A TEXT-BOOK OF PHYSICS

WENTWORTH AND HILL

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PREFACE.

THIS book aims to give a rational explanation of the more important physical phenomena, and to prepare the way for further investigations and study of physical science.

The progress of Physics during the nineteenth century has been so rapid, and the useful applications of physical knowledge have become so numerous and important, that there is danger of underrating the importance of the fundamental principles established by the great founders of the science. These principles will always remain the necessary basis of all systematic knowledge of the subject.

Modern Physics assumes that bodies consist of molecules, and modern Chemistry assumes that molecules consist of atoms. The student cannot too early become familiar with these assumptions and the grounds on which they rest. In Chapter IV some of the evidence for the theory of the molecular structure of bodies is brought together, and the nature of a chemical change is carefully explained. The reader is thus prepared to understand the references to chemical changes found in later chapters.

Any one who masters the first six chapters of this book will have laid a good foundation for the further study of Physics. Chapters VII and VIII are independent of each other; if found necessary, either one of them may be omitted.

Laboratory experiments, requiring simple apparatus only, are described for the purpose of *verifying* laws previously stated, *not for discovering* laws; and many numerical exercises are introduced into each chapter for practice in applying the principles of Physics to the common problems of life.

A pamphlet containing solutions of the numerical problems and full directions for performing the laboratory experiments is published for teachers only. On applying to the publishers, the pamphlet may be obtained by any teacher who is using the text-book in his school.

NOTE TO REVISED EDITION.

In the present edition the work has been revised in accordance with the suggestions of teachers who have used the book; and a new chapter on some of the modern applications of Physics has been added.

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TABLES OF FUNDAMENTAL UNITS.

	English.	Metric.
Length.	inch (in.) foot (ft.) = 12 in. yard (yd.) = 3 ft. rod = $16\frac{1}{2}$ ft. mile = 5280 ft.	millimeter (mm.) centimeter (cm.) = 10 mm. decimeter (dm.) = 10 cm. meter (m.) = 10 dm. kilometer (km.) = 1000 m.
Surface.	square inch (sq. in.) square foot (sq. ft.) = 144 sq. in. square yard (sq. yd.) = 9 sq. ft.	square centimeter (qcm.) square decimeter (qdm.) = 100 qcm. square meter (qm.) = 100 qdm.
Volume.	cubic inch (cu. in.) cubic foot (cu. ft.) = 1728 cu. in. cubic yard (cu. yd.) = 27 cu. ft. liquid gallon = 231 cu. in.	cubic centimeter (ccm.) cubic decimeter (cdm.) also called a liter = 1000 ccm. cubic meter (cbm.) = 1000 cdm.
Mass and Weight.	grain (gr.) ounce (oz.) = $437\frac{1}{2}$ gr. pound (lb.) = 16 oz. ton = 2000 lb.	milligram (mg.) gram (g.) = 1000 mg. kilogram (kg.) = 1000 g. tonne = 1000 kg.
	1 inch = 2.54 cm. 1 mile = 1.609 km. 1 square inch = 6.45 qcm. 1 cubic inch = 16.387 ccm. 1 grain = 0.0648 g. 1 ounce = 28.35 g. 1 pound = 0.4536 kg.	1 centimeter = 0.3937 in. 1 meter = 3.28 ft. 1 square centimeter = 0.155 sq. in. 1 cubic centimeter = 0.061 cu. in. 1 milligram = 0.01543 gr. 1 gram = 0.03527 oz. 1 kilogram = 2.2046 lb.
	1 cubic foot of water weighs 62.4 pounds, very nearly.	

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A TEXT-BOOK OF PHYSICS.

CHAPTER I.

BALANCED FORCES.

Elementary Ideas about Matter.

1. Body. That which fills space and acts on our senses is called *matter*. A limited portion of matter is called a *body;* for example, a table, a raindrop, the earth, the sun.

If two bodies have the *same properties* we say that they are composed of the *same substance*, and give that substance a name, as glass, wood, charcoal, iron, sulphur, water.

2. Changes of Matter. When an apple falls to the ground, it suffers a change of place, but no change of substance; the apple after falling has the same properties as before.

If the apple is left on the ground it gradually decays; it suffers a change in color, in taste, in weight, and in various other ways. In this case a change of substance occurs. The decayed apple has properties quite unlike those possessed by the sound apple.

Every *change of substance* is called a *chemical* change.

Every change which *does not involve a change of substance* is called a *physical* change.

Chemistry is the study of chemical changes, their laws, and their causes. *Physics* is the study of physical changes, their laws, and their causes.

3. States of Matter. Matter exists in three different states, the *solid* state, the *liquid* state, and the *gaseous* state.

Bodies that offer resistance to change of shape or to division into parts are called *solids.*

Bodies that offer practically no resistance to change of shape or to division into parts are called *liquids.*

Bodies that offer no resistance to change of shape or to division into parts, and *show a constant tendency to expand* or occupy more space are called *gases.*

Gases are easily compressed; liquids are almost incompressible.

Liquids and gases, however, have certain properties in common; as, for example, the property of flowing. For this reason they are often put into one class and called *fluids.*

By means of heat, solids may be changed to liquids and liquids to gases. Conversely, by cooling (or cooling and pressure combined), gases can be converted to liquids and liquids to solids. These changes are called *changes of state.*

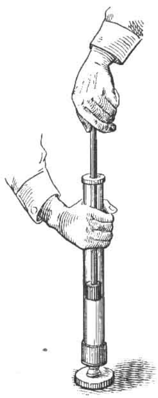

FIG. 1.

Water usually is a liquid, but in winter it often changes to ice (solid water), and when boiled it changes to steam (gaseous water).

4. Compressibility. If we squeeze a sponge with the hand, the sponge is reduced in size, or *compressed.* If we push an air-tight piston down a cylinder, the lower end of which is closed (Fig. 1), the air within can be very much compressed.

Air and all gaseous bodies are very compressible. There is good reason to believe that every body can be compressed if sufficient force is used. Even iron is compressed by rolling, by hammering, and by the process of wire drawing.

Compressibility is, therefore, a general property of matter.

5. Porosity. A body is said to be *porous* when it contains small cavities or *pores* not filled with the substance of which the body consists. Sponge and charcoal, for example, contain pores which can be easily seen (sensible pores).

In many cases we *infer* that a body is porous from its action upon other bodies or the action of other bodies upon it.

Thus a liquid must be porous if it will dissolve a certain quantity of a solid without sensibly increasing in bulk, and a solid must be porous if it will allow a liquid or a gas to pass through it. The following experiments are illustrations.

1. Dissolve fine sugar in a measuring glass containing water up to a certain mark. The water will dissolve a large quantity of sugar without sensibly increasing in bulk. The only rational explanation is that the water receives the sugar into its pores, somewhat as a hod full of lump coal will receive a large number of bullets and then in addition a large quantity of sand.

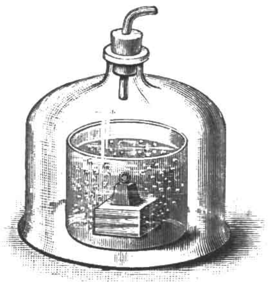

FIG. 2.

2. When a piece of wood is placed under water in an air-tight vessel (Fig. 2), and the air is then removed, large numbers of air bubbles are seen to form on the surface of the wood and also in the water, and to rise to the surface of the water. What do you infer from this experiment?

Two general facts lead us to believe that even the densest body contains very minute pores, called *physical* pores, too small to be seen even under the most powerful microscope.

First, bodies are compressible; and secondly, bodies in general expand when heated and contract when cooled.

Porosity is, therefore, a general property of matter.

Glass apparently has no pores, and no solid or liquid or gas has ever been made to pass through it. But glass expands when heated and contracts when cooled; therefore it must contain physical pores.

6. Divisibility. Every body can be divided into parts. The extent to which the subdivision of matter can be carried is very remarkable.

A piece of blue vitriol not larger than a pea, when dissolved in a quart of water, will give to the water a uniform blue color. A mere speck of musk will soon fill a large room with its odor.

Facts like these can be explained only by supposing that matter is capable of subdivision into parts far too small to be separately visible, even with the aid of the most powerful microscope.

Divisibility is a general property of matter.

7. Molecules and Atoms. The properties of compressibility, porosity, and divisibility, and the behavior of matter in the liquid and gaseous states suggest strongly the idea that every body is composed of a great multitude of small distinct parts which have fixed relative positions in a solid, but are capable of moving freely from place to place in a liquid, and still more freely in a gas. Accordingly this hypothesis is accepted as true by men of science. The smallest portion of a body capable of retaining the properties of the body is called a *molecule.* All physical changes are believed to be due to the motions either of bodies or of their molecules (molecular motion).

When a chemical change occurs, each molecule is supposed to break up into two or more smaller parts called *atoms*, which at once recombine in such a way as to form *new molecules* possessing properties unlike the original ones.

Molecules and atoms are too small to be seen. Their existence is inferred from the changes which matter undergoes and which can be explained only by supposing that they exist. Some of the grounds for believing that molecules and atoms exist will be given in Chap. IV. Additional evidence will be presented in the latter part of Chap. VI.

8. Indestructibility. There is one change that matter cannot undergo, namely, destruction or annihilation. When the oil in a lamp burns, it disappears from view, and at first seems to have been destroyed. But it is now well known that the oil in burning unites with oxygen from the air and forms an invisible gas which mixes with the air. So it is in all cases. Whenever matter appears to be destroyed, it merely suffers some change in form or properties which renders it incapable of affecting our senses as it did before. There is no truth in science more firmly established than that *matter is indestructible.*

CLASS-ROOM EXERCISES.

1. What is matter? How do you know that air consists of matter?

2. What property of matter is illustrated when you put a lump of sugar into a cup of tea and stir it around?

3. In Fig. 3 we see a beam bent by a heavy load. What effect has the bending on the length of the upper side? What effect has the bending on the lower side? How could you prove that these are the effects?

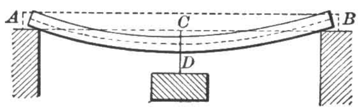

FIG. 3.

4. A hollow globe of lead was once filled with water by Lord Bacon, and the hole securely closed. Then the globe was hammered so as to flatten it out and diminish the space inside. The outside was then found to be covered with a fine dew. What did this prove?

5. Water and alcohol when mixed contract in bulk. What do you infer from this fact?

6. Is the falling of a stone a physical or a chemical change? the bending of a bow? the melting of ice? the boiling of water? the burning of coal? the rusting of iron? the ringing of a bell? the sprouting of a seed?

7. When phosphorus is burned in a closed vessel, it is found that the vessel and its contents weigh exactly the same after the burning as before. What truth does this experiment illustrate? What kind of a change does the phosphorus undergo?

Fundamental Units.

9. Units of Extension. To *measure* a magnitude of any kind is to find the number of times a magnitude of the same kind chosen as a *unit* is contained in the magnitude to be measured.

The *standard units* of length are the *yard* and the *meter.* Both are defined by law with reference to material standards, the yard with reference to a bronze bar kept at London, the meter with reference to a platinum bar kept at Paris.

From these standards other units of length, and units of surface and of volume are derived. The units derived from the meter form the so-called *metric system.*

Angles are expressed in *degrees, minutes,* and *seconds.*

If the radius of a circle is made to turn through one revolution, it describes an angle of 360 degrees.

A degree $(^\circ) = 60$ minutes $(')$; a minute $= 60$ seconds $('')$.

10. Measurement of Extension. Short lengths (such as lines drawn on paper) are measured by applying to them an *inch scale* or a *millimeter scale.* For longer lines *yardsticks, meter sticks,* etc., are used. Distances too great for direct measurement are measured indirectly by methods explained in Geometry and Trigonometry.

The circumference of a circle and the surfaces and volumes of regular solids are also measured indirectly; certain straight lines (radius, base, altitude, etc.) are first measured and then the quantity sought is computed with the aid of formulas proved in Geometry.

The volume of a liquid body or an irregular solid may be found by means of a *measuring glass* (Fig. 7). The interior volume of a glass vessel may be found by measuring or weighing the water which it will hold.

Angles are measured with *protractors, theodolites,* or *sextants.*

11. Weight. If we hold a body in the hand, we feel that it is exerting pressure downwards; if we release the body, it falls to the ground. In short, the body behaves as if the earth attracted it. This attractive force is called *gravity*, and the downward pressure exerted by a body upon its support is called its *weight*. If we place two bodies in the pans of a scale-pan balance (Fig. 4), the arms AB, AC of which are equal in length, and if then the beam BC remains horizontal, we infer that the weights of the bodies are equal; for they exactly counterbalance when acting against each other under the same conditions. This operation is called *weighing;* it enables us to compare the weights of different bodies if suitable units are chosen.

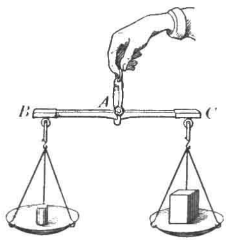

FIG. 4.

12. Mass. The quantity of matter which a body contains is called its *mass*. Although weight and mass are quantities unlike in kind, there exists a simple relation between them. If we hold a glass in the hand and pour into it sand or water, we observe that the weight appears to increase just as fast as the quantity of matter in the glass. We make weight the practical test of mass in all cases, by assuming that two bodies have the same mass if they have the same weight, or more generally, that *mass is directly proportional to weight.*

When we come to the study of the laws of motion (Chap. V) we shall see more clearly the real meaning of mass, and why two, three, four, etc., times the weight necessarily implies two, three, four, etc., times the mass. Meanwhile mass and weight should be carefully distinguished from each other. When we lift a body we feel its *weight* acting against us. When we push horizontally against the bob of a pendulum at rest, it is the *mass* of the bob and not its weight that opposes motion. If the earth ceased to attract bodies they would cease to have weight, but their masses would remain precisely the same as before.

13. Units of Mass and Weight. The English standard of mass is a certain piece of platinum kept at London, and is called a *pound*.

The metric standard of mass is a certain piece of platinum kept at Paris, and is called a *kilogram*.

The kilogram is equal practically to the mass of 1 cubic decimeter (or liter) of pure water at 4° Centigrade.

A kilogram contains 1000 grams. Since a cubic decimeter contains 1000 cubic centimeters, the gram is the mass of 1 cubic centimeter of pure water at 4° Centigrade.

The units of weight in common use are the weights of the units of mass, and have the same names. Thus the downward pressure exerted by a mass of 1 lb. is called a weight of 1 lb.

This double use of the words pound and kilogram, as units for both mass and weight, is a disadvantage, but cannot very well be avoided. Usually the context shows clearly enough the proper meaning.

14. Measurement of Mass and Weight. With the units defined as in the last section, both the mass and the weight of a body are found by weighing the body with a scale-pan balance. We place the body in one pan and add standard weights (really standard masses) to the other pan until there is exact equilibrium. The sum of the standard weights used gives the mass, and also the weight of the body.

This method of estimating weight assumes that the weight of a body does not change with locality. But we know that the weight of a body increases very slowly as we go away from the equator. Now a scale-pan balance cannot measure or even detect changes in weight, because they affect equally the body in one pan and the standard weights in the other. Accordingly, when it is important to take into account the small variations of weight due to change of locality, a scale-pan balance cannot be employed. A good spring balance will detect these changes, and roughly measure them.