ECLECTIC EDUCATION SERIES

Norton's Elements of Physics

THE

ELEMENTS OF PHYSICS

A TEXT-BOOK FOR

ACADEMIES AND COMMON SCHOOLS

BY

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PREFACE.

This volume has been prepared, at the request of many teachers, for the use of pupils in academies and common schools. The topics considered have been selected with reference both to the average age of such pupils and to the time usually allotted to the study of Physics.

The object of this book is not merely to give a systematic and symmetrical epitome of the Science, but so to present each topic that the pupil shall receive, from the first, clear, accurate, and scientific ideas. In no other way can the study of any science be made a means of mental discipline. No pains have been spared to attain this result; and it is hoped that, however much has been omitted that many teachers would desire to have presented, the pupil will, at least, have nothing to unlearn.

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THE

ELEMENTS OF PHYSICS.

CHAPTER I.

GENERAL NOTIONS OF MATTER AND FORCE.

1. Matter is any thing that is capable of affecting our senses. The objects that surround us, the food we eat, the water we drink, the air we breathe, are different forms of matter.

2. A body is any separate portion of matter, whether large or small: thus a mountain, a pebble, or a dew-drop, is a body. The different materials of which bodies are composed are called *substances:* thus iron, wood, and sugar are substances.

3. Some substances contain but one kind of matter. These are called *simple substances*, or the ELEMENTS. There are sixty-three elements now known. The most abundant of these are oxygen, silicon, aluminium, iron, calcium, magnesium, sodium, potassium, nitrogen, hydrogen, and carbon.

4. Compound substances are composed of at least two elements, so firmly united that they can not be separated except by chemical processes. These compound substances make up the bulk of the globe: thus water is composed of oxygen and hydrogen; quartz and white sand, of silicon and oxygen; clay, mainly of silicon, oxygen, and aluminium.

5. **Many bodies are mixtures** of several substances: thus gunpowder is a mixture of niter, carbon, and sulphur. The air is also a mixture. The most important of its constituents are oxygen, nitrogen, carbonic acid, and the vapor of water.

6. **Many substances can exist** at different times in three different states: thus water can exist as ice, as water, or as steam.

A body is in the *solid state* when its particles are held firmly together, and retain the shape that has been given them by nature or art. Ice, wood, and tallow are solids.

A body is in the *liquid state* when its particles easily change their relative positions. When a liquid is poured into an open vessel, it adapts itself to the shape of the vessel, except that its upper surface is horizontal. Water, alcohol, and oil are liquids.

A body is in the *aëriform state* when its particles tend to separate from each other, and to occupy a greater volume. Bodies in this state are called *aëriform bodies*, *gases*, or *vapors*. Aëriform bodies can not be retained in an open vessel; and when shut in on all sides, completely fill the vessel in which they are placed. Steam, the air, and illuminating gas are aëriform bodies.

The term *fluid* is applied both to liquids and aëriform bodies: thus we may speak of water as a liquid or as a fluid; or of air as an aëriform body or as fluid.

7. **No one can conceive** of a body which does not possess length, breadth, and thickness. Even the fine particles of dust which are seen only in the path of the sunbeam must have a certain shape or figure, and occupy a certain amount of space. The amount of space that a body occupies is called its *bulk* or *volume*.

The ordinary measures in the United States are derived from an arbitrary unit called the yard; although we may use any one of its divisions or multiples as a unit—as the inch, foot, or mile. The square inch, square yard, etc., are units of surface. The cubic inch, cubic foot, etc., are units of volume.

The wine gallon of the United States contains 231 cubic inches. The imperial gallon of England contains 277.274 cubic inches.

The French unit of length is the metre, which is equal to 39.3685 of our inches. All the French measures increase or decrease in decimal proportion. For the increase the Greek prefixes deca (10), hecto (100), and kilo (1000), are used; for the decrease the Latin prefixes deci ($\frac{1}{10}$), centi ($\frac{1}{100}$), and milli ($\frac{1}{1000}$), are used. A decimetre is drawn in Figure 1, in comparison with a scale of inches. One inch is very nearly 25.4 millimetres.

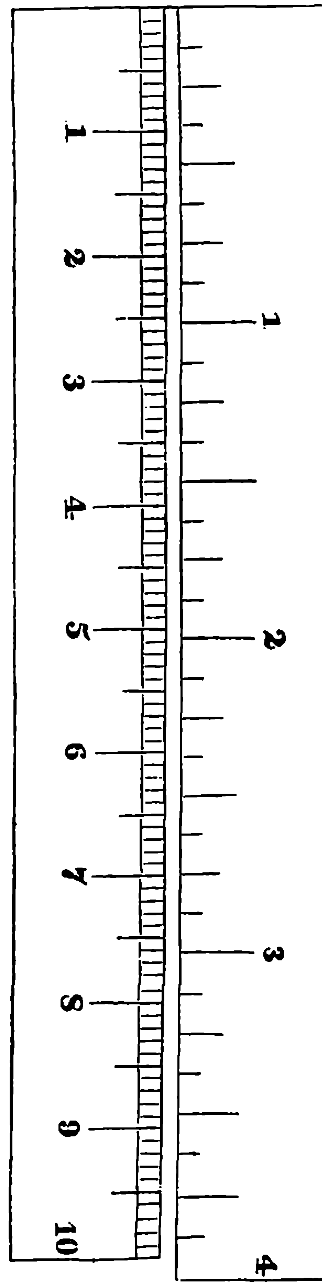

Fig. 1.

The French unit of volume is a cubic decimetre, and is called the litre. It contains 61.022 cubic inches, or 2.113 wine pints.

8. All bodies may be divided into very minute particles: thus stones may be crushed to powder; the hardest steel may be broken; and even the diamond may be reduced to dust. Wonderful examples of minute divisibility are afforded by odors and coloring matters. Odors can be caused only by particles of matter in the air; and yet how small must those be that enable a hound to follow his game! A grain of musk has perfumed a large apartment for several years without perceptibly losing in weight. An ounce of aniline is capable of coloring two hundred ounces of silk thread. We may separate this thread into 3,000,000,000,000 parts and discern the red color of the aniline in each one of them.

Many chemical tests reveal the presence of exceedingly small quantities of matter. If a grain of iron or of copper be dissolved in nitric acid, and then added to a tumblerful of water, the presence of either metal may be detected in every part of the mixture. This may be done by placing a drop of the solution on a watch-glass and then adding a solution of ferrocyanide of potassium, when the iron solution will be turned blue, and the copper solution will be reddened.

Even by mechanical means we may obtain particles so small that it is difficult to form just conceptions of their size. Gold leaf is sometimes so thin that fifteen hundred leaves placed one above another will not equal the thickness of ordinary paper. One square inch of this leaf weighs less than one twenty-thousandth part of an ounce; and we can divide this into ten-thousand parts, each one of which is distinctly visible to the eye, though weighing less than one two-hundred-millionth part of an ounce.

9. There are many reasons for believing that there is a limit to the divisibility of matter. The smallest conceivable particle of water, or of any compound body, is called a *molecule.* A molecule is so small that no microscope will ever enable us to see it. It is the smallest particle into which a body may be divided without losing its identity.

10. By chemical means a molecule of water may be still further divided into its components oxygen and hydrogen, and thus particles obtained which are the smallest conceivable. These are called *atoms.* An atom is the smallest particle of matter capable of entering into a molecule.

11. How the atoms are arranged to form molecules, or how the molecules are arranged in bodies, is unknown. We know that all bodies expand when heated, and contract when cooled.* Thus, if an empty flask is inverted in a vessel of water, and heat is applied (Fig. 2), the air will expand so much that a portion will be expelled. On cooling, the air remaining in the flask will resume its original volume. We know also that all bodies are made smaller by pressure: thus a bottle of "soda water" contains several times its volume of compressed gas, which expands to its original volume when the cork is removed. All bodies are expansible and compressible. Gases show these properties very readily, but they are also exhibited by solids and liquids.

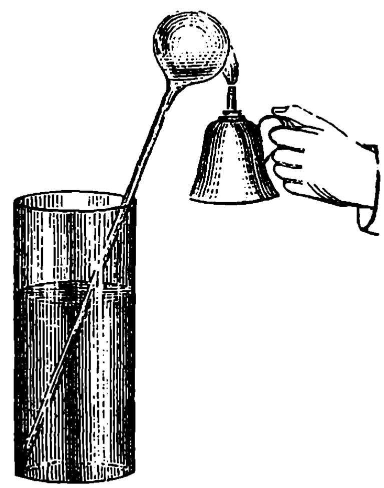

FIG. 2.

These and similar phenomena render it probable (1) that the molecules of a body do not touch each other, but are separated by vacant spaces or pores; and (2) that the molecules are free to move even in the most rigid bodies. When bodies expand, the molecules separate, and the pores become larger; when bodies contract, the molecules approach, and the pores become smaller.

12. The pores of bodies are of two kinds. (1) Those which exist between molecules are called *physical pores*. These are so small that they can not be seen even by the aid of a microscope. (2) *Sensible pores* are cavities that may be seen, as the pores in bread, or in some kinds of wood.

If water is heated in a glass vessel, bubbles of air sep-

*When clay is heated, it contracts permanently, because its particles suffer a chemical change.

arate out and cling for a time to the sides of the vessel. These must have come from the physical pores of the water. So also, if a cup be filled to the brim with hot water, two or three spoonfuls of pulverized sugar may be gradually added before the cup overflows. The molecules of the sugar find sufficient space in the pores of the water. Sometimes an actual contraction of volume occurs on mixing two liquids. Thus, if a long and slender test-tube be half filled with water, and strong alcohol be poured carefully in, so as not to mix the two liquids until the tube is quite filled, and then the tube be tightly closed and inverted, the liquids will mix and no longer fill the tube. The explanation of this phenomenon is that the molecules of the alcohol and the water are mutually so arranged as partially to fill the pores previously existing in the two bodies.

13. **We do not believe** it possible that any two particles of matter can occupy the same place at the same time. In other words, we believe that *matter is impenetrable.* If a pebble be dropped into a tumblerful of water, enough water will overflow to equal the bulk of the pebble. The examples given in the preceding section are only apparent exceptions to the property of impenetrability. There are other apparent exceptions, which can be even more readily explained.

If one end of a glass tube be closed by the thumb, and the other end plunged into a vessel of water, the water can not fill the tube because of the impenetrability of the air inclosed in the tube. Nevertheless it will be seen that the water will rise a little way in the tube; but this is because the air is compressed, and so allows space for the water to enter.

An easy experiment, which illustrates the same fact, may be made by wrapping moistened paper around the tube of a funnel, so that it may be made to fit air-tight in the neck of a bottle, as shown in Fig. 3. Now, if water be quickly poured into the funnel, only so much will enter the bottle as corresponds to the compressed or displaced air.


FIG. 3.

14. Space which contains no matter is called a vacuum.

15. Bodies vary greatly with respect to the pores which they contain. Those that contain large pores are called *rare* bodies; those that have small pores are called *dense* bodies. Density is, therefore, a term which expresses the relative amount of matter which equal volumes of different substances contain. Iron, for example, is denser than stone, but is less dense than gold. In comparing the relative density of bodies, it is convenient to select some substance which shall be taken as the standard of comparison, and reckoned as unity, or 1. Thus the air is a standard of density for all aëriform bodies, and water is a standard of density for liquids and solids. It is also necessary to select some temperature at which the comparison shall be made. The temperature usually taken is 32° F. for all bodies excepting water, which is unity when at 39°.2 F. In the case of gases, it is also necessary that they should be compared when under the same pressure. The pressure assumed is the average pressure of the atmosphere at the level of the sea, which is 14.7 pounds to the square inch, and which equals a column of mercury 29.92 inches high.* These are called the normal conditions of temperature and pressure.

16. The ratio which shows how many times heavier any given substance is than an equal volume of water or of air,

* See Section 31.

under the normal conditions, is the *specific gravity* of the substance. The specific gravity of chlorine gas is 2.47, which means that a given bulk of chlorine, as a pint or a gallon, is 2.47 times heavier than the same bulk of air. The specific gravity of silver is 10.5, which means that a given bulk of silver, as a cubic inch, weighs 10.5 times more than the same bulk of water.

Weights of the Standards.

One cubic inch of air weighs,	at 32° F.,	0.32712	grains.
	at 60° F.,	0.30954	grains.
One cubic in. of water weighs,	at 32° F.,	252.875	grains.
	at 60° F.,	252.456	grains.

Specific Gravities Compared.

	at 32° F.	at 62° F.
Ratio of air to water,	1 to 773.2	1 to 816.8
Ratio of water to air,	1 to .00129363	1 to .0012243

Table of Specific Gravities.

GASES.		SOLIDS.	
Air,	1.	Cork,	0.24
Steam,	.622	Ice,	0.93
Hydrogen,	.069	White Oak,	0.86
Oxygen,	1.106	Ebony,	1.33
LIQUIDS.		Glass,	3.
Pure Water,	1.	Iron,	7.78
Sea Water,	1.026	Copper,	8.85
Olive Oil,	0.915	Lead,	11.35
Sulphuric Acid,	1.84	Gold,	19.26
Saturated Brine,	1.205	Platinum,	21.53

17. Matter is every-where subject to change. When the smith heats a bar of steel, it expands; when he beats it on his anvil, he is changing its form; when he hurls it from him, he is changing its position. If the steel be rubbed on a magnet, it acquires the property of attracting iron filings. It may be melted to a fluid state and cast into any shape. Such changes as these are called *physical changes*. Physical changes are those by which the substance is not altered so as to lose its identity.

On the other hand, in *chemical changes* the identity of the substance is entirely lost. Thus, when steel rusts, the red powder which forms is due to a chemical change in which water has been decomposed into oxygen and hydrogen; the oxygen has united with the iron in the steel, to form a new kind of substance, and the hydrogen has escaped into the air. So, also, the decay of leaves, the burning of wood, the souring of cider, are chemical changes.

18. Force is that which causes any change in the form or condition of matter. All the phenomena of the visible universe are caused by the action of force upon matter.

The simplest change in matter is that of position. We determine the motion or rest of a body by its relation to some given point; but as this point may be itself fixed or moving, motion or rest is either (1) absolute, or (2) relative.

19. Absolute motion is change of place with regard to a fixed point: relative motion is change of place with regard to a point in motion.

The motion of the heavenly bodies with reference to ideal fixed points in space are examples of absolute motion. Strictly speaking, no bodies are in a state of absolute rest. Every particle on the earth's surface partakes of all the daily and annual motions of the earth; and, therefore, the terms absolute motion and rest, when applied to bodies on the earth's surface, have reference to objects that appear fixed.

A person seated on a steamboat in motion is in absolute motion with respect to the harbor he has left, or to the harbor he is approaching, and is in a state of relative rest with regard to the parts of the vessel. If he walks toward the stern of the boat as fast as the vessel moves forward, he is in a state of relative motion with regard to the parts of the vessel, but is in absolute rest with regard to the harbors.

20. Velocity is the rate of motion. It may be found by dividing the space passed over by the time occupied in the transit. Thus, if a locomotive is five hours in going one hundred miles, its velocity is twenty miles an hour.

The formula, $v = s \div t$

Expresses the relation between space, time, and velocity.

21. A natural unit of time is the day, but any of its subdivisions—hour, minute, or second—may be assumed as convenience dictates.

Table of Velocities.

	MILES PER HOUR.	FEET PER SECOND.
Man walking,	3	4.4
Man running,	10	14.66
Swift trotting horse,	27	40.
A rifle ball,	1,000	1,466.66
Sound,	762	1,117.6

22. Motion and rest are equally natural to a body. When the forces that are acting upon matter exactly balance each other, it is at rest, and is in motion when they do not. We say, then, that matter has the property of *inertia*, by which we mean that it tends to retain its present state, whether of motion or of rest.

It requires some force to set a body in motion, and when it is in motion, it requires force to stop it. The inertia of the air becomes manifest by the resistance it offers to a body moving through it. If we endeavor to run with an open umbrella, we need to employ considerable force to overcome the resistance of the air, because we shall have to displace or set in motion the air which is in front of us.

The heavier a body is, the greater will be its inertia; that is, it will require more force than a lighter body to set it in motion, or to stop it when it is moving. Thus, a small boy will easily "dodge" a larger, because the heavier boy will be unable to change his course at once.

A person standing in a wagon partakes of its condition of motion or rest. If it is suddenly set in motion, he is thrown backward, because his feet are drawn along by the friction against the bottom, before his head can acquire the motion forward. If the wagon is suddenly stopped when in rapid motion, he is thrown forward.

23. There are many forces in Nature, and it is convenient to divide them into three classes.

(1) Those which act only upon the molecules of matter, and at distances which are inappreciable to our senses. These are named Cohesion, Adhesion, and Affinity. Taken collectively, they are called the *molecular forces.*

(2) Those which act also upon bodies taken as a whole, and at both sensible and insensible distances. These are Gravitation, Light, Heat, and Electricity.

(3) Those which take part in the phenomena of living plants and animals by controlling or modifying the forces of inanimate nature. These are called the *vital forces.*

24. Cohesion causes like molecules to unite in one mass. It keeps the particles of a body together. It is strongly exerted in solids, feebly in liquids, and not at all in aëriform bodies. Thus a dew-drop is spheroidal because of the cohesive force. When the drop is very large it becomes flattened, because the force of cohesion is partly overcome by the force of gravitation.

The following pretty experiment illustrates the tendency of liquids to assume the spheroidal form: Take a wine-glass half full of water, and carefully fill it with alcohol so as not to mix the two liquids; then drop a very little olive oil through the alcohol. It will come to rest in the middle of the glass, and, if the quantity taken is not too great, will assume the shape of a ball.

When the cohesion of solids has been once destroyed, it is difficult to cause the particles to reunite. If a bar of lead be cut in two, the severed parts may be made to cohere by so cutting their faces that they will present a bright and even surface, and then pressing them tightly together with a slight twisting motion. Two plates of polished glass will cohere, under pressure, so firmly that they may be worked as a single piece.

25. Adhesion causes the molecules of different kinds of matter to cling together. Thus, adhesion causes the dust to cling to any thing it falls upon; chalk to cling to blackboards, and dew-drops to leaves. Under the name of Friction it diminishes the work of moving force, (1) by stiffening the joints of machines, (2) by increasing the resistance to be overcome. Friction often acts as a mechanical advantage, as in retaining nails and screws in their sockets, in preventing our feet from slipping when standing or walking, and in enabling us to take firm hold upon objects.

26. Affinity causes the atoms of unlike substances to unite and form new kinds of matter. All chemical phenomena are due to affinity. When iron dissolves in nitric acid a new kind of matter (the nitrate of iron), differing both from the iron and the acid, is formed.

Adhesion and cohesion differ from affinity in this, that their action on bodies does not effect any essential change in the properties of the bodies acted upon. They differ from each other in this, that adhesion acts between unlike particles, and cohesion between like particles. They all agree in this, that their energy increases with the number of molecules that are acted upon. This statement, when applied to solids, may be expressed in these words: the energy of molecular forces increases with the extent of surface exposed to their action.

27. Gravitation is a force by virtue of which every particle of matter attracts every other particle of matter toward itself. The term *mass* is used to denote the amount of matter in a body, and it has been established that *gravity is proportional to mass.*

If a stone were dropped from a balloon it would fall toward the earth by reason of the attraction of the earth, or terrestrial gravitation. The earth also tends to fall toward the stone, but its mass is so much the greater that its motion is inconceivably small.

But gravitation does not always produce motion. A stone resting on the top of a table is not free to fall, and, in such a case, the force of the earth's attraction is expended in pressure against its support. This pressure is called the absolute *weight* of the body. Hence, weight is the measure of the earth's attraction.

28. Gravity is also influenced by distance, as will be shown hereafter. An iron ball which weighs one hundred and ninety-four pounds at the equator will weigh one hundred and ninety-five pounds at the poles. Hence, weight does not always mean the same as mass, for a body will always contain the same amount of matter in every conceivable place. Nevertheless, as weight is always proportional to mass, we may use weight as a means of estimating mass, or, in most instances, use the two terms interchangeably without sensible error.