GENERAL PHYSICS

A Textbook for Colleges

BY

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PREFACE

This book is an outgrowth of experience in the use of the *Introductory College Physics* and reproduces many of its features. For example, the interest of the student is stimulated by the use of vital illustrative material. The automobile is drawn upon in every branch of physics but especially in mechanics. The skidding of its tires on the roadway and the streamlining of its body to diminish air friction are pointed out. Attention is drawn to the forces that are experienced by the driver when his car goes around a curve or runs into a telephone pole. These forces are correlated by appropriate equations; typical problems are solved, and then the equations are derived. The student is guarded against discouragement during the crucial first days of the course by beginning the journey slowly, with wide consideration of the meaning of physics and its place among the sciences. Simple harmonic motion, though logically part of mechanics, is presented in connection with wave motion and sound.

In comparison with the earlier book, the present volume has additional illustrations, a greater number of problems arranged in order of difficulty, and supplementary problems in the Appendix. The treatment of sound and light has been elaborated, and new chapters on the emission of light and on alternating-current theory have been introduced.

Numerous illustrative examples are stated with units, thereby clarifying the distinctions between physical quantities such as velocity and acceleration. Important statements are printed in bold-face type or in italics. The legends are unusually complete so that the figures may teach as much physics as possible.

One of the most difficult problems has been the choice of force units. To use both the metric absolute and the British engineering systems seems inadvisable because of the contrasting treatment of $f = m \times a$ and $f = (W/g) \times a$. Therefore the absolute units are stressed. A simplified version of the meter-kilogram-second system is presented with the hope that it may become sufficiently familiar to justify its exclusive use in a later edition.

Criticisms of the book will be gratefully received.

OSWALD BLACKWOOD

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MECHANICS

CHAPTER 1

SCIENCE AND MEASUREMENT

The truth shall make you free.

1. The Slow Progress of Civilization. Two hundred centuries ago, the cave men were able to use simple tools such as levers, hammers, and flint knives. They knew how to carve, on the walls of their dwellings,

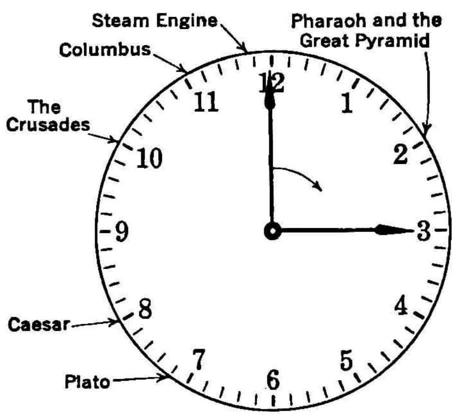

FIG. 1. A slow-ticking clock.

pictures which have artistic merit. Then, more than 160 centuries passed before the beginnings of history and the rise of civilization in Egypt and Mesopotamia. Imagine a clock driven so slowly that 6,000 years are required for a single revolution of the minute hand (Fig. 1). By this slow-moving timepiece, the cave men carved their pictures three hours ago. Fifty minutes have crept away since the great pyramid was built in Egypt. Twenty minutes ago, Julius Caesar was born, and the Roman Empire extended its law and order to the boundaries of the known world. Four and one-half minutes have ticked away since Columbus discovered the New World. Less than two minutes ago, two very important events happened: the writing of the Declaration of Independence and the invention of the steam engine.

During the last century the changes have crowded so closely that they can be followed only on the second hand of our clock. About 70 seconds have passed since Faraday invented a toylike dynamo which was the forerunner of those giant generators that supply energy to light our houses and actuate our radios. This was followed by the electric telegraph, and the motor. The last 40 years, 24 seconds on the imaginary clock, bring the radio, radium, and the dream of the alchemist, the transmutation of the elements. Less than 10 seconds have slipped by since Lindbergh made his lonely flight across the ocean.

Why this sudden increase in the knowledge of and the control of the physical world? Is it not surprising that the ancient Greeks, with their highly developed civilization and culture, made so little progress in the physical sciences? One reason that our advance is more rapid than theirs is that in modern times men have learned to use a very effective technique called the *scientific method.* In the words of Huxley:

The introduction of this method with its dispassionate, objective analysis of material forces and with the constant testing of theories by experiment, is one of the most valuable achievements of the ages.

2. What is the Scientific Method? A competent physician uses all the successive steps which characterize the complete scientific method. These are as follows:

1. *Observation.* He determines the patient's temperature, pulse, respiration rate, blood pressure, and other relevant "symptoms."
2. *Organization.* He carefully considers the results of his observations and compares them with the knowledge of diseases which has accumulated through the centuries.
3. *Hypothesis.* He makes a diagnosis or a hypothesis as to the nature of the disease.
4. *Verification.* He prescribes a treatment and by further observations finds out whether or not his hypothesis was correct.

Thus by trial and error the physician gradually increases his own skill and also adds to the knowledge of his profession.

An example of long-established, crude use of the scientific method is provided by a market gardener as he tries to find out in which part of his land beans will grow best. He plants the seed in several plots. By trial and error, in the course of a few years, he learns where beans flourish, and this information he gives to his children.

Most of our knowledge of the times of planting, the choice of seeds, fertilizers, and the like was garnered through the ages by the slow and painful method of trial and error, and progress was very tedious. The gardener's son attacks the same problem, having had the advantage of training in an agricultural school. There he has learned that beans thrive in soils which are slightly acid, and he uses this knowledge in testing his fields. By simple methods he determines the acidities of the different parts of his land and gets information in a few hours instead of years. Both men use the scientific method, yet one does so more effectively than the other.

As Thomas Huxley says, "The man of science, in fact, simply uses with exactness the methods which we all habitually and at every moment use carelessly, and the man of business must as much avail himself of the scientific method, must be as truly a man of science as the chemist, the physicist, or the biologist."

It should be emphasized that the scientific method was practiced before the dawn of history. The primitive "medicine man," trying various vile concoctions, was practicing a crude form of scientific method. Why was he less successful than the modern physician? For this failure, several reasons are worthy of mention.

Men Have Greater Faith in the Uniformity of Nature. In primitive societies, disease was regarded as the result of the wrath of some offended witch, hobgoblin, or demon. The question asked was not *what* caused the disease but rather *who* caused it. The medicine man tried to placate the evil spirits, whereas today the physician zealously observes symptoms and performs experiments, assuming that nature's laws do not vary.

Scientific Men Have Greater Skill and Knowledge. Because of the increased leisure made possible by machinery, the scientist nowadays has a thorough formal education. Investigations formerly were carried on principally by amateurs, but today thousands of well-trained workers are devoting their lives to scientific research.

The Scientist Has Better Libraries, Tools, and Instruments. Franklin performed his famous experiments on electricity using a few pieces of fur and cloth, some bits of wax, some needles, and the like. He had but a meager library, and communication with friends in Europe required many months. Today, Millikan, Compton, and Lawrence have great libraries to use. They have intricate instruments and—best of all—the encouragement of other zealous workers.

The increasing control of nature made possible by scientific research and the development of machinery has brought great blessings to humanity. Often we belittle these achievements and advocate the return to a simpler way of living. When we do, it is helpful to remember that in the days when Greek civilization flourished two-thirds of the inhabitants of Athens were slaves. Moreover, the wise and good Greek philosopher Plato once justified slavery, saying that without it there could be no leisure class of cultivated people. In his day, to gain the most meager subsistence required unending toil. Today the machine has brought a great amount of leisure, and work is looked upon as something desirable because of the rewards it brings. The machine has freed the slave and has provided possibilities of culture for the common people.

In recent decades the scientific method has been applied to the study of man and of society. The results in historical research in psychology and in sociology give promise of greater security and freedom for all.

3. What is a Science? The word *science* is used in many ways. It is derived from the Latin word *scire*, meaning *to know*, and might, therefore, be applied to all kinds of knowledge. Usually it is restricted to those highly organized fields in which there is an incessant search for the relationships between cause and effect. Some divisions of knowledge are partly included in the limits of science although they extend beyond its borders. For example, as will be seen later, there is a well-developed science of musical sounds, in which are studied the physical differences between musical sounds and noises, the laws of harmony, and the methods of tone production. Yet few singers or violin players are scientists. Though skilled in the techniques of producing musical sounds, they know little about the science behind their art.

4. Meet the Sciences. Scientific knowledge in olden times was so limited that one man could be an expert in many fields. Scientists called themselves natural philosophers rather than physicists, chemists, or astronomers. For instance, Franklin's experiments with lightning made him famous, yet he found time to interest himself in studies of the weather, of ocean currents, of water films, and of dietetics. He wrote treatises on economics and politics and was an eminent statesman. Franklin was an amateur in science; his great achievements were in diplomacy.

After Franklin, came the age of specialization in which we live. The term "natural philosophy" was abandoned about seventy-five years ago and "physics" was adopted. This word is derived from the Greek *phusis*, meaning nature, which might well be applied to all the natural sciences. Actually the physicist usually limits his attention to the general and fundamental aspects of matter and energy, other scientists having taken over the more specialized fields. Thus we have:

Physics—the fundamental science of matter and energy.

Astronomy—the science of the stars.

Chemistry—the science of the properties of atoms and molecules.

Geology—the science of the earth.

Biology—the science of living organisms.

5. The Subdivisions of Physics. The foundation part of physics is mechanics, in which the effects of forces in producing motion are studied and the meaning of such terms as mass and energy is made clear. Afterward the mechanics is applied in the study of heat, sound, light, and electricity. Thus, we shall consider

Mechanics—the effects of forces in producing motion, and the meaning of mass and energy.

Heat—the motions and energies of molecules and atoms.

Sound—the properties of the waves by which we hear.

Light—the properties of the agency by which we see.

Electricity and magnetism—the motions and energies of electrons, ions, and other charged particles.

6. Measurement. Since physics concerns itself almost exclusively with measurable quantities, it is very important to know precisely what this term means. When any quantity is measured, we determine **the ratio of that quantity to a chosen unit.** For example, in measuring the width of a room, we find the number of yardsticks which, placed end to end, would reach from one wall to the opposite side.

It is interesting to consider the development of weights and measures from the earliest times. In primitive societies there was little commerce outside the village, and the units of measure were very crude and simple. The yard was often defined as one-half of the distance from finger tip to finger tip of the king's outstretched arms, and the pound-weight as the weight of 7,000 "grains of barley chosen from the middle of the ear." Simple, inexact units served well enough for barter among friends and neighbors, but trouble arose when commerce developed between the cities and towns of a country. To meet the needs of traders, some of the commonly used units of measure were legalized throughout an entire nation. As no attempts were made to interrelate them, the result was a hodgepodge. In America, the system of measures, inherited from Great Britain, has as units of volume the cubic foot, gill, pint, quart, gallon, peck, and bushel. Every schoolboy finds it hard to remember that 1,728 cubic inches equals 1 cubic foot or that 5,280 feet equals 1 mile. Most of the tables are quickly forgotten; few people are certain which is larger, the troy pound or the pound avoirdupois. Further confusion arises because units of different magnitudes have the same name. In some cities, coal and coke are sold by the "long" ton of 2,240 pounds, in others by the "short" ton of 2,000 pounds. In still other communities coal is sold by the long ton and coke by the short ton. Pharmacists purchase their supplies by apothecaries' weight and sell them by avoirdupois weight.

The difficulty increases when a national boundary is crossed. A citizen of the United States taking an automobile trip into Canada supposes that gasoline is more expensive there than it is in his own country, but he may not know that the imperial gallon of Canada is about 20 per cent larger than the gallon which is legal in the United States, and that he therefore gets more gasoline per "gallon."

As civilization and technology have advanced, there has come great emphasis upon precision of measurement. In one of the three most widely used automobiles, more than 300 parts are machined to an accuracy of one ten-thousandth of an inch. Moreover, nowadays we attempt to measure many non-physical phenomena. For example, the Gallup polls make many numerical estimates of public opinion as to controversial questions. Increasingly people appreciate the validity of Lord Kelvin's statement, "When you cannot measure, your knowledge is very meager and unsatisfactory."

7. The Metric System. The French Revolution in the latter part of the eighteenth century brought a pronounced tendency to abandon customs and usages. Scientific men had been greatly hindered by the absence of an international system of weights and measures, and they introduced a new *metric* system which is so convenient that it is used everywhere for scientific work. It has been adopted commercially by all excepting the English-speaking nations; even by them, it is being gradually accepted. One great advantage of the metric system is that all the units for measuring a quantity are related decimally. To change centimeters to meters is as easy as converting cents into dollars. All that is needed is to shift the decimal point. For instance, 1.23 meters = 123 centimeters; 3.456 kilograms = 3,456 grams. A second advantage is that the metric system is a truly international language of measurement and it is understood by educated people everywhere.

8. Metric and British Units of Length—the Meter and the Yard. The metric standard of length is the **meter,** which is defined as the distance between two scratches on a certain platinum-iridium bar, at the temperature of melting ice. This bar is kept at the International Bureau of Weights and Measures at Sèvres (pronounced Sayver), near Paris. Replicas of the standard meter are deposited at Washington, London, Berlin, and other capitals.

In establishing the meter, it was desired to choose some object as a standard which could not be lost or damaged, and which would not shrink or expand. The object chosen was the earth. Originally the meter was defined as the one ten-millionth part of the distance from the equator to the north pole, on a line through Paris, and a platinum bar was constructed whose length was as near as possible to this. The "meter stick" was later found to be a hair's breadth too short, and in 1872 the platinum-iridium bar itself was adopted as the primary standard.

The yard, legal in the United States, is defined as a certain fraction (3,600/3,937) of the standard meter. Thus 39.37 inches equals 1

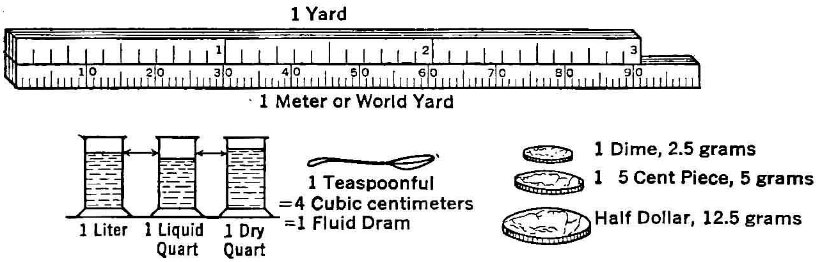

FIG. 2. Metric and British units of length, volume, and mass.

meter, which is about 10 per cent longer than a yard. Also 2.54 centimeters equals 1 inch, and 30.5 centimeters approximately equals 1 foot (Fig. 2).

Table I, of metric and British units, shows the advantage of the metric system.

TABLE I

METRIC UNITS OF LENGTH AND THEIR APPROXIMATE BRITISH EQUIVALENTS

1 megameter	= 1,000,000 meters
1 kilometer	= 1,000 meters = $\frac{5}{8}$ mile
1 meter	= 1.1 yard
1 centimeter	= 1/100 meter = 1/2.54 inch = 1/30.5 feet
1 millimeter	= 1/1,000 meter
1 micron	= 1/1,000,000 meter

BRITISH UNITS AND THEIR APPROXIMATE METRIC EQUIVALENTS

12 inches	= 1 foot = 30.5 centimeters
3 feet	= 1 yard = 0.91 meter
$5\frac{1}{2}$ yards	= 1 rod
40 rods	= 1 furlong
8 furlongs	= 1 mile
5,280 feet	= 1 mile = $\frac{8}{5}$ kilometers
3 miles	= 1 league

9. What is Mass? Another very important unit is that of mass, by which is meant the amount of matter in a body. One way to compare the masses of two bodies is to exert equal forces on them and to see which is easier to "get going." Suppose that two pasteboard boxes are lying on the pavement, one empty, the other containing a brick. If a boy kicks first one and then the other, he quickly determines which box has the greater mass and is harder to "speed up." Another application of this method of comparing masses is as follows: Place two cars on a level table, and compress a spring between them, tying the two by a cord (Fig. 3). Burn the cord, releasing the cars, and the spring will exert equal forces on each of them. Then, if the masses are equal, the cars will travel equal distances in equal times. If the masses are not equal, the car of smaller mass will acquire the greater speed. (The measurement of masses will be discussed more completely later.)

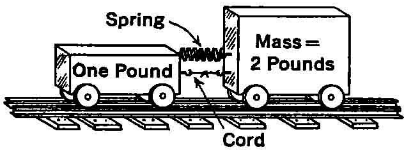

FIG. 3. The more massive body acquires the smaller speed.

10. Units of Mass—the Gram and the Pound. The metric unit of mass, the gram (abbreviated gm.), is **the one-thousandth part of the quantity of matter in a certain platinum-iridium cylinder which is kept with the standard meter.** One gram is nearly equal to the mass of a cubic centimeter of water at 39.2° Fahrenheit or 4° centigrade. A new five-cent piece has a mass of 5 grams; the mass of a dime is one-half as great. The pound-mass equals 454 grams (more exactly 453.6 grams), so that 2.20 pounds equals 1 kilogram, approximately.

SOME METRIC UNITS OF MASS AND VOLUME, AND THEIR APPROXIMATE BRITISH EQUIVALENTS

1 metric ton (1,000 kilograms)	= 0.98	long ton
	= 1.10	short tons
1 gram	= 1/454	pound = 1/28.4 avoirdupois ounce
		= 1/31 troy ounce
1 kilogram	= 2.20	pounds
1 liter (1,000 cubic centimeters)	= 1.06	liquid quarts
	= 0.91	dry quart

(See Appendix A for other equivalents.)

11. Units of Time—the Mean Solar Day and the Second. From prehistoric epochs the motions of the heavenly bodies have served to measure time. The apparent motion of the sun gives us our day, that of the moon measures off the months, and the positions of the stars tell us the passing of the year. About 7,000 years ago Egyptian scholars first noticed that in the spring the star Sirius was barely visible on the eastern horizon at sunrise, and thus they marked the beginning of their year. The **mean solar day** is the average time from noon to noon, as measured on a sundial. This day is divided into 24 equal hours, and each of these into 3,600 seconds. The solar second, the unit of time in both the metric and the British systems, is the 1/86,400 part of a solar day.

12. Derived Units. These units of length, mass, and time are called the *fundamental* units; all other units of mechanics can be derived from them. For example, as units of area in the two systems we have the square centimeter and the square foot, respectively, and as units of speed the centimeter per second and the foot per second.

The set of units derived from the *centimeter, gram,* and *second* is known as the c.g.s. system. Recently a new "m-k-s" system of units has been introduced in which the meter is the fundamental unit of length, the kilogram is the unit of mass, and the second is the unit of time. The British units derived from the *foot, pound,* and *second* constitute the f.p.s. system.

13. Units of Force. A force is an agency that, exerted on a body, will deform it or change its velocity. Presently we shall devote a good deal of attention to force, but now we shall merely define some of its important units.

One pound-weight (abbreviated lb. from the Latin *libra* = pound) is equal to the earth-pull on a body the mass of which is 1 pound. One gram-weight (gwt.) is equal to the earth-pull on a body whose mass is 1 gram. One dyne is the 1/980 part of the weight of 1 gram, so that 980 dynes = 1 gram-weight. 100,000 dynes = 1 newton.

SUMMARY

The complete scientific method comprises (1) observation, (2) organization, (3) hypothesis, and (4) verification.

A science is a highly organized body of knowledge, developed by the scientific method, characterized by an incessant search for relationships between causes and effects.

To measure a quantity means to find the ratio of that quantity to its unit.

The metric system is convenient because its units are decimally related and because it is used internationally.

The meter is the distance between two scratches on a certain platinum-iridium bar when it is at the temperature of melting ice. One meter = 39.37 inches; 2.54 centimeters = 1 inch.

The kilogram is the mass of a certain platinum-iridium cylinder.

One kilogram = 2.20 pounds; 28.4 grams = 1 ounce.

A force is an agency that will deform a body or change its velocity. One pound-weight is equal to the earth-pull on a body whose mass is 1 pound. One gram-weight is equal to the earth-pull on a body whose mass is 1 gram. One dyne = 1/980 gram-weight.

REVIEW QUESTIONS

1. Why is scientific progress more rapid now than it was a century ago? (Can you find other reasons in addition to those cited in the text?)
2. What are the four consecutive steps in the scientific method? Illustrate by a practical problem.
3. Define science, and name several sciences not mentioned in this chapter.
4. Define measurement, and give illustrations of things which cannot be measured.
5. Define meter, kilogram-mass, and mean solar second.
6. Define derived unit, and cite several examples.

PROBLEMS

1. A man's height is 5 ft. 10 in., and his mass is 150 pounds. Express his height in centimeters and his mass in kilograms.
2. Prove that 1 kilometer = 0.621 mi.
3. The elevation above sea level of the top of Mt. Everest is 29,000 ft. Find the elevation in kilometers.
4. Compute the number of grams in 1 ounce.
5. When the price of gasoline in Detroit is 18 cents per gallon, what is the equivalent price in Canada where the gallon is 5/4 as large as that in the United States?
6. A motor car travels 16 mi./gal. of gasoline. Express this value in kilometers per gallon, also in kilometers per liter.
7. Express your height in meters and your mass in kilograms.
8. In short-distance running, the "440-yard dash" is used. How many meters is this?
9. Estimate the thickness in centimeters of a single leaf of paper from this book.

CHAPTER 2

WORK, POWER, AND MACHINES

14. The word work is related to the same Greek word as irksome. It is used in many senses and often means some activity, perhaps unpleasant, for which pay is received. A golf caddy is working when he stands idly while the perspiring player tries to hit a golf ball. A watchman works when he sits by a railroad crossing. A schoolboy works his problem in arithmetic.

In physics it is important in order to avoid misunderstanding that each term shall have but one restricted meaning, and so it is necessary to define work very carefully.

15. What is Work? The following are examples of work as the physicist uses the term. When a laborer carries coal up a flight of stairs, or lifts it up onto a wagon, he does work. Likewise, when a team of horses drags a plow across a field, or a locomotive pulls a train along a railway, work is done. In each of these examples a force acts on a *moving* body, and the amount of work done depends upon two factors, namely, the amount of force exerted and the distance that the body advances in the direction of the force.

We define the work done in moving a body as **the product of the force exerted on the body and the distance that the body moves in the direction of the force.**

The **foot-pound** equals the work done when a body which weighs 1 pound-weight is raised vertically through a distance of 1 foot.

Example. How much work is required to lift a cask weighing 100 lb. onto a platform which is 4.0 ft. above the pavement? *

$$\text{Work} = \text{Force} \times \text{Vertical displacement}$$
$$= 100 \text{ lb.} \times 4.0 \text{ ft.}$$
$$= 400 \text{ ft-lb.}$$

* In stating problems the units of measure as well as the numbers will be given. These units may be multiplied and divided just like numbers, and the result tells the units of the answer. For example:

$$3 \text{ ft.} \times 4 \text{ ft.} = 12 \text{ ft.}^2$$

$$40 \text{ mi.} \div 2.0 \text{ hr.} = 20 \text{ mi./hr.}$$

[*Footnote continued on next page*