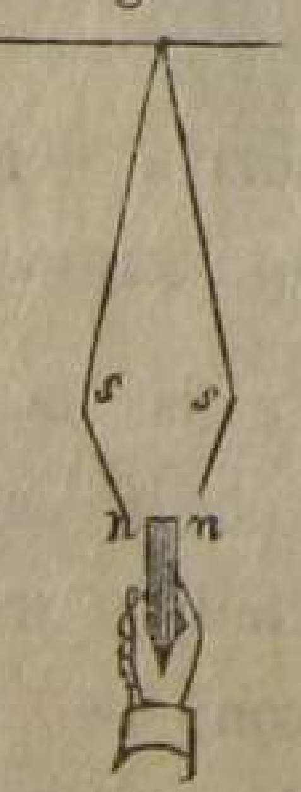
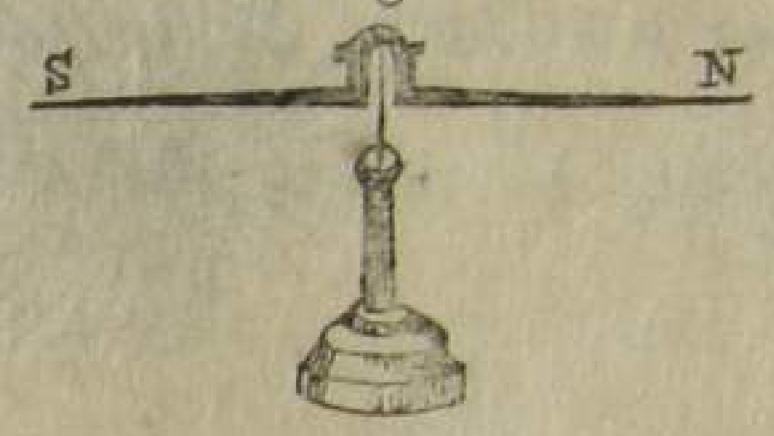


Fig. 69.



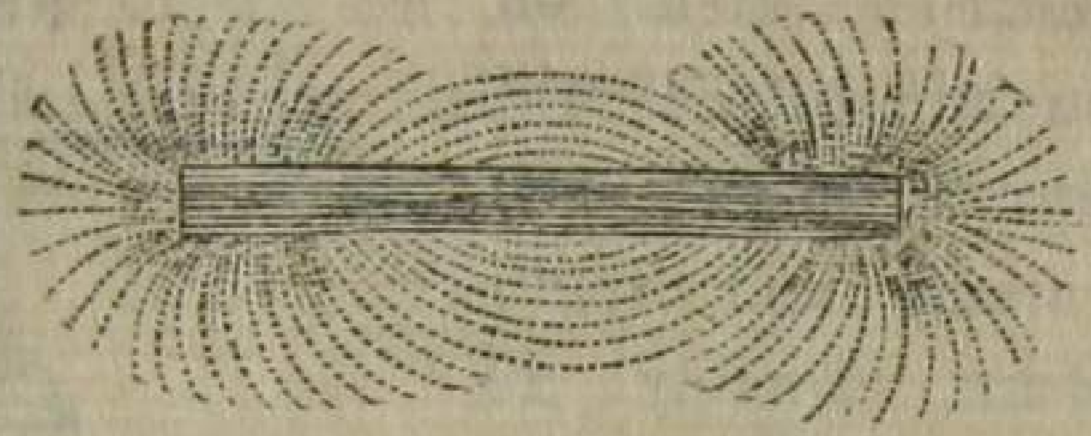
150. Let us suppose that the long needle represented in figure 70, has been rubbed on a magnet, so as to imbibe its properties, or to become *magnetized;* then, on balancing it on a pivot, it will of its own accord place itself in nearly a north and south line, and return forcibly to this position when drawn aside from it. This property is called the *directive,* while the other is called the *attractive,* property of the magnet. That end which points northward, is called the *North Pole* of the magnet, and that end which points southward, is called the *South Pole.* Every magnet has these two poles, whatever may be its size or shape. A magnetic bar has usually a mark across one end, to denote that it is the north pole, the other, of coures, being the south pole. If the north pole of a bar be brought toward the north pole, N, (Fig. 70,) of the needle, it will repel it, and the more forcibly in proportion as we bring it nearer to N. On the contrary, if the north pole of the bar be brought toward the south pole S of the needle, it will attract it. Also, if we present the south pole of the bar first to one pole of the needle, and then to the other, we shall find that the bar will repel the pole of the same name with its own, and attract its opposite. These facts are expressed by the proposition that *similar poles repel, and opposite poles attract each other.* When a magnetic bar is laid on a sheet of paper, and iron filings are

Fig. 70.



sprinkled on it, they will arrange themselves in curves around it, as in figure 71.

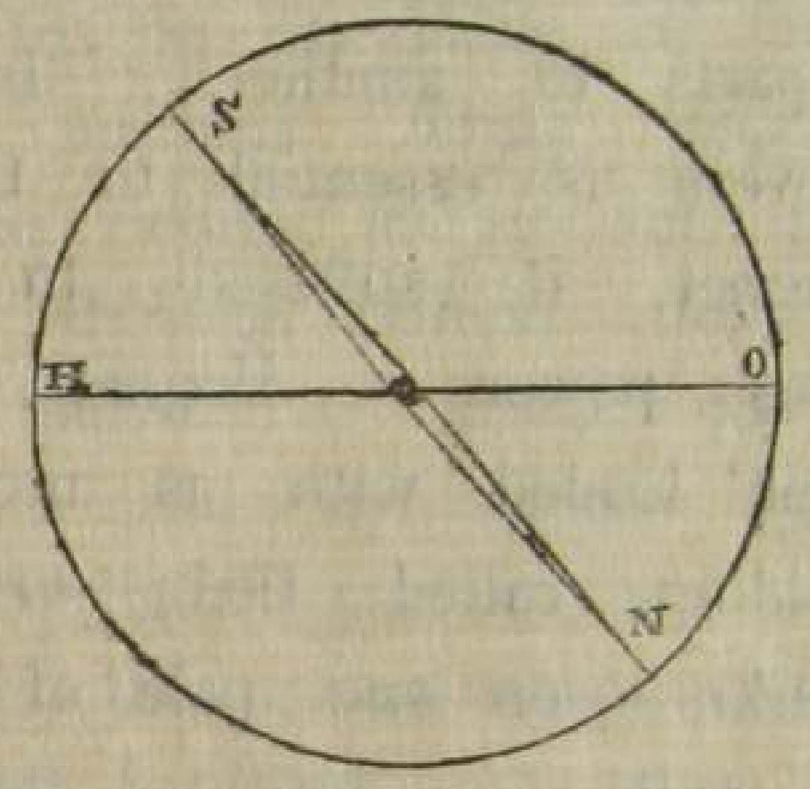
Fig. 71.



151. The magnetic needle, when freely suspended, seldom points directly to the pole of the earth, but its deviation from that pole, either east or west, is called the *variation* of the needle. A line drawn on the surface of the earth, due north and south, is called a *meridian line.* The needle usually makes a greater or less angle with this line. Its direction is called the *magnetic meridian*, and the place on the earth to which it points, is called the *magnetic pole.* The earth has two magnetic poles, one in the northern, the other in the southern hemisphere. The north magnetic pole is in the part of North America lying north of Hudson's and west of Baffin's Bay, in latitude 70°. The variation of the needle is different in different countries. In Europe, the needle points nearly N. W. and S. E.; while in the United States it deviates nowhere but a few degrees from north and south; and along a certain series of places, passing through Western New York and Pennsylvania, the variation is nothing; that is, the needle points directly north and south. At the same place, moreover, the variation of the needle is different at different periods. For a long series of years, the needle will slowly approach the North pole, come within a certain distance of it, and then turn about and again slowly recede from it. At Yale College, the variation in 1843, was $6\frac{1}{2}$ degrees West, and is increasing at the rate of $4\frac{1}{2}$ minutes a year.

152. A needle first balanced on its center of gravity, and then magnetized, no longer retains its level, but it points below the horizon, making an angle with it, called the *Dip of the needle.*

Fig. 72.



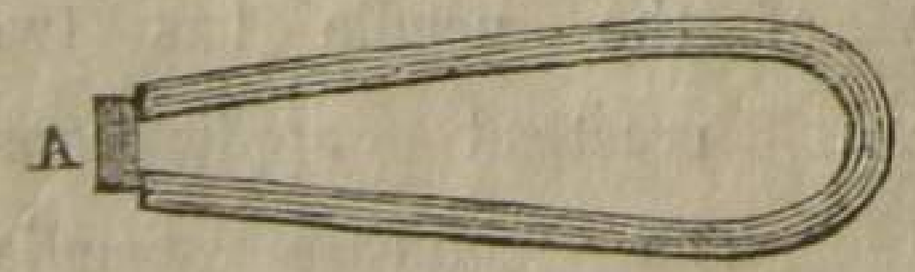
The dipping needle is shown in figure 72, adapted to a graduated circle in order to indicate the amount of the depression, and is sometimes fitted with screws and a level to adjust it for observation. The dip of the needle varies very much in different parts of the earth, being in geenral least in the equatorial, and greatest in the polar regions. At Yale College, it is about 73 degrees, being greater than is exhibited in the figure.

153. The directive property of the needle has two most interesting and important practical applications, in surveying and navigation. The compass needle, in order to keep it at a horizontal level, and prevent its dipping, has a counterpoise on one side, which exactly balances the tendency to point downward. By the aid of this little instrument, lands are measured, and boundaries determined; the traveller finds his way

through unexplored forests and deserts; and mariners guide their ships through darkness and tempests, and across pathless oceans.

154. There are various methods of *making compass needles*, or artificial magnets. Soft iron readily receives magnetism, but as readily loses it; hard steel receives it more slowly, but retains it permanently. It is a singular property of a magnet, whether natural or artificial, that, like virtue, it loses nothing by what it imparts to another. In fact, such an exercise of its powers is essential to their preservation. The strongest magnet, if suffered to remain unemployed, gradually loses power. Magnets, therefore, and loadstones, are kept loaded with as much iron as they are capable of holding, called their *armature*. If we simply rub a penknife on one pole of a magnet, we render it magnetic, as will be indicated by its taking up iron filings or sewing needles. Magnetism is most readily imparted by a bar, when both its poles are made to act together. This is done by giving the bar the form of a horse-shoe, as in figure 73. To magnetize a needle, we lay it flat on a table, and place the two poles of the horse-shoe magnet near the middle, and rub it on the needle, backward and forward, first toward one end and then toward the other, taking care to pass over each half of it an equal number of times. The needle may then be turned over, and the same process performed on the other side, when it will be found strongly and permanently magnetized.

Fgi. 73.



CHAPTER IX.

OPTICS.

DEFINITIONS—REFLEXION AND REFRACTION—COLORS—VISION—MICROSCOPES AND TELESCOPES.

155. Optics *is that branch of Natural Philosophy which treats of Light.* Light proceeds from the sun, a lamp, and all other luminous bodies, in every direction, in straight lines, called *rays*. If it consists of matter, its particles are so small as to be incapable of being weighed or measured, many millions being required to make a single grain. Some bodies, as air and glass, readily permit light to pass through them, and are called *transparent*; others, as plates of metal, do not permit us to see through them, and are called *opake*. Any substance through which light passes, is called a *Medium*. Light moves with the astonishing velocity of 192,500 miles in a second. It would cross the Atlantic Ocean in the sixty-fourth part of a second and in the eighth part of a second, would go round the earth. When light strikes upon bodies, some portion of it enters the body, or is *absorbed*, and more or less of it is thrown back, and is said to be *reflected;* when it passes through transparent bodies, it is turned out of its direct course, and is said to be *refracted*. The light of the sun consists of seven different colored rays, which, being variously absorbed and reflected by different bodies, constitute all the varieties of *colors*. Light enters the eye, and forming within it pictures of external objects, thus gives the sensation of vision. The knowledge of the properties of light, and the nature of vision, has given rise to the invention of many noble and excellent instruments, which afford

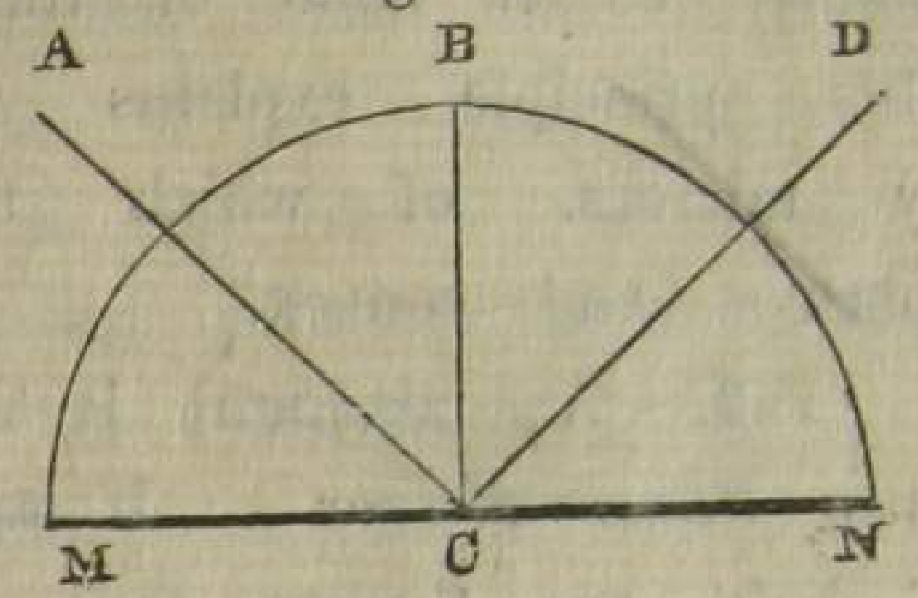
wonderful aid to the eye, such as the *microscope* and the *telescope*. Let us examine more particularly these interesting and important subjects, under separate heads.

SEC. 1. *Of the Reflexion and Refraction of Light.*

156. When rays of light, on striking upon some body, are turned back into the same medium, they are said to be *reflected*. Smooth polished surfaces, like mirrors and wares of metal, reflect light most freely of any, and hence their brightness. Most objects, however, are seen by reflected light; few shine by their own light. Thus, the whole face of nature owes its brightness and its various colors to the light of the sun by day, and to the light of the moon and stars by night. The rays that come from these distant luminaries, fall first upon the atmosphere, and are so reflected and refracted from that as to light up the whole sky, which, were it not for such a power of scattering the rays of light that fall upon it, would be perfectly black. On account of the transparency of the atmosphere, the greater part of the sun's rays pass through it, and fall upon the surface of the earth, and upon all objects near it. These reflect the light in various directions, and are thus rendered visible by that portion of the light which proceeds from them to the eye.

157. When a ray of light strikes upon a plane surface, the angle which it makes with a perpendicular to that surface, is called the *angle of incidence*, and the angle which it makes with the same perpendicular, when reflected, is called the *angle of reflexion*. *The angle of reflexion is equal to the angle of incidence.* Thus, a ray of light, A C, striking upon a plane mirror, M N, at C, will be reflected off into the line C D, making the angle of incidence, M C A, equal to the angle of reflexion, N C D. It is not necessary that the surface on which the light strikes should be a *continued* plane; the small part of a curved surface, on which a ray of light falls, may be considered as a plane, touching the curve at that point, so that the same law of reflexion holds in curved as in plane surfaces. Now the grains of sand on a sandy plain, present surfaces variously inclined to each other, which scatter the rays of the sun in different directions, many of which enter the eye, and make such a region appear very bright; while a smooth surface, like a mirror, or a calm sheet of water, reflects the light that falls on it chiefly in one direction, and hence appears bright only when the eye is so situated as to receive the reflected beam. Thus, the ocean appears much darker than the land, except when the sun shines upon it at such an angle as to throw the reflected beam directly toward the eye, as at a certain hour of the morning or evening, and then the brightness is excessive.

Fig. 74.

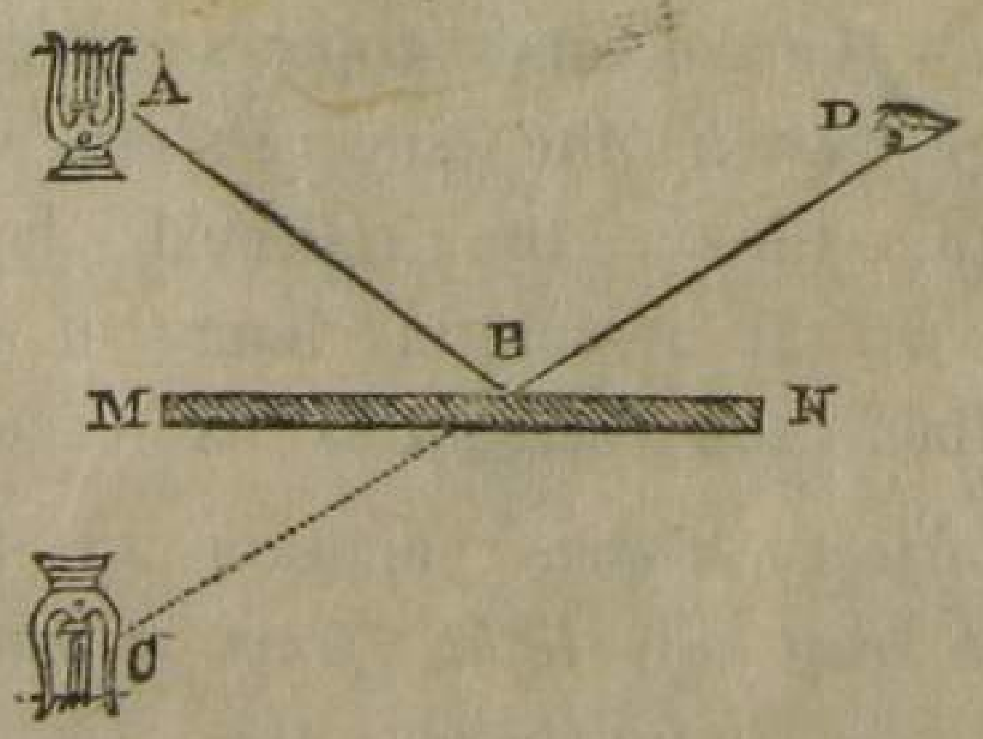


158. An object always appears in the direction in which *the last ray of light from it comes to the eye.* Thus, we see the sun below the surface of a smooth lake or river, because every ray of light, being reflected from the water as from a mirror, comes to the eye

in the direction in which the image appears; and if the light of a star were to change its direction a hundred times in coming through the atmosphere, we should see the star in the direction of the last ray, in the same manner as if none of the other directions had existed. This principle explains various appearances presented by mirrors, of which there are three kinds—plane, concave, and convex.

159. A common looking-glass furnishes an example of a *Plane Mirror.* If we place a lamp before it, rays of light are thrown from the lamp upon every part of the mirror, but we see the lamp by means of those few of the rays only which are reflected to the eye; all the rest are scattered in various quarters, and do not contribute at all to render the object visible to a spectator at any one point, although they would produce, in like manner, a separate image of the lamp wherever they entered an eye so situated as to receive them. Hence, were there a hundred people in the room, each would see a separate image, and each in the direction in which the rays came to his own eye. We will suppose M N to be the looking-glass, having a harp placed before it, and the eye of the spectator at D. Of all the rays that strike on the glass, the spectator will see the image by those only which strike the mirror in such a direction, A B, that when reflected from the mirror at the same angle on the other side, they shall enter the eye in the direction B D. The image will appear at C, and *will be just as far behind the mirror as the harp is before it.* This last principle is an important one, and it must always be remembered, that every point in an object placed before a plane mirror, will appear in the image just as far behind the mirror as that point of the object is before it; so that the image will be an exact copy of the object, and just as much inclined to the mirror. We learn, also, the reason why objects appear inverted when we see them reflected from water, as the surface of a river or lake, since the parts of the object most distant from the water, that is, the top of the object, will form the lowest part of the image.

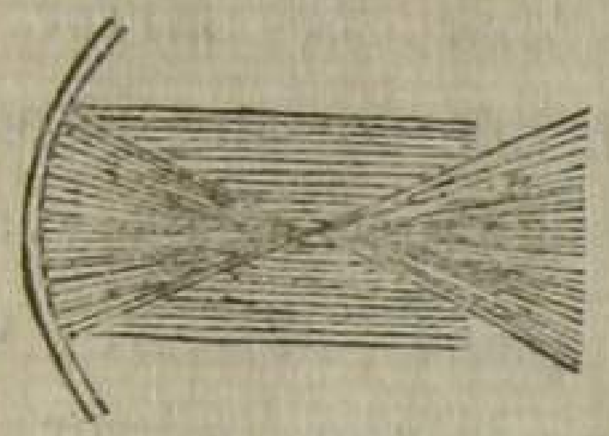
Fig. 75.



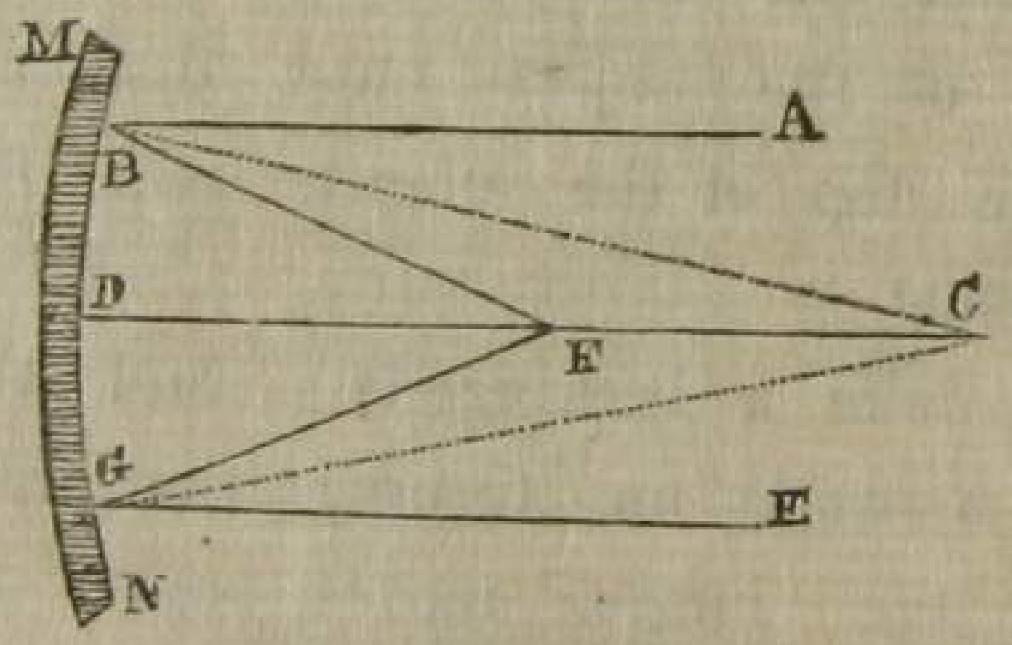
160. If we take a looking-glass and throw an image of the sun on a wall, on turning the mirror round we shall find that the image moves over twice as many degrees as the mirror does. If the image is at first thrown against the wall of a room, horizontally, (in which case the mirror itself would be perpendicular to the horizon,) by turning the mirror through half a right angle, the place of the image would be changed a whole right angle, so as to fall on the ceiling over head. A common table-glass, which turns on two pivots, being placed before a window when the sun is low, will furnish a convenient means of verifying this principle.

161. A *Concave Mirror* collects rays of light. If we hold a small concave shaving glass, for instance, toward the sun, it will collect the whole beam of light that falls upon it into one point, called the *focus*. Figure 76 will give some idea of the manner in which paralled rays strike a concave mirror, converge to a focus, and then diverge. The angle of reflexion is equal to the angle of incidence here, as well as in a plane mirror; but the perpendicular to a curved surface is the radius of the circle of which the curve is a part. Thus, the line C B is the radius of the concave mirorr, M N, and, in a circle, every radius is perpendicular to the surface. The sun's rays are parallel to each other, or so nearly so, that they may be considered as parallel; and when rays fall upon the mirror, in the lines A B and E G, they are reflected on the other side of the perpendiculars, meeting in a common focus, F, which point is called the *focus of parallel rays*. Into this point, or a small space around it, a concave mirror will collect a beam

Fig. 76.



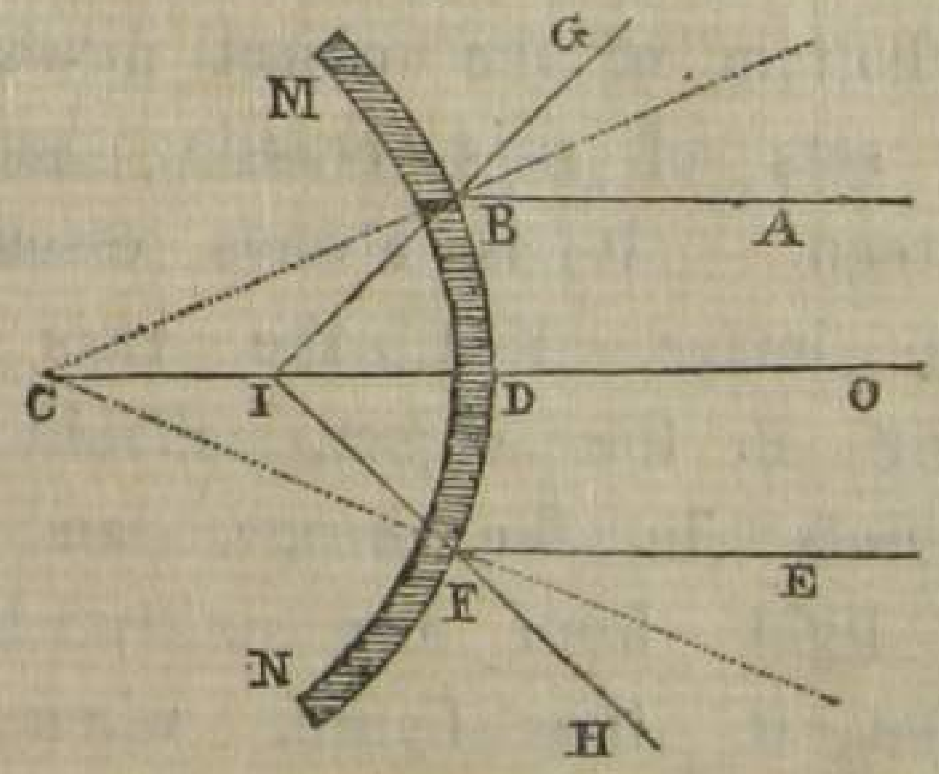
Eig. 77.



of the sun, increasing in heat in the same proportion as the illuminated space at F is less than the whole surface of the mirror. In large concave mirrors, the heat at the focus often becomes very powerful, so as not only to set combustibles on fire, but even to melt the most infusible substances. Hence the name focus, which means a *burning* point. If a lamp is placed at F, the rays of light proceeding from it in the lines F G and F B, will strike upon the mirror and be reflected back into the parallels, G E and B A. We shall see hereafter how useful this property of concave mirrors,—to collect parallel rays of light into a focus,—is in the construction of that most noble of instruments, the telescope.

A *Convex Mirror*, on the other hand, *separates* rays of light from each other, still observing the same law, that of making the angle of incidence equal to the angle of reflexion. In figure 78, the parallel rays, A B, O D, E F, are represented as falling on a convex mirror, M N. A B and E F, being reflected to the other sides of the radii, C B and C F, are separated

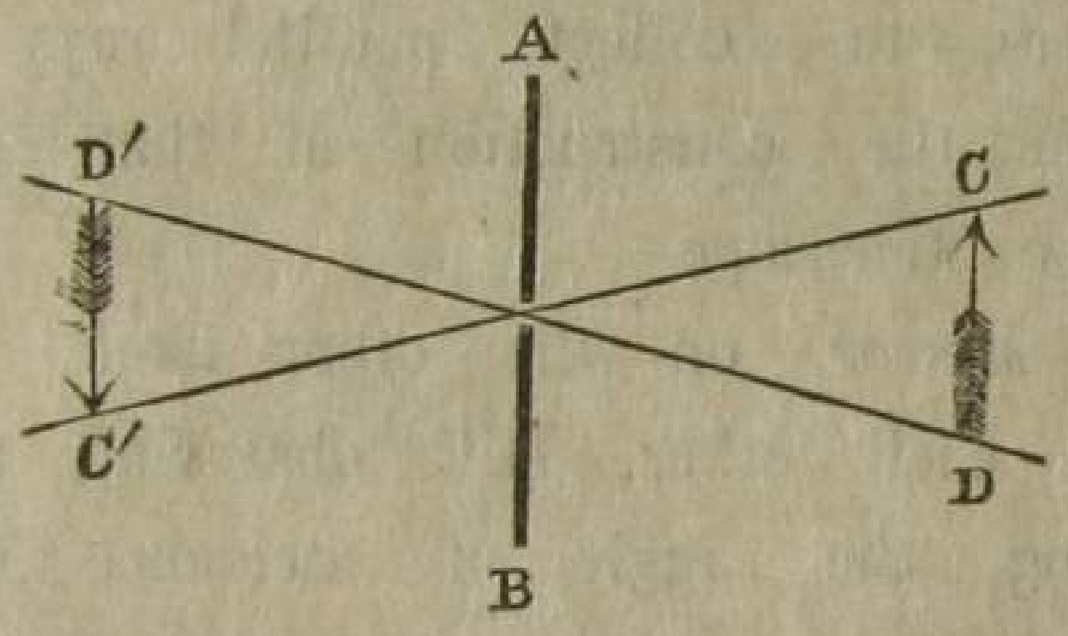
Fig. 78.



from each other, and form the image at I, which is called the *imaginary focus* of parallel rays, because, at this point, the parallel rays that fall upon the mirror *seem* to meet in a focus behind the mirror, and to diverge again into the lines B G and F H.

162. Whenever the rays of light from the different parts of an object cross each other before forming the image, the image will be *inverted.* It is manifest from figure 79, that the light by which the top of the object is represented forms the bottom of the image, and the light from the bottom of the object forms the top of the image, the two sets of rays crossing each other at the hole in the screen. It is always essential to the distinctness of an image, that the rays which proceed from every point in the object, should be arranged in corresponding points in the image, and should be unaccompanied by light from any other source. Now a screen like that in the figure, when interposed, permits only those rays from any point in the object that are very near together and nearly parallel to each other, to pass through the opening, after which they continue straight forward and form the corresponding point of the image; while rays coming from any other point in the object cannot fall upon the point occupied by the

Fig. 79.



former pencil, but each finds an appropriate place of its own in the image, and all together make a faithful representation of the object.

163. Concave mirrors form *images* of objects, by collecting the rays from each point of the object into corresponding points in the image, unaccompanied by rays from any other quarter. If the object be nearer than the focus, as in figure 80, a magnified image appears behind the mirror, and in its natural position; but if the object be between the focus and the center, the image is before the mirror, on the other side of the center, larger than the object, and inverted, as it is in figure 81, where the small arrow, A B, situated between the focus and the center of the mirror, is reflected into the image *a, b,* inverted and larger than the object. These cases may be verified in a dark room, by placing a lamp at different distances from a concave mirror. As such mirrors form their images in the air without any visible

Fig. 80.

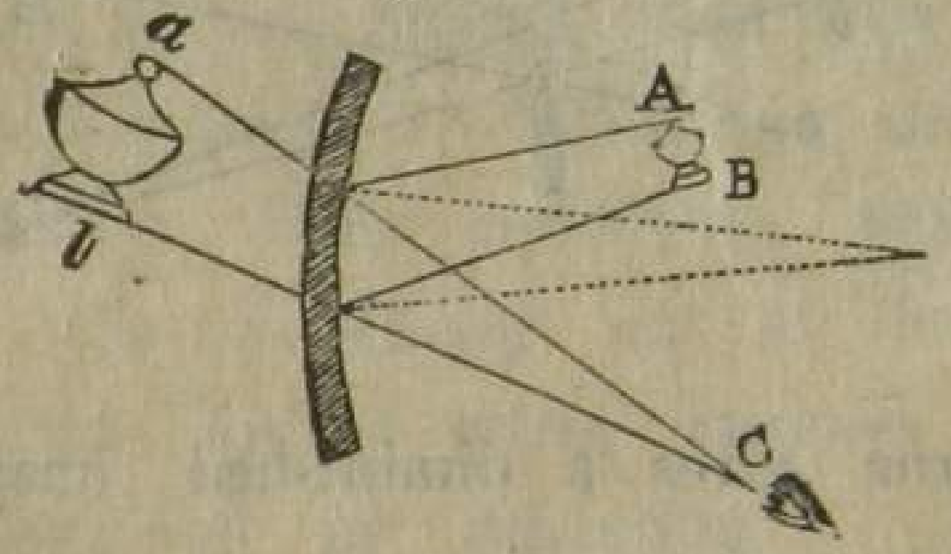
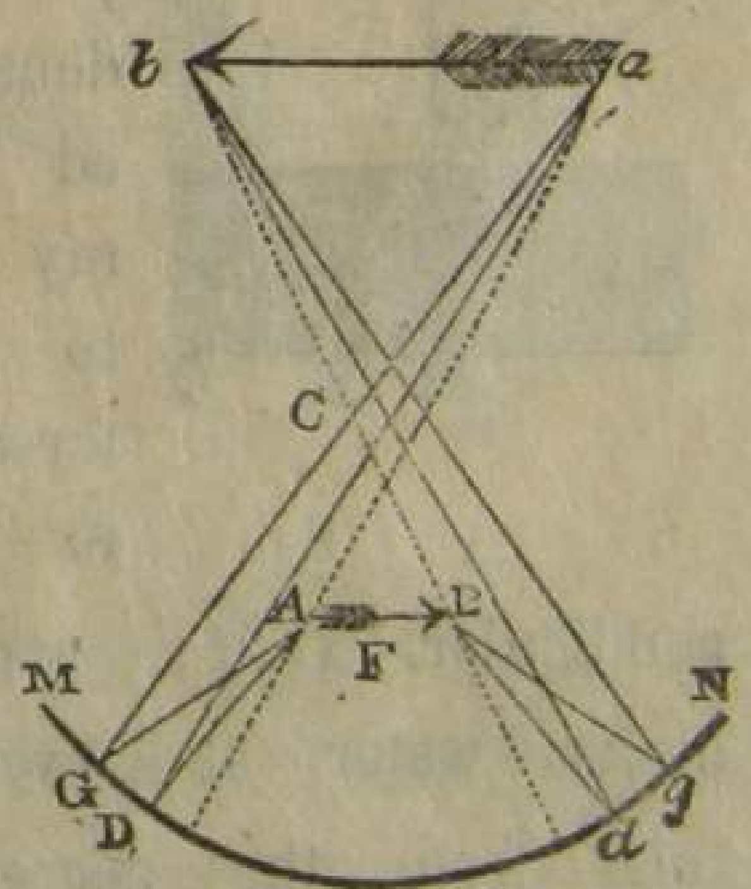
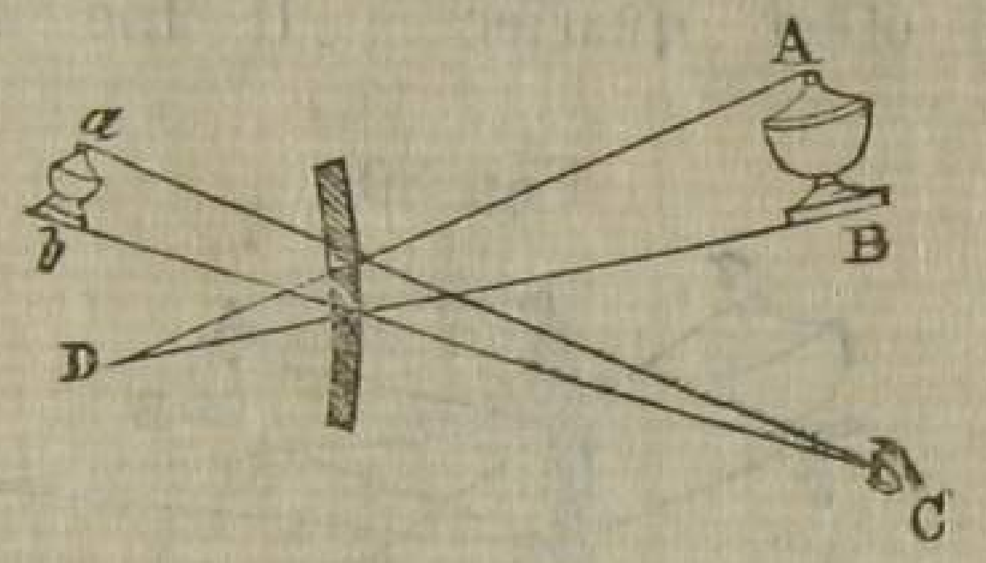


Fig. 81.



support, they have sometimes been employed by jugglers to produce apparitions of ghostly figures, drawn swords, and the like, which were made to appear in terrific forms, while the apparatus by which they were produced, was entirely concealed from the spectators.

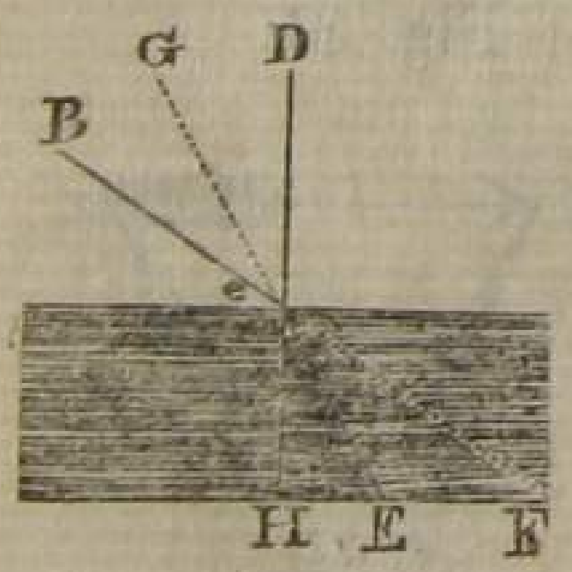
Fig. 82.



A convex mirror gives a diminished image of any object placed before it, representing it in its natural position, and behind the mirror, as in figure 82.

164. *Refraction is the change of direction which light undergoes by passing out of one medium into another.*

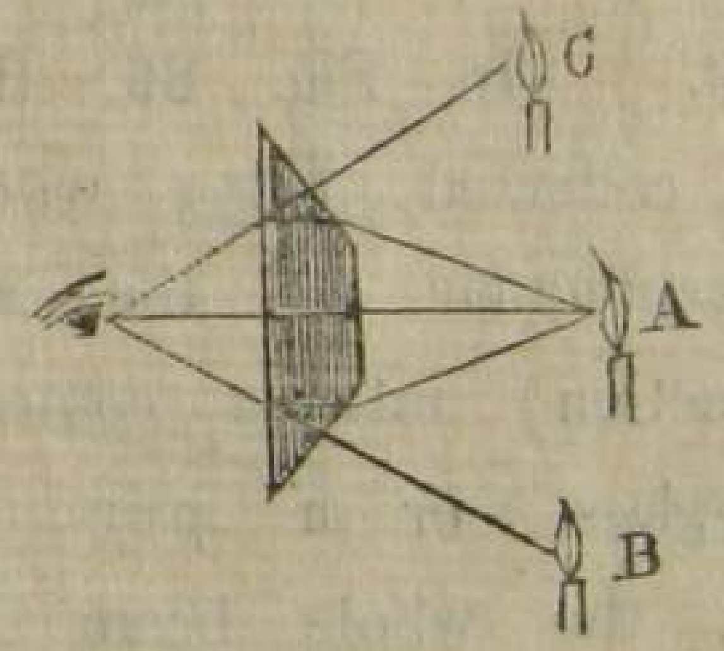
Fig. 83.



When light passes out of a rare medium, like air, into a dense medium, like water, it is turned *toward* a perpendicular; when it passes out of a dense into a rare medium, it is turned *from* a perpendicular. When the ray of light, B C, passes out of air into water, it will not proceed straight forward in the line C F, but will go in the line C E, nearer to the perpendicular, C H; and light proceeding from an object under water at E would, on passing into the air at C, turn from the perpendicular into the line C B. Since objects always appear in the direction in which the light finally comes to the eye, the place of an image is changed by its light passing through a refracting medium before it reaches the eye. Fig. 84 represents a bowl with a small coin at the bottom. An eye situated as in the figure, would not see the coin; but, on turning water into the bowl, the coin becomes visible at B, because the light proceeding from the coin is bent toward the eye in passing out of the water. For a similar reason, an oar in water appears bent, the part immersed being elevated by refraction. The bottom of a shallow river appears higher than it really is, and people have been drowned by attempting to ford a river which, from the effect of refraction, appeared less deep than it was.

Fig. 84.

Fig. 85.



165. The Multiplying-Glass shows as many images of an object as there are surfaces, since each surface refracts the light that falls upon it, in a different angle from the others; of course the rays meet the eye in the same number of different directions, and the object appears in the direction of each. The candle at A, Fig. 85, sends rays to each of the three surfaces of the glass. Those which fall on it perpendicularly, pass directly through the

glass to the eye, without change of direction, and form one image in its true place at A. But the rays which fall on the two oblique surfaces, have their directions changed both in entering and in leaving the glass, (as will be seen by following the rays in the figure,) so as to meet the eye in the directions of B and C. Consequently, images of the candle are formed, also, at both these points. A multiplying glass has usually a great many surfaces inclined to one another, and the number of images it forms is proportionally great.

166. This property of light—the power of having its direction changed by refraction—is converted to very important and interesting uses by means of LENSES. A lens is exemplified in a common sun-glass, (or even in a spectacle-glass,) and is either convex or concave. Convex lenses, like concave mirrors, *collect* rays of light. In Fig. 86, the parallel rays, A *a* and C *c*, are collected along with the central ray (which being perpendicular to the surfaces of the lens, suffers no refraction) into a common focus in F. If I hold a sun-glass, or a pair of convex spectacles toward the sun, the whole beam that falls upon the glass will be collected into a small space, forming a bright point, or focus, at a certain distance from the lens on the side opposite the sun, where it may be received on a screen or sheet of white paper. A *concave* lens, like a convex mirror, *separates* rays of light. Thus, in Fig. 87, the solar beam is spread over a greater space on the screen than the size of the lens, indicating that the rays are separated from each other by passing through the lens. Hence, concave lenses do not form images as convex lenses do, and are therefore but little employed in the construction of optical instruments.

Fig. 86.

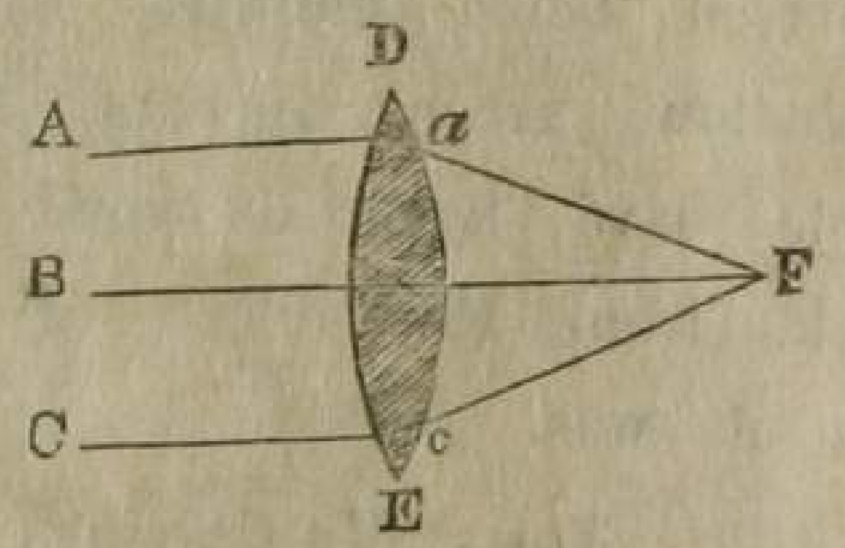
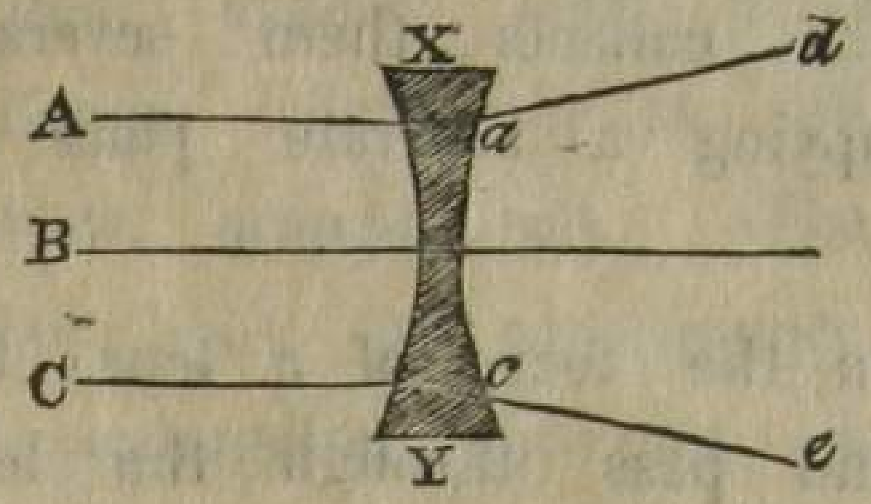
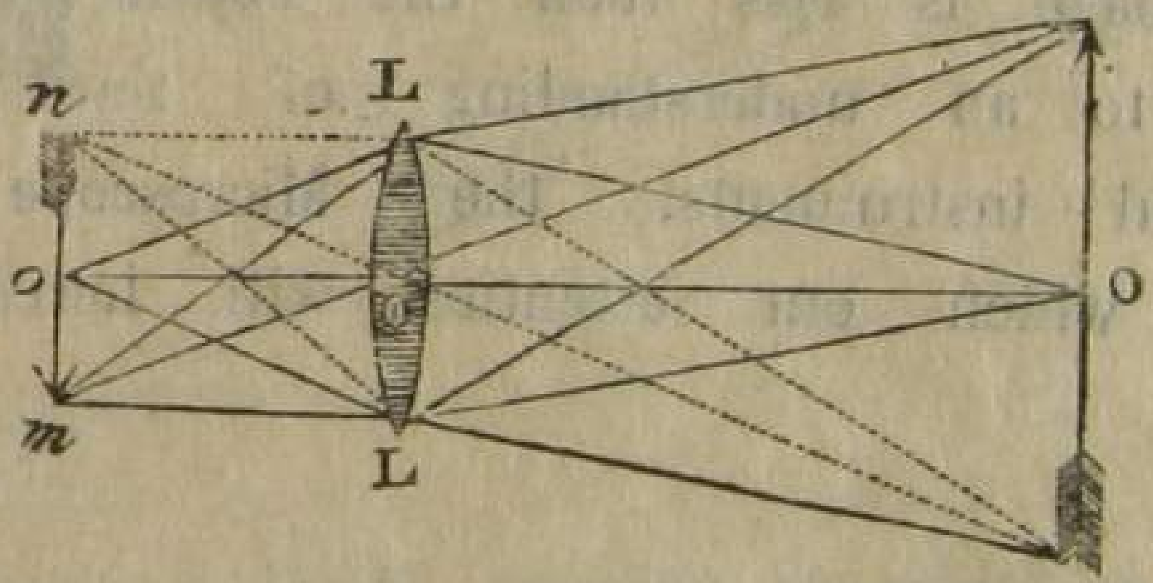


Fig. 87.



167. A convex lens, like a concave mirror, forms an *image* of an object without, by collecting all the pencils of rays that proceed from every point of the object and fall upon the lens, into corresponding points at the place of the image. The image is inverted because the pencils of rays cross each other, those from the top of the object going to the bottom of the image, and those from the bottom going to the top. In the figure, the central ray of each pencil (called the *axis*) and the extreme rays are represented. The ex-

Fig. 88.



treme rays cross each other in the center of the lens, and thus necessarily produce an inverted image; but we must conceive of a great number of rays proceeding from every point in the object, and each pencil covering the whole lens, which collects them severally into distinct points, each occupying a separate place in the image.

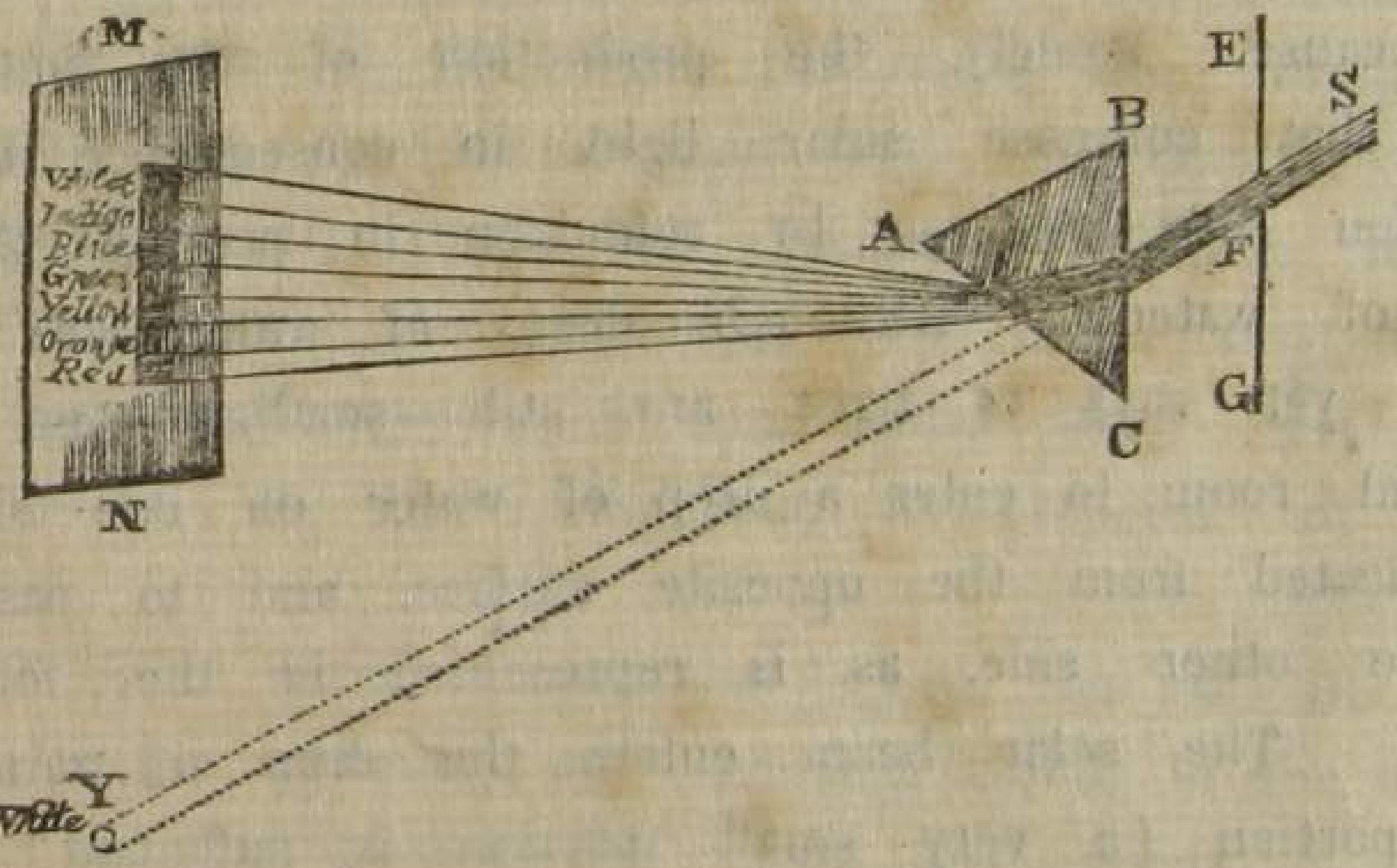
168. If we place a lamp in the focus of a lens, the rays that proceed from it and pass through the lens, go out parallel, and will never come to a focus on the other side, so as to form an image. But if we remove the lamp farther from the lens, so as to make the rays fall upon the lens in a state less diverging, then it will collect them into a distinct image on the other side, which image will be large in proportion as it is more distant from the lens. As the object is withdrawn from the lens, the image approaches it; when they are at equal distances from the lens, they are equal in size; but when the object is farther from the lens than the image, the image is less than the object. These principles lead to an understanding of those interesting and wonderful instruments, the Microscope and the Telescope, to which our attention will hereafter be directed.

Sec. 2. *Of Colors.*

169. The philosophy of colors has been unfolded chiefly by means of the *Prism.* A Prism is a triangular piece of glass, usually four or five inches long, presenting three plane smooth surfaces. When we look through the prism, all external objects appear in

the most brilliant hues, diversified by the various colors of the rainbow. The reason of this is, that light consists of seven different colors, which, when in union with each other, compose white light; but when separated, appear each in its own peculiar hue. The different colors are as follows—violet, indigo, blue, green, yellow, orange, red. The prism separates the rays of solar light, in consequence of their having the property of undergoing different degrees of refraction in passing through it, the violet being turned most out of its course and the red least, and all the others differing among themselves in this respect, as is shown in the following diagram. E F represents the window shutter of a dark room, through a small opening in which a beam of solar rays shines. They fall on the prism, A B C, and are refracted, by which they are turned upward, but in different degrees, the red least and the violet most. By this means they are separated from each other, and lie one above another on the opposite wall, constituting

Fig. 89.



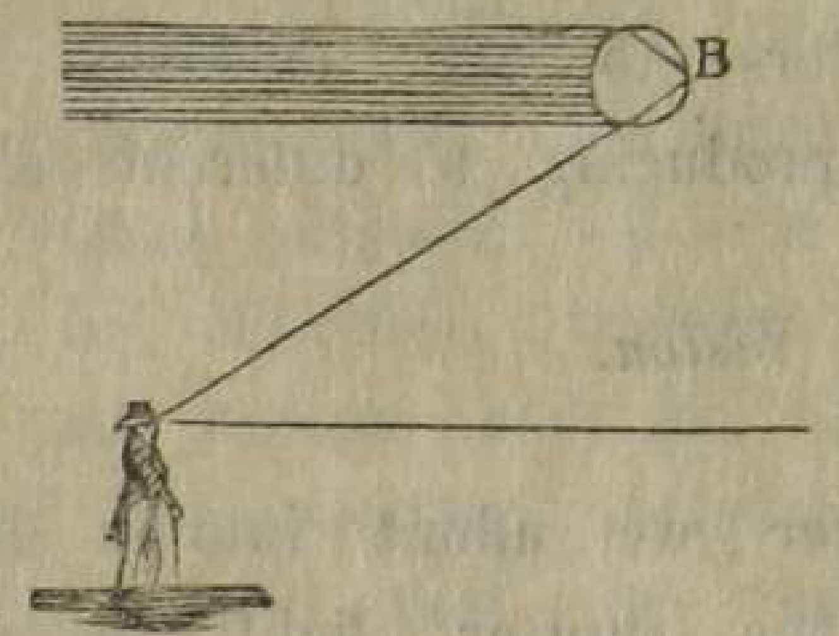
the beautiful object called the *solar spectrum.* We may now introduce a double convex lens into the spectrum, just behind the prism, and collect all the rays which have been separated by the prism, and they will recompose white light. The elongated spectrum on the wall, presenting the seven primary colors, will vanish, and in the place of it will appear a round image of the sun as white as snow.

170. We may now learn the reason why so many different colors appear when we look through the prism. The leaves of a tree, for example, seem to send forth streams of red light on one side and of violet on the other. The intermediate colors lap over, and partly neutralize each other, while on the margin each color exhibits its own proper hue.

171. The *rainbow* owes its brilliant colors to the same cause, namely, the production of the individual colors that compose solar light, in consequence of the separation they undergo by refraction in passing through drops of water. Although drops of water are small objects, yet rays of light are still smaller, and have abundant room to enter a drop of water on one side, to be reflected from the opposite surface, and to pass out on the other side, as is represented in the following figure. The solar beam enters the drop of rain, and some portion (a very small portion is sufficient) being refracted to B, then reflected and finally refracted again in leaving the drop, is conveyed to the eye of the spectator. As in undergoing these two refractions, some rays are refracted more than others, consequently they are separated from each other, and coming to the eye of the spectator in this divided state, produce each

its own color. The spectator stands with his back to the sun, and a straight line passing from the sun through the eye of the spectator, passes also through the center of the bow. When the sun is setting, so that this line becomes horizontal, the summit of the bow reaches an altitude of about 42°, and the bow is then a semicircle. When the sun is 42° high, the same line would pass 42° below the opposite horizon, and the summit of the bow would barely reach the horizon. When the sun is between these two altitudes, the bow rises as the sun descends, composing a larger and larger part of a circle, until, as the sun sets, it becomes an entire semicircle.

Fig 90.



172. The varied colors that adorn the face of nature, as seen in the morning and evening cloud, in the tints of flowers, in the plumage of birds and wings of certain insects, and in the splendid hues of the precious gems, arise from the different qualities of different bodies in regard to the power of refracting or of reflecting light. When a substance reflects all the prismatic rays in due proportion, its color is white; when it absorbs them all, its color is black; and its color is blue,

green, or yellow, when it happens to reflect one of these colors, and to absorb all the others of the spectrum. These hues are endlessly varied by the power natural bodies have of reflecting a mixture of some of the primary colors to the exclusion of others, every new proportion producing a different shade.

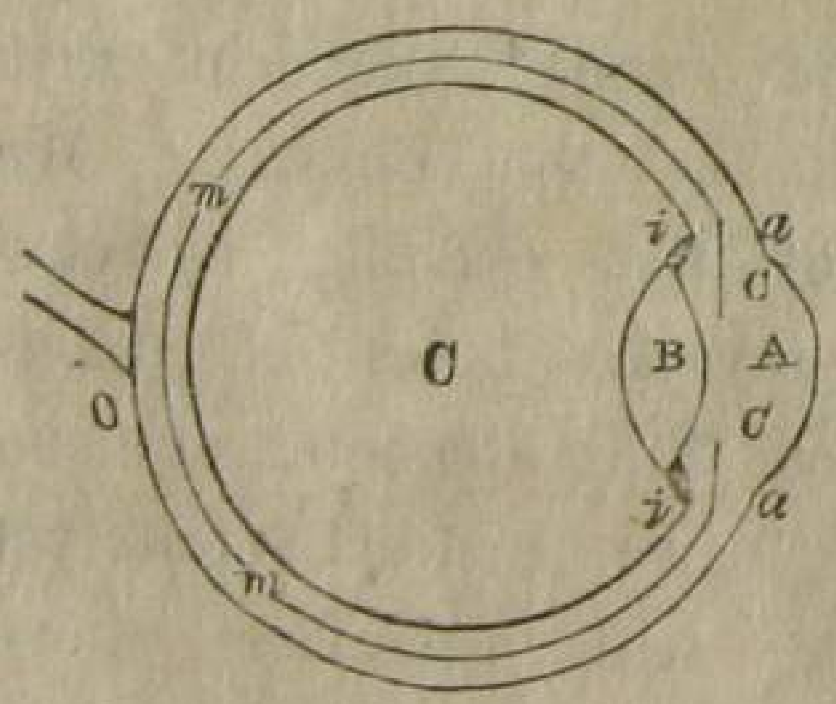
SEC. 3. *Of Vision.*

173. Whenever we admit into a dark room through an opening in the shutter, light reflected from various objects without, an inverted picture of these objects will be formed on the opposite wall. A room fitted for exhibiting such a picture, is called a *Camera Obscura.* In a tower which has a window opening toward the east, upon a beautiful public square, containing churches and other public buildings, and numerous trees, and the various objects of a populous city, a little dark chamber is fitted up for a camera obscura, having a white concave stuccoed wall opposite to the window, ten feet from it, and all the other parts of the room painted black. The afternoon, when the sun is shining bright in the west, and all objects seen to the east present their enlightened sides toward the window, is the time for forming the picture. For this purpose, a round hole about three inches in diameter, is prepared in the shutter, which admits the only light that can enter the room. The room is made black everywhere except the wall that is to receive the picture, otherwise light would be reflected from different parts of the room upon the picture; whereas it is essential to its distinctness, that the image should be unaccompanied by light from any other source. The wall that is to receive the picture is made concave, so that every part of it may be equally distant from the orifice in the shutter.

174. We now close the shutter, and instantly there appears on the opposite wall a large picture, representing all the varied objects of the landscape seen from the window, as churches, houses, trees, men and women, carriages and horses, and in short every thing that is in view of the window, including the blue sky, and a few white clouds that are sailing through it. Each is represented in its proportionate size and color, and if it is moving, in its true motion. Two circumstances, only, impair the beauty of the picture; one is, that it is not perfectly distinct, the other, that it is inverted—the trees appear to grow downward, and the people to walk with their feet above their heads. The picture appears indistinct, because the opening in the shutter is so large that rays coming from different objects fall upon the picture and mix together, whereas each point in the image must be formed alone of rays coming from a corresponding point in the object. We will therefore diminish the size of the opening by covering it with a slide containing several holes of different sizes. We will first reduce the diameter to an inch. The picture is now much more distinct, but yet not perfectly well defined. We will therefore move the slide, and reduce the opening to half an inch. Now the objects are perfectly well defined, for through so small an opening none but the central ray, or axis, of each pencil can enter, and each axis will strike the opposite wall in a point distinct from all the rest. But though the picture is no longer confused, yet it lacks brightness, for so few rays scattered over so large a

surface, are insufficient to form a bright image. We will now remove the slide, open the original orifice of three inches, which lets in a great abundance of light, and we will place immediately before the orifice, (within the room,) a convex lens of ten feet focus, which will collect all the scattered rays into separate foci, and thus form a picture at once distinct and bright, so that the most delicate objects without, as the trembling of the leaves of the trees, and the minutest motions of animals, are all very plainly discernible. Only one thing is wanting to make the picture perfect, and that is, to turn it right side upward. This may be done, and is done in some forms of the camera obscura; but for our present purpose, which is to illustrate the principles of the eye, where the image formed is also inverted, it is better as it is.

Fig 91.



175. The eye is a camera obscura, and the analogy between its principal parts and the contrivances employed to form a picture of external objects, as in the foregoing dark chamber, will appear very striking on comparison. Figure 91 represents the human eye, which is a circular chamber, colored black on all sides except the back part, called the *retina*, which is a delicate white membrane, like the finest gauze, spread to receive the image The front part of the eye, A, is a lens of a shape exactly adapted to the purpose it is intended to serve, which projects forward so as to receive the light that comes in sidewise, and guides it into the eye. The *pupil* is an opening between *c* and *c*, like the opening in the window shutter, just behind which is a convex lens, B, which collects all the scattered rays, and brings each pencil to a separate focus, where they unite in forming a bright and beautifully distinct image of all external objects O represents the *optic nerve*, by which the sensations made on the retina are conveyed to the brain. The substances with which the several parts of the eye, A, B, and C, are filled, are limpid and transparent, and purer than the clearest crystal.

176. It is essential to distinct vision, that the rays which enter the eye should be brought accurately to a focus at the place of the retina; and in ninety-nine cases out of a hundred, this adjustment is perfect. But in a few instances, the lens, B, called the *crystalline humor*, is too convex, and then the image is formed before it reaches the retina. This is the case with nearsighted people. Their eyes are too convex; but by wearing a pair of concave spectacles, they can destroy the excess of convexity in the eye, and then the crystalline lens will bring the light to a focus on the retina and the sight will be distinct. Sometimes, particularly as old age advances, the crystalline lens becomes less convex, and does not bring the rays to a focus soon enough, but they meet the retina before they have come accurately to a focus, and form a confused image. In this case a pair of convex spectacles aids the crystalline lens, and both together cause the image to fall exactly on the retina. As a piece of mechanism, the eye is unequalled for its beauty and perfection, and no part of the creation proclaims more distinctly both the existence and the wisdom of the Creator.

Sec. 4. *Of the Microscope.*

177. The Microscope is an optical instrument, designed to aid the eye in the inspection of *minute* objects. The simplest microscope is a convex lens, like a spectacle glass. This, when applied to small objects, as the letters of a book, renders them both larger and more distinct. When an object is brought nearer and nearer to the eye, we finally reach a point within which vision begins to grow imperfect. That point is called the *limit of distinct vision.* Its distance is about five inches. If the object be brought nearer than this distance, the rays come to the eye too diverging for the lenses of the eye to bring them to a focus soon enough, so as to make their image fall exactly on the retina. Moreover, the rays which proceed from the extreme parts of the object, meet the eye too obliquely to be brought to the same focus with those rays which meet it more directly, and hence contribute only to confuse the picture.

178. We may verify these remarks by bringing gradually toward the eye a printed page with small letters. When the letters are within two or three inches of the eye, they are blended together and nothing is seen distinctly. If we now make a pin-hole through a piece of paper, and look at the same letters through this, we find them rendered far more distinct than before at near distances, and larger than ordinary. Their greater *distinctness* is owing to the exclusion of those oblique rays which, not being brought by the eye to the same focus with the central rays, only tend to confuse the image formed by the latter. As

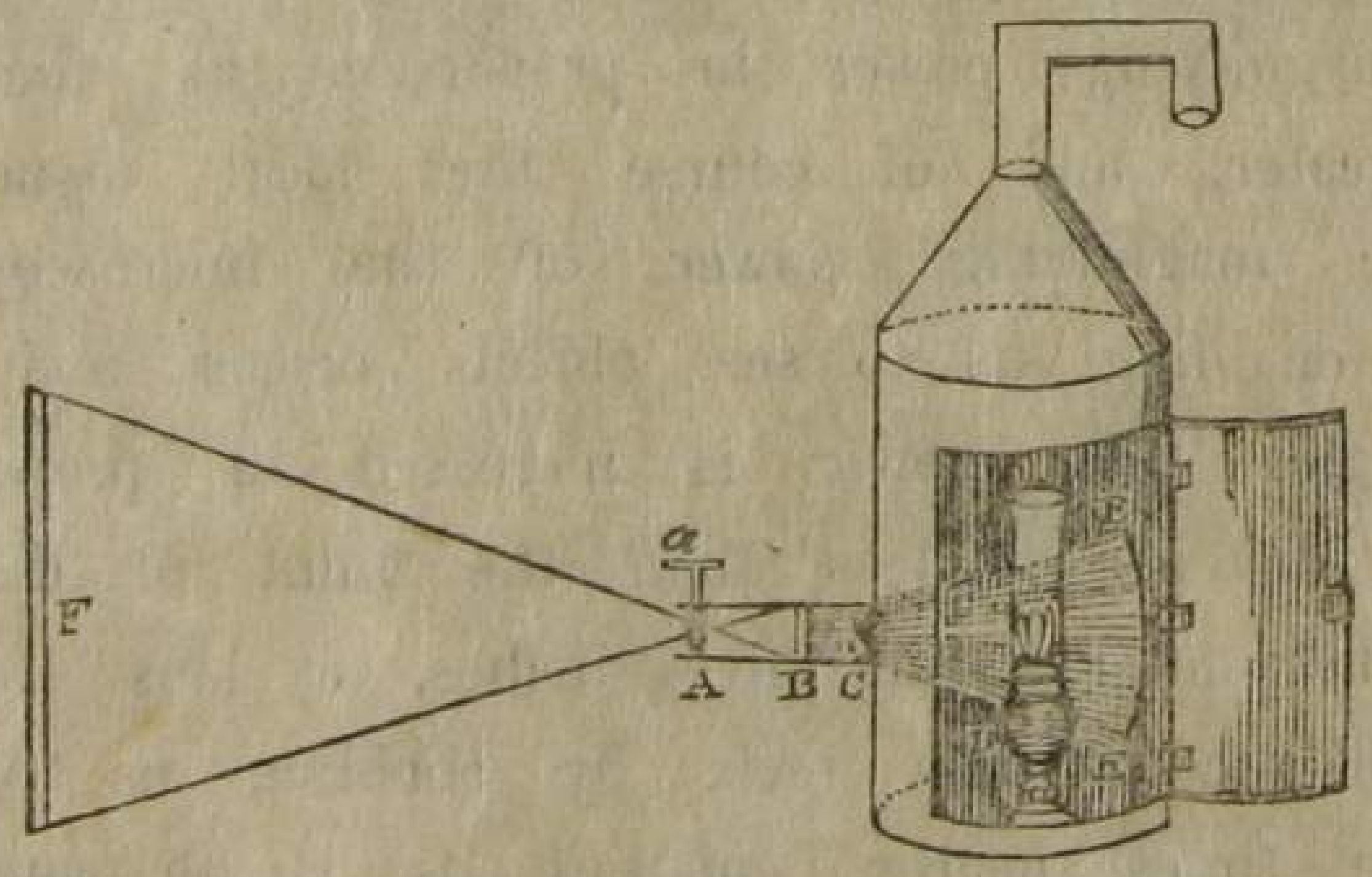
only the central rays of each pencil can enter so small an orifice, the picture is made up chiefly of the *axes* of all the pencils. These occupy each a separate point in the image, a point where no other rays can reach. The *increased magnitude* of the letters is owing to their being seen nearer than ordinary, and thus under a greater angle, and of course magnified.

179. A convex lens acts much on the same principles, but is still more effectual. It does not *exclude* the oblique rays, but it diminishes their obliquity so much as to enable the eye to bring them to a focus, at the distance of the retina and thus makes them contribute to the *brightness* of the picture. The object is *magnified*, as before, because it is seen nearer and consequently under a larger angle, so that the eye can distinctly recognise minute portions of the object, which were before invisible, because they did not occupy a sufficient space on the retina. Lenses have greater magnifying power in proportion as the convexity is greater, and of course the focal distance less. Since the magnifying power of the microscope arises from its enabling us to see objects nearer and under a larger angle, that power is increased in proportion as the focal distance is less than the limit of distinct vision. The latter being five inches, a lens which has a focal distance of one inch, by enabling us to see the object five times nearer, enlarges its length and breadth each five times, and its surface twenty-five times. Lenses have been made capable of affording a distinct image of very minute objects, when their focal distances were only one-sixtieth of an inch. In this case, the magnifying power would be as one-sixtieth to five;

or it would magnify the length and breadth each 300 times, and the surface 90,000 times.

180. The *Magic Lantern* and *Solar Microscope* owe their astonishing effects to the magnifying power of a simple lens. When the image so much exceeds the object in magnitude, were the object only enlightened by the common light of day, when it came to be diffused over so great a space, it would be very feeble, and the image would be obscure and perhaps invisible. The two instruments just named, have each an apparatus connected with the magnifying lens, which serves to illuminate the object highly, so that when the rays that proceed from it and form the enlarged image are spread over so great a space, they may still be sufficient to render the image bright and distinctly visible.

Fig. 92.



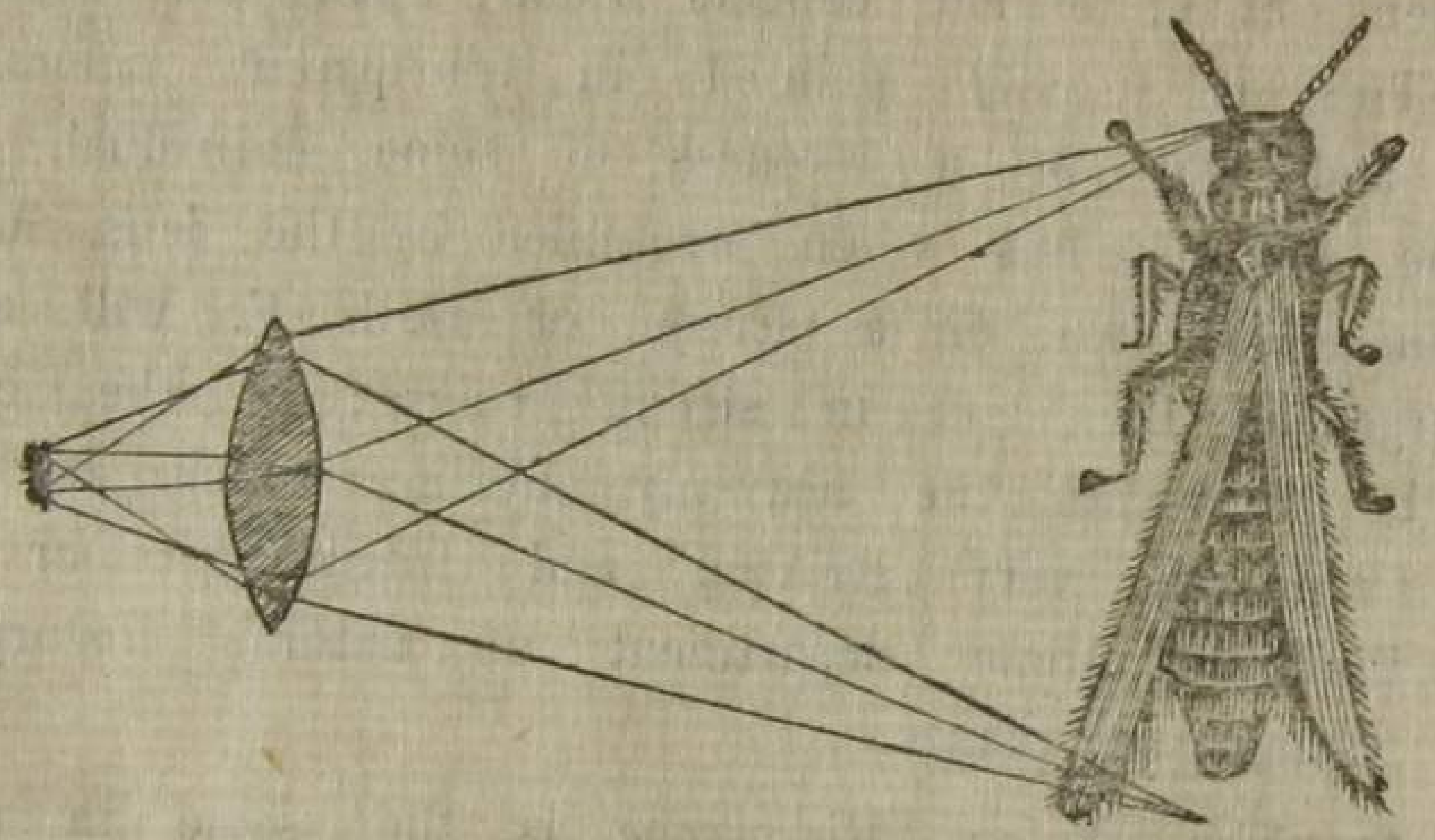
181. In the Magic Lantern, the illumination is afforded by a lamp, the light of which is reflected from a concave mirror placed behind it, which makes the light on that side return to unite with the direct light

of the lamp, so that both fall on a large lens which collects them upon the object, thus strongly illuminating it. The foregoing diagram exhibits such a lantern, where the concave mirror behind is seen to reflect back the light to unite with that which proceeds directly from the lamp, so that both fall on the large convex lens at C, which collects them upon the object at B. This is usually painted in transparent colors on glass, and may be a likeness of some individual, small in the picture, but when magnified by the lens, A, and the image thrown on a screen or wall, F, will appear as large as life, and in strong colors; or the objects may be views of the heavenly bodies, which are thus often rendered very striking and interesting; or they may illustrate some department of natural history, as birds, fishes, or plants.

182. The *Solar Microscope* is the same in principle with the Magic Lantern, but the light of the sun instead of that of a lamp is employed to illuminate the object. As a powerful light may thus be commanded, very great magnifiers can be employed; for if the object is highly illuminated, the image will not be feeble or obscure when spread over a great space. By means of this instrument, the eels in vinegar, which are usually so small as to be invisible to the naked eye, may be made to appear six feet in length, and, as their motions as well as dimensions are magnified, they will appear to dart about with surpaising velocity. The finest works of art, when exhibited in this instrument, appear exceedingly coarse and imperfect. The eye of a finished cambric needle appears full of rough projections; the blade of a razor looks like a saw; and the finest muslin exhibits threads as large as the cable of a ship. Thus, the small and almost invisible insect

represented in figure 93, gives out, when illuminated, so few rays, that when spread over the large surface of the image, the light would be too feeble to render the image visible; but, on strongly illuminating the

Fig 93.

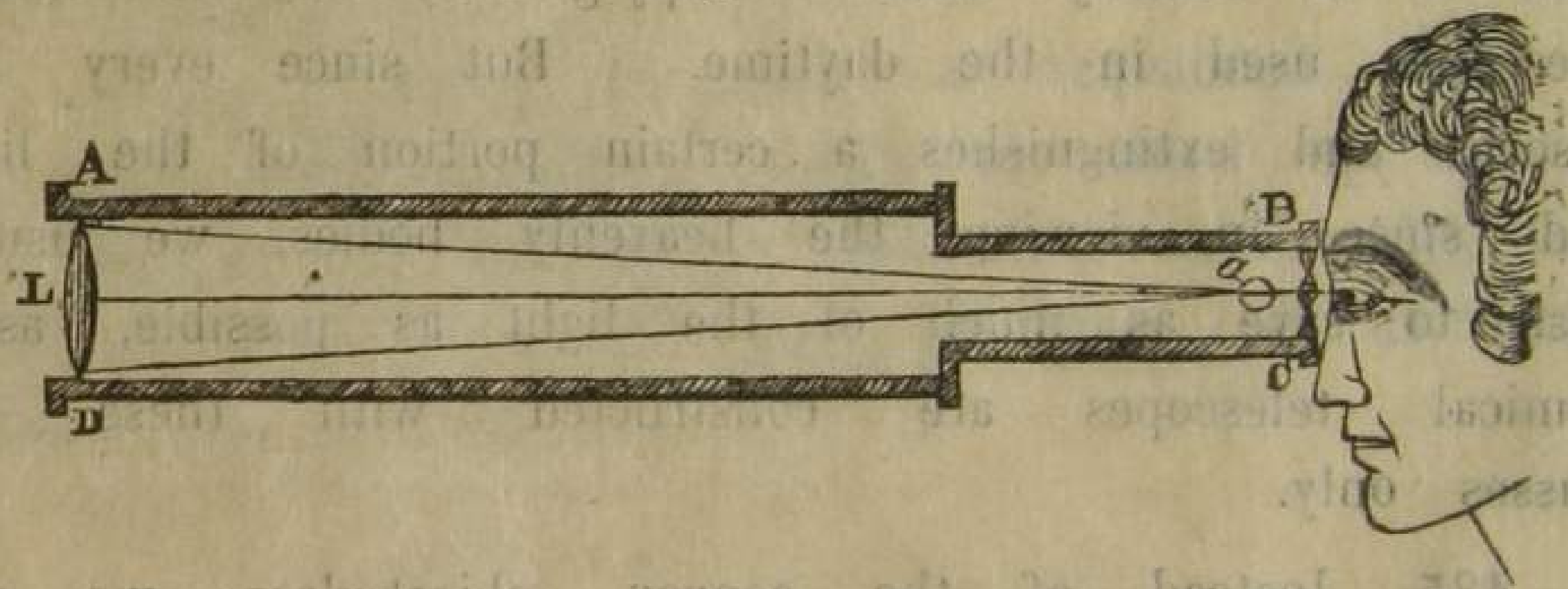


insect by concentrating upon it a large beam of the sun's light, the image becomes distinct and beautiful, although perhaps a million times as large as the object. Even the minute parts of the insect, as the hairs on the legs, are revealed to us by the microscope.

Sec. 5. *Of the Telescope.*

183. The Telescope is an instrument employed for viewing *distant* objects. It aids the eye in two ways; first, by enlarging the angle under which objects are seen, and, secondly, by collecting and conveying to the eye a much larger amount of the light that proceeds from the object, than would enter the naked pupil. *We first form an image of a distant object, the moon, for example, and then magnify that image by a microscope.* The image may be formed either by a concave mirror or a convex lens, for both, as we have seen, form images. Although we cannot go to distant objects, as the moon and planets, so as to view them under the enlarged dimensions in which they would then appear, yet by applying a microscope to the image of one of those bodies, we may make it appear as it would do, were we to come much nearer to it. To apply a microscope which magnifies a hundred times, is the same thing as to approach a hundred times nearer to the body.

Fig. 94.



184. Let A B C D represent the tube of the telescope. At the front end, or the end which is directed toward the object, (which we will suppose to be the moon,) is inserted a convex lens, L, which receives the rays of light from the moon, and collects them into the focus at *a*, forming an image of the moon. This image is viewed by a magnifier attached to the end, B C. The lens, L, is called the *object-glass*, and the microscope, in B C, the *eye-glass*. A few rays of light only from a distant object, as a star, can enter so small

a space as the pupil of the eye; but a lens one foot in diameter will collect a beam of light equal to a cylinder of the same dimensions, and convey it to the eye. The object-glass merely forms an image of the object, but does not magnify; the microscope or eye-glass magnifies. By these means, many obscure celestial objects become distinctly visible, which would otherwise be too minute, or not sufficiently luminous, to be seen by us. A telescope, like the foregoing, having simply an object-glass and an eye-glass, inverts objects, since the rays cross each other before they form the image. By employing more lenses, it may be turned back again, so as to appear in its natural position, as is usually done in spy-glasses, or the smaller telescopes used in the daytime. But since every lens absorbs and extinguishes a certain portion of the light, and since, in viewing the heavenly bodies, we usually wish to save as much of the light as possible, astronomical telescopes are constructed with these two glasses only.

185. Instead of the convex object-glass, we may employ the concave mirror to form the image. When the lens is used, the instrument is called a *refracting* telescope; when a concave mirror is used, it is called a *reflecting* telescope. Large reflectors are more easily made than large refractors, since a concave mirror may be made of any size; whereas, it is very difficult to obtain glass that is sufficiently pure for this purpose above a few inches in diameter, although Refractors are more perfect instruments than Reflectors, in proportion to their size. Sir William Herschel, a great astronomer of England, of the last century, made a

reflecting telescope forty feet in length, with a concave mirror more than four feet in diameter. The mirror alone weighed nearly a ton. So large and heavy an instrument must require a vast deal of machinery to work it and keep it steady; and accordingly, the framework surrounding it was formed of heavy timbers, and resembled the frame of a house. When one of the largest of the fixed stars, as Sirius, was entering the field of this telescope, its approach was announced by a bright dawn, like that which precedes the rising sun; and when the star itself entered the field, the light was too dazzling to be seen without a colored glass to protect the eye.

The telescope has made us acquainted with innumerable worlds, many of which are fitted up in a style of far greater magnificence than our own. To the interesting and ennobling study of these, let us next direct our attention.

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