organized. Natural Philosophy admits of two corresponding divisions: *Science of Organized Matter*, or PHYSIOLOGY, and *Science of Unorganized Matter*, or GENERAL PHYSICS.

Physiology, which treats of the laws of matter as modified by the principle of vitality, is divided into two principal branches: *Animal Physiology*, or ZOÖLOGY, and *Vegetable Physiology*, or BOTANY. Both of these branches, with their various subdivisions, belong to the domain of NATURAL HISTORY.

All unorganized matter may be divided into two classes, *Celestial* and *Terrestrial*. General Physics admits of two corresponding divisions. That branch which treats of celestial bodies, including the earth as whole, is called ASTRONOMY; that which treats of terrestrial bodies, is called TERRESTRIAL PHYSICS.

TERRESTRIAL PHYSICS is again subdivided into two branches. The first is called *Physics Proper*, or simply PHYSICS; it treats of the general properties of bodies. The second is called CHEMISTRY; it treats of the nature of the ultimate particles of bodies and of their laws of combination. The first of these branches, or PHYSICS, is the subject treated of in the following pages.

Besides the branches above enumerated, and which may be called *Pure Sciences*, there are others that depend upon, or are applications of, two or more of them. Such, for example, are the sciences of GEOLOGY, MINERALOGY, PHYSICAL GEOGRAPHY, &c. These are called *Mixed Sciences*.

Into what may Natural Philosophy be divided? What is Physiology, and what are its branches? How may Unorganized Matter be divided? What are the corresponding divisions of General Physics? Define them. How is Terrestrial Physics divided? What is Physics Proper? Chemistry? What are the Pure Sciences, and what are some of the Mixed Sciences?

CHAPTER I.

PRELIMINARY PRINCIPLES AND MECHANICS OF SOLIDS.

I.—DEFINITIONS AND GENERAL PROPERTIES OF MATTER.

Definition of Physics—Physical Agents.

1. PHYSICS is that branch of Natural Philosophy which treats of the general properties of bodies, and of the causes that modify these properties.

The principal causes that modify the properties of bodies are: *Gravitation*, *Heat*, *Light*, *Magnetism*, and *Electricity*. These causes are called *Physical Agents*.

Definition of a Body.

2. A BODY is a collection of material particles; as a stone, or a block of wood. A body which is exceedingly small is called a *Material Point*.

Bodies are made up of small particles, called *Molecules*, and these again are composed of still smaller elements, called *Atoms*. These atoms are inconceivably small, and are held in their places by the action of two opposing systems of forces, called *Molecular Forces*. Those which tend to draw atoms together are called *Attractive Forces*, and those which tend to push them asunder are called *Repellent Forces*. Heat is the principal if not the only repellent force in Nature.

(**1.**) What is Physics? What are Physical Agents? Name them. (**2.**) Define a Body. A Material Point. An Atom. A Molecule. What are Molecular Forces? Define Attractive and Repellent Forces.

Mass and Density.

3. The Mass of a body is the quantity of matter which it contains.

Different bodies, having the same volume, contain very different quantities of matter; for example, a cubic inch of lead contains nearly eleven times as much matter as a cubic inch of water. The masses of bodies are proportional to their weights.

The Density of a body is the degree of closeness of its particles.

Those bodies in which the particles are close together are said to be *dense;* thus, platinum and mercury are *dense* bodies. Those in which the particles are not close together are said to be *rare;* thus, steam and air are *rare* bodies. The densities of bodies having the same bulk are proportional to their weights.

Classification of Bodies.

4. Bodies may exist in two different states, the *solid* and the *fluid.*

Solids are those which tend to retain a permanent form; as stones, metals, and the like. The particles of such bodies adhere to each other with considerable energy, and this adhesion can only be overcome by the exertion of some effort.

Fluids are those whose particles move freely amongst each other; as water, alcohol, and air. Such bodies have no tendency to retain a permanent form, but assume at once the form of the containing vessel.

Fluids are divided into *Liquids* and *Gases* or *Vapors. Liquids* are sensibly incompressible; as water, wine, and milk. *Gases* and *vapors* are highly compressible; as atmospheric air and steam.

(**3.**) What is the mass of a body? Density? Give examples of dense and rare bodies. (**4.**) How are bodies divided? Define solids and fluids. How are fluids divided? Define liquids, and gases or vapors.

In solids, the molecular forces of attraction are greater than the repellent forces, hence the difficulty of separating their molecules; in liquids, the attractive and repellent forces are sensibly balanced; in gases, the repellent are more powerful than the attractive forces.

Many bodies may exist in each of the three states in succession. Thus, if ice be heated until the repellent forces balance those of attraction, it passes into the liquid state and becomes water; if still more heat be applied, the repellent forces prevail over those of attraction, and it passes into the state of vapor and becomes steam.

General Properties of Bodies.

5. All bodies possess certain properties, the most important of which are: *Magnitude, Form, Impenetrability, Inertia, Porosity, Divisibility, Compressibility, Dilatability, and Elasticity.*

Magnitude and Form.

6. The Magnitude of a body is its bulk, or the portion of space that it fills. It is evident that a body can not exist without possessing the three attributes of length, breadth, and thickness.

The Form of a body is its external shape. Bodies may have the same magnitude and be very different in shape; they may likewise be of the same form and yet be of very different magnitudes.

Impenetrability.

7. Impenetrability is that property by virtue of which no two bodies can occupy the same place at the same time. This property is self-evident, although phenomena are observed which would seem to conflict with it. Thus, when a pint of alcohol is mixed with a pint of water, the volume of the resulting mixture is less than a quart. This diminu-

Illustrate. (**5.**) What properties belong to all bodies? (**6.**) What is Magnitude? Form? (**7.**) What is Impenetrability? Illustrate.

tion of volume arises from the particles of one of the fluids insinuating themselves between those of the other; but it is clear that where a particle of alcohol is, there a particle of water can not be. In like manner when a nail is driven into a board, the particles of the latter are thrust aside and compressed to make room for those of the latter.

Inertia.

8. INERTIA is the tendency which a body has to maintain its state of rest or motion. If a body is at rest it has no power to set itself in motion, or if it is in motion it has no power to change either its rate of motion or the direction in which it is moving. Hence, if a body is at rest, it will remain at rest, or if in motion, it will move on uniformly in a straight line until acted upon by some force.

The reason why we do not see bodies continue to move on uniformly in straight lines, when set in motion, is that they are continually acted upon by forces which change their state of motion. Thus, a ball thrown from the hand, besides meeting with the resistance of the air, is continually drawn downwards by the attraction of the earth, till at last it is brought to rest.

Many familiar phenomena are explained by the principle of inertia. For example, when a vehicle in motion is suddenly arrested, loose articles in it are thrown to the front, because they tend to keep the motion which they had acquired. When a man in running strikes his foot against an obstacle, the inertia of the upper part of his body carries it forward, and he falls to the ground. For the same reason, when a man jumps from a car in motion, he will be in danger of falling in the direction of the moving car. It is inertia which renders accidents upon railroads so terrible. When from any cause the locomotive is suddenly arrested, the inertia of the entire train acts to pile the cars together in one general wreck. It is the inertia of the hammer that enables it to overcome the resistance

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Give examples of apparent penetrability. (8.) What is Inertia? Illustrate. *Why do we not see bodies conform to the law of inertia? Give examples of the principle of inertia.*

which the wood offers to the entering nail; and in driving piles, the principal effect is due to the inertia of the descending ram.

Porosity.

9. POROSITY is the degree of separation between the molecules of a body. The intervals between the molecules are called *pores*. When these intervals are very great, the body is said to be *porous*, as in steam, air, and gases. When the intervals are very small, the body is said to be *dense*, as in gold, platinum, and mercury. *Pores* must not be confounded with *cells*, as in sponge, light bread, and the like.

All bodies are more or less porous.

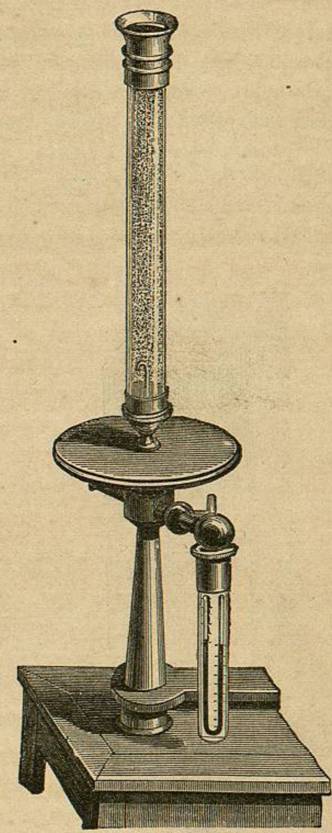

Fig. 1.

The following experiment shows the porosity of leather. A long glass tube (Fig. 1) is surmounted by a brass cup, with a thick leather bottom, fitting the tube air-tight. The lower end of the tube terminates in a brass cap, which is attached to a machine for exhausting the air from the tube, called an air-pump.

If a quantity of mercury is

(9.) What is Porosity? When are bodies porous? When dense? *Explain the experiment showing the porosity of leather.*

poured into the upper cup, and the air exhausted from the tube, the mercury, being pressed down by the external air, is seen falling through the leather in small drops like rain.

Gold was shown to be porous by some Florentine philosophers in the following manner. A hollow sphere of gold was filled with water and tightly closed, after which it was subjected to great pressure. The water was seen to issue from the globe and form on its surface like dew. The experiment has since been repeated with other metals, and with like results.

Gases are shown to be porous by their enormous reduction in volume when compressed; if a gas be introduced into a jar, it will spread by its expansive force and completely fill the vessel; if a second gas be introduced into the same vessel, it likewise expands and fills the vessel as though the first gas did not exist. This proves that the molecules of the second gas arrange themselves in the pores of the first.

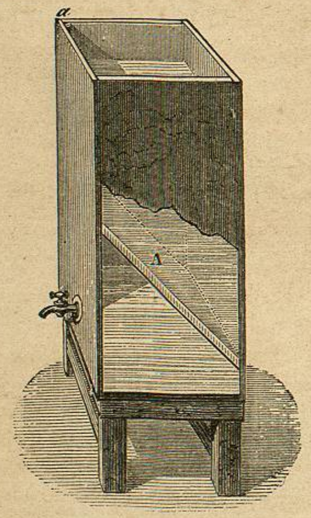

Fig. 2.

Fig. 3.

The property of porosity finds an important application in the process of filtering, that is, in separating foreign particles from liquids.

Explain the Florentine experiment. What are filters?

Fig. 2 represents a filter for purifying water; it is simply a box divided into two parts by a partition of porous stone, *A*. The water to be filtered is placed in the upper part, from which it passes slowly into the lower part through the pores of the stone. In one corner of the box is a tube, *a*, which permits the air to escape as the lower part of the box fills with water. The purified water is drawn off by means of a faucet near the bottom of the box.

Fig. 3 represents a filter used by chemists. It consists of a pocket of some porous material, as felt, for example, suspended by cords. The substance to be filtered is poured into the pocket, from which the liquid escapes slowly through the pores, leaving the solid parts behind.

Filters are also formed by layers of powdered charcoal, or finely ground quartz, through the pores of which the liquids pass. It is to a natural filtration through sand that many kinds of spring water owe their purity.

It is in consequence of porosity, that burning coals covered up with ashes continue to burn slowly. The air which is necessary to combustion penetrates through the pores of the ashes, in sufficient quantity to keep the fire from being entirely extinguished.

Finally, it is in consequence of their porosity, that many kinds of wood absorb moisture from the air, and tend to swell and crack; this difficulty is remedied by applying oils and varnishes, which close the pores and exclude the moisture.

Divisibility.

10. Divisibility is that property by virtue of which a body may be divided into parts. All bodies are capable of subdivision, and in many cases the parts that may be obtained are of almost inconceivable minuteness.

The following examples serve to show the extreme smallness of the molecules of matter. A single grain of carmine imparts a sensible color to a gallon of water; this gallon of water may be separated into a million of drops, and if we suppose each drop to contain ten particles of carmine, which is a low estimate, we shall have

Explain the water filter. Explain the chemist's filter. Other applications of porosity. (**10**) What is Divisibility? *Give examples of divisibility by solution.*

divided the grain of carmine into ten million of molecules, each of which is visible to the naked eye.

The microscope reveals to us, in certain vegetable infusions, *animalculæ* so small that several hundred of them can swim in a drop of water that adheres to the point of a needle. These little animals are capable of motion, and even of preying upon each other; they therefore possess organs of motion, digestion, and the like. How minute, then, must be the molecules which go to make up these organs.

A grain of musk is capable of diffusing its odor through an apartment for years, with scarcely an appreciable diminution of its weight. This shows that the molecules of musk continually given off to replenish the odor, are of inconceivable smallness.

The blood of animals consists of minute red globules swimming in a serous fluid; these globules are so small that a drop of human blood, no larger than the head of a small pin, contains at least 50,000 of them. In many animals these globules are still smaller; in the musk deer, for example, a single drop of blood of the size of a pin's head contains at least a million of them.

Compressibility.

11. COMPRESSIBILITY is the property of being reduced to a smaller space by pressure. This property is a consequence of porosity, and the change of bulk comes from the particles being brought nearer together by the pressure. Sponge, india-rubber, cork, and elder pith, are examples of compressible bodies; they may be sensibly diminished in volume by the pressure of the fingers. Gases are, however, the best examples of compressible bodies.

Fig. 4 represents an apparatus by means of which the compressibility of gases may be shown. It consists of a tube of glass, with metallic caps, completely closed at its lower end. An air-tight piston is introduced at the upper end, and on being pushed down we see the inclosed air reduced to the half, fourth, and even the hundredth part of its original bulk.

Examples of minute animals. Examples of odoriferous bodies. Blood globules. (**11.**) What is Compressibility? Examples. *Explain the experiment.*

Liquids are only slightly compressible, nevertheless nice experiments show that even they can be somewhat reduced in bulk by pressure.

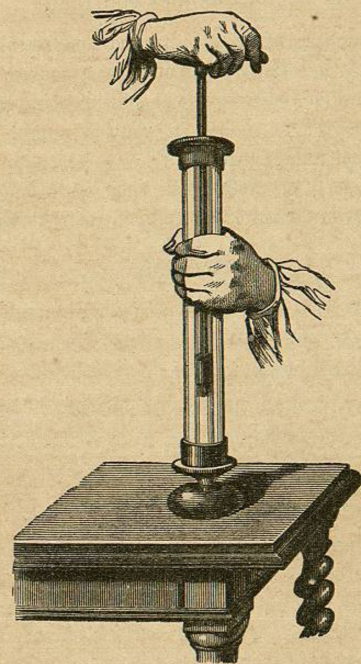

Fig 4.

Metals are compressible, as is shown in the process of stamping coins, metals, and the like.

Dilatability.

12. DILATABILITY is the property that a body possesses of assuming a greater bulk under certain circumstances.

In the experiment upon air, explained in the last article,

Are liquids compressible? Are metals compressible? How shown? (**12.**) What is Dilatability?

if the piston be raised after the air has been compressed, it will expand and fill the tube. Almost all bodies expand on being heated. It is on this principle that thermometers are constructed. In cooling, bodies contract.

A familiar example of dilatability and contractibility is shown in the process of fitting the tire upon a carriage wheel. The tire is made a little smaller than the wheel, but on being heated it expands so as to embrace it: on cooling it contracts again and draws the parts of the wheel tightly together.

The same property of metals has been used for producing great pressures, and even for restoring inclined walls to an erect position.

Elasticity.

13. Elasticity is the property which bodies possess of recovering their original shape and size after having been either compressed or extended.

Bodies differ in their degree of elasticity, yet all are more or less elastic. India-rubber, ivory, and whalebone are examples of highly elastic bodies. Putty and clay are examples of those which are only slightly elastic.

If air be compressed, its elasticity tends to restore it to its original bulk: this property has been utilized in making air-beds, air-cushions, and even in forming car-springs. If a spring of steel be bent, its elasticity tends to unbend it; this principle is employed in giving motion to watches, clocks, and the like. If a body be twisted, its elasticity tends to untwist it, as is observed in the tendency of yarn and thread to untwist; this principle, under the name of *torsion*, is used to measure the deflective force of magnetism. If a body be stretched, its elasticity tends to reduce it to its original length, as is shown by stretching a piece of india-rubber, and then allowing it to contract.

We see that the elasticity of a body may be brought into play by four different methods: by *pressure*, by *flexure* or bending, by *torsion*

Example. *Application in putting tire upon a wheel. Example of restoring walls.* (**13.**) What is Elasticity? Give examples of highly and slightly elastic bodies. *Give examples of the applications of elasticity. How may elasticity be brought into play? Examples.*

or twisting, and by *tension* or stretching. In whatever way it may be developed, it is the result of molecular displacement. Thus, when air is compressed, the repulsions between the molecules tend to expand it. Again, when a spring is bent, the particles on the outside are drawn asunder, whilst those on the inside are pressed together; the attractions of the former and the repulsions of the latter tend to restore the spring to its original shape.

The most elastic bodies are gases; after them come tempered steel, whalebone, india-rubber, ivory, glass, &c.

Fig. 5 illustrates the method of showing that ivory is elastic, and at the same time that the cause of its elasticity is molecular displacement. It consists of a polished plate of marble, over which is spread a thin layer of oil. If a ball of ivory be let fall upon it from different heights, it will at each time rebound, leaving a circular impression on the plate, which is the larger as the ball falls from a greater height. This experiment shows that the ball is flattened each time by the fall, that the flattening increases as the height increases, and that the action of the compressed molecules causes it to rebound.

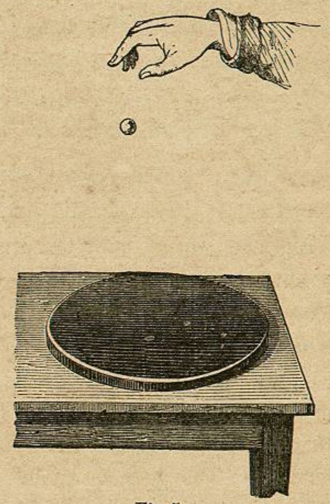

Fig. 5.

The property of elasticity is utilized in the arts in a great variety of ways. When a cork is forced into the mouth of a bottle, its elasticity causes it to expand and fill the neck so as to render it both water and air-tight. It is the elasticity of air which causes india-rubber balls, filled with air, to rebound when thrown upon hard substances. It is the elasticity of steel which renders it of use in

What bodies are most elastic? How is it shown that ivory is elastic? Explain the experiment. Explain some of the applications of elasticity. Corking bottles Springs.

springs for moving machinery, as well as for easing the motion of carriages over rough roads. It is the elasticity of cords that renders them applicable to musical instruments. It is the elasticity of air that renders it a fit vehicle for transmitting sound. It is the elasticity of the etherial medium pervading space which renders it capable of transmitting light.

II.—MECHANICAL PRINCIPLES

Definition of Mechanics.

14. MECHANICS is that branch of Physics which treats of the laws of rest and motion. It also treats of the action of forces upon bodies.

Rest and Motion.

15. A body is at REST when it retains its position in space. It is in MOTION when it continually changes its position in space.

A body is at rest with respect to surrounding bodies, when it retains the same relative position with respect to them, and it is in motion with respect to surrounding objects when it continually changes its relative position with respect to them. These states of rest and motion are called *Relative Rest* and *Relative Motion*, to distinguish them from *Absolute Rest* and *Absolute Motion.*

When a body remains fixed on the deck of a moving vessel or boat, it is at rest with respect to the parts of the vessel, although it partakes with them in the common motion of the vessel. When a man walks about the deck of a vessel, he is in motion with respect to the parts of the vessel, but he may be at rest with respect to objects on shore; this will be the case when he travels as fast as the vessel sails, but in an opposite direction. In consequence of the earth's motion around its axis and about the sun, together with the motion

Stringed instruments. Transmission of light. (**14.**) What is Mechanics? (**15.**) When is a body at rest? When in motion? Explain relative and absolute rest and motion. *Illustrate by examples.*

of the whole solar system through space, it is not likely that any part of our system is in a state of absolute rest for any appreciable length of time.

Different kinds of Motion.

16. MOTION may be *rectilinear* or *curvilinear;* it is rectilinear when the path of the moving body is a straight line, and it is curvilinear when this path is a curved line. The motion of a train of cars along a straight track is an example of rectilinear motion; the motion of the same train in passing round a curve is an example of curvilinear motion.

Uniform Motion—Velocity.

17. UNIFORM MOTION is that in which a body passes over equal spaces in equal times. Thus, every point on the surface of the earth is, by its revolution, carried around the axis with a uniform motion.

In this kind of motion the space passed over in one second of time is called the *velocity.* Thus, if a train of cars travel uniformly at the rate of 20 miles per hour, its velocity is 293 feet. Instead of taking a second as the unit of time, we might adopt a minute, or an hour. In the same case as before we might say, that the velocity of the train is one third of a mile per minute, or twenty miles per hour.

Varied Motion—Accelerated and Retarded Motion.

18. VARIED MOTION is that in which a body passes over unequal spaces in equal times. If the spaces passed over in equal times go on increasing, the motion is *accelerated;* such is the motion of a train of cars when starting, or that of a body falling towards the surface of the earth. If the spaces passed over go on decreasing, the motion is

(**16.**) What is Rectilinear Motion? Curvilinear Motion? Examples.
(**17.**) What is Uniform Motion? Example. What is meant by velocity? Example.
(**18.**) What is Varied Motion? When is it accelerated and when retard ed?