A FIRST COURSE IN PHYSICS

MILLIKAN AND GALE

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SHANGHAI
COMMERCIAL PRESS, LTD.

1911

PREFACE

The course presented in this book, and in the *List of Laboratory Experiments* which is published in a separate volume, has grown out of the actual needs of the elementary work in physics in the University of Chicago, particularly in the University High School of the School of Education and the affiliated secondary schools. Its most characteristic features have been on trial for three or four years in more than a score of different secondary schools in various parts of the country.

The books represent primarily an attempt to give concrete expression to a rapidly spreading movement to make high-school physics, to a less extent than it has been in the past, either a condensed reproduction of college physics, or a mathematical and mechanical introduction to technical science, and to a greater extent than it has heretofore been, *a simple and immediate presentation, in language which the student already understands, of the hows and whys of the physical world in which he lives.*

A second aim has been to develop a course in which the laboratory and class-room phases of elementary instruction in physics are carefully differentiated and, at the same time, closely correlated. It is hoped that something may thus be done toward remedying the inadequacy which still exists in the laboratory instruction of many of the smaller schools. A very carefully selected and tested list of distinctively class-room demonstrations will be found to run through the book in fine print, while foot-notes indicate the location and nature of the laboratory exercises which should be inserted. For the sake of definiteness and simplicity the references are made simply to the authors' manual, though the exercises may be taken from any good laboratory text.

In the chapters on Molecular Motions and Molecular Forces, the authors have sought to bring into their proper relations to one another and to the modern theory of physics a large number of phenomena which are sometimes thrown together in somewhat scrappy and illogical form under the general head, Properties of Matter.

In the treatment of image formation the time-honored fiction of rays has been replaced by the truer, simpler, and more comprehensible view point of change in wave curvature. In the treatment also of surface tension, electro-magnetic induction, and the mechanism of tone production by wind instruments, it is thought that some familiar fictions of physics have been replaced by "causally conditioning" facts.

In the description and illustration of *physical appliances* the course has been made unusually complete. It is not expected that all of the material of this sort which has been introduced will under all circumstances be assigned for recitation purposes. It is inserted because it is precisely what the student is usually most eager to learn, but cannot, in general, obtain from books because their language is too technical for him, nor yet from his teacher because the latter lacks the necessary diagrams. It is thought that it will be read by most pupils whether it is assigned or not.

In the last chapter are presented in some detail the recent epoch-making discoveries which have brought *the electron* into prominence and have so profoundly modified molecular, electrical and optical theories.

Much attention has been given to the Questions and Problems which are placed at the end of each subdivision of a chapter, so that they may be made, in so far as is possible, a part of each day's assignment.

In the *illustration* of the course an effort has been made to make each of the very large number of figures not in any sense showy, but in the fullest possible sense *educative*. The portraits of sixteen of the great makers of physics have been inserted for the sake of adding human and historic interest.

Finally, *the authors have endeavored to avoid sacrificing comprehensibility to condensation.* Although they have presented a smaller number of subjects than is often found in an elementary text, they have striven to present each subject with sufficient illustration and amplification to make it easily and quickly intelligible. This, together with the large number of figures, has added to the number of pages in the book, although it has actually shortened the course. For the sake, however, of indicating in what directions omissions may be made, if necessary, without interfering with continuity, paragraphs have here and there been thrown into fine print. These paragraphs will easily be distinguished from the class-room experiments, which are in the same type. They are, for the most part, descriptions of physical appliances.

It is quite impossible to make suitable recognition of the assistance which has been derived from the close coöperation of more than a score of men who have taken an active interest in the development of this course. All of the following have read either the whole or large parts of the manuscript or proof, and all of them have made important suggestions which have been incorporated in the text: Dr. C. J. Ling of the Manual Training High School, Denver, Colorado; Superintendent H. O. Murfee of the Marion Military Institute, Marion, Alabama; Mr. C. F. Adams of the Central High School, Detroit, Michigan; J. C. Packard, Sub-master of Brookline High School, Brookline, Massachusetts; Dr. T. C. Hebb of the Central High School, St. Louis, Missouri; Professor B. O. Hutchison of Shurtleff College, Upper Alton, Illinois; Mr. C. C. Kirkpatrick of the Seattle High School, Washington; Dr. G. M. Hobbs, Dr. C. J. Lynde, and Mr. F. H. Wescott of the University High School; and Mr. Harry D. Abells of the Morgan Park Academy of the University of Chicago. The part which Dr. Ling has had in the development of the course has been of especial importance.

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CHAPTER I

MEASUREMENT

FUNDAMENTAL UNITS

1. The historic standard of length. Nearly all civilized nations have at some time employed a unit of length the name of which bore the same significance as does *foot* in English. There can scarcely be any doubt, therefore, that in each country this unit has been derived from the length of the human foot.

But, as might have been expected from such an origin, no two peoples have agreed in the length of their standard. Thus the Greek foot, supposed to represent the length of the foot of Hercules, was 12.14 English inches; the Macedonian foot was 14.08 inches, the Pythian 9.72, and the Sicilian 8.75. In Europe during the Middle Age almost every town had its own characteristic foot; thus in Rome a foot was 11.62 inches, in Milan 13.68, in Brussels 10.86, in Göttingen 11.45, and in Geneva 19.21.

It is probable that in England, after the yard (a unit which is supposed to have represented the length of the arm of King Henry I) became established as a standard, the foot was arbitrarily chosen as one third of this standard yard. The mean length of the male foot in the United States, according to measurements made upon 16,000 men in the United States army, is 10.05 inches.

2. Relations between different units of length. It has also been true, in general, that in a given country the different units of length in common use, such, for example, as the inch, the hand, the foot, the fathom, the rod, the mile, etc., have been derived either from the lengths of different members of the human body or from equally unrelated magnitudes, and in consequence have been connected with one another by no common multiplier. Thus there are 12 inches in a foot, 3 feet in a yard, $5\frac{1}{2}$ yards in a rod, 1760 yards in a mile, etc. Furthermore the multipliers are not only different, but are frequently extremely awkward; e.g. there are $16\frac{1}{2}$ feet, or $5\frac{1}{2}$ yards, in a rod.

3. Relations between units of length, area, volume, and mass. A similar and even worse complexity exists in the relations of the units of length to those of area, capacity, and mass. For example, a square field containing an acre measures 12.649 rods, 69.569 yards, or 208.708 feet on a side; one square rod contains $272\frac{1}{4}$ square feet; there are $57\frac{3}{4}$ cubic inches in a quart, and $31\frac{1}{2}$ gallons in a barrel.

When we turn to the unit of mass we find that the grain, the ounce, the pound, the ton, etc., not only bear different and often very inconvenient relations to one another, but also that none of them bear any simple and logical relations to the units of length. Thus, for example, the pound, instead of being the mass of a cubic inch or a cubic foot of water, or of some other common substance, is the mass of a cylinder of platinum, of inconvenient dimensions, which is preserved in London.

4. Origin of the metric system. At the time of the French Revolution the extreme inconvenience of existing weights and measures, together with the confusion arising from the use of different standards in different localities, led the National Assembly of France to appoint a commission to devise a more logical system. The result of the labours of this commission was the present metric system, which was introduced in France in 1793, and has since been adopted by the governments of most civilized nations except those of Great Britain and the United States; and even in these countries its use in scientific work is practically universal.

5. The standard meter. The standard *length* in the metric system is called the *meter*. It is the distance, at the freezing temperature, between two transverse parallel lines ruled on a bar of platinum (Fig. 1), which is kept in the Palace of the Archives in Paris.

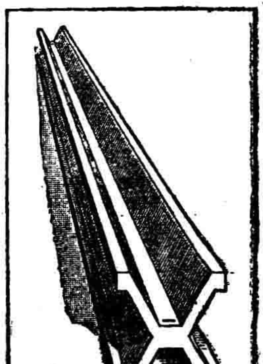

FIG. 1. The standard meter

In order that this standard length might be reproduced if lost, the commission attempted to make it one ten-millionth of the distance from the equator to the north pole, measured on the meridian of Paris. But since later measurements have thrown some doubt upon the exactness of the commission's determination of this distance, we now define the meter, not as any particular fraction of the earth's quadrant, but simply as the distance between the scratches on the above bar. This distance is equivalent to 39.37 inches, or about 1.1 yards.

6. Metric standards of area and capacity. The standard *area* in the metric system is the *are*. It is equal to 100 square meters, or about 119.6 square yards.

The standard unit of capacity is called the *liter*. It is the volume of a cube which is one tenth of a meter (about 4 inches) on a side. It is equivalent to 1.057 quarts. A liter and a quart are therefore roughly equivalent measures.

7. The metric standard of mass. In order to establish a connection between the unit of length and the unit of mass, the commission directed a committee of the French Academy to prepare a cylinder of platinum which should have the same weight as a liter of water at its temperature of greatest density, namely, 4° Centigrade, or 39° Fahrenheit. This cylinder was deposited with the standard meter in the Palace of the Archives and now represents the standard of mass in the metric system. It is called the *standard kilogram* and is equivalent to about 2.2 pounds. One one-thousandth of this mass was adopted as the fundamental unit of mass and was named the *gram*.

8. The other metric units. The four standard units of the metric system—the meter, the liter, the gram, and the are—have decimal multiples and submultiples, so that every unit of length, area, volume, or mass is connected with the unit of next higher denomination by an invariable multiplier, and that the simplest possible multiplier,—namely, ten.

The names of the multiples are obtained by adding to the name of the standard unit the Greek prefixes, *deka* (ten), *hecto* (hundred), *kilo* (thousand), and *myria* (ten thousand), while the submultiples are formed by adding the Latin prefixes, *deci* (tenth), *centi* (hundredth), and *milli* (thousandth). Thus:

1 dekameter	= 10 meters	1 decimeter	= $\frac{1}{10}$ meter
1 hectometer	= 100 meters	1 centimeter	= $\frac{1}{100}$ meter
1 kilometer	= 1000 meters	1 millimeter	= $\frac{1}{1000}$ meter

The most common of these units, with the abbreviations which will henceforth be used for them are the following:

meter (m.)	cubic centimeter (cc.)
kilometer (km.)	hectare (ha.)
centimeter (cm.)	gram (g.)
millimeter (mm.)	kilogram (kg.)
liter (l.)	milligram (mg.)

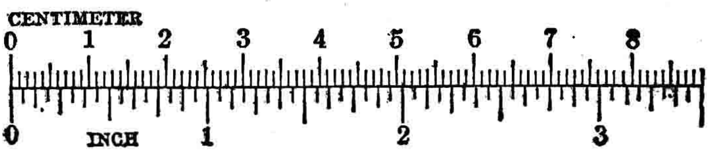

FIG. 2. Centimeter and inch scales

9. Relations between the English and metric units. The following table gives the relation between the most common English and metric units.

1 inch (in.)	= 2.54 cm.	1 cm.	= .3937 in.
1 foot (ft.)	= 30.48 cm.	1 m.	= 1.094 yd. = 39.37 in.
1 mile (M.)	= 1.609 km.	1 km.	= .6214 M.
1 sq. in.	= 6.45 sq. cm.	1 sq. cm.	= .1550 sq. in.
1 sq. ft.	= 929.03 sq. cm.	1 sq. m.	= 1.196 sq. yd.
1 acre	= .405 ha.	1 ha.	= 2.47 acres
1 cu. in.	= 16.387 cc.	1 cc.	= .061 cu. in.
1 cu. ft.	= 28,317 cc.	1 cu. m.	= 1.308 cu. yd.
1 qt.	= .9463 l.	1 l.	= 1.057 qt.
1 grain	= 64.8 mg.	1 g.	= 15.44 grains
1 oz. av.	= 28.35 g.	1 g.	= .0353 oz.
1 lb. av.	= .4536 kg.	1 kg.	= 2.204 lb.

This table is inserted chiefly for reference; but the relations 1 in. = 2.54 cm., 1 m. = 39.37 in., 1 kilo (kg.) = 2.2 lb. should be memorized. On account of its more convenient size, the centimeter, instead of the meter, is universally used for scientific purposes as the fundamental unit of length. Portions of a centimeter and of an inch scale are shown together in Fig. 2.

10. The standard unit of time. The *second* is taken among all civilized nations as the standard unit of time. It is $\frac{1}{86400}$ part of the time from noon to noon.

11. The three fundamental units. It is evident that measurements of both area and volume may be reduced simply to measurements of length; for an area is expressed as the product of two lengths, and a volume as the product of three lengths. Hence one single instrument, namely, the meter stick, is all that is absolutely essential to the determination of any or all of these quantities. For these reasons the units of area and volume are looked upon as *derived* units, depending on one *fundamental* unit, the unit of length.

The *mass* of a body is found by weighing it upon a balance. This operation is something wholly distinct from a measurement of length and requires a new form of instrument. Also the measurement of time is wholly unlike the measurement of either length or mass, and is made with another distinct kind of instrument, namely, a clock, or watch.

Now it is found that just as measurements of area and of volume can be reduced in the ultimate analysis to measurements of length, so the determination of any measurable quantities, such as the pressure in a steam boiler, the velocity of a moving train, the amount of electricity consumed by an electric lamp, the amount of magnetism in a magnet, etc., can be reduced simply to measurements of length, mass, and time. Hence the units of length, mass, and time are considered as *the three fundamental units*, and the three instruments which measure these three quantities, namely, the meter stick, the balance, and the clock, are considered the most fundamental of all instruments.

Whenever any measurement has been reduced to its equivalent in terms of the units of length, mass, and time, it is said to be expressed in *absolute* units. Furthermore, since in all scientific work the centimeter, the gram, and the second are now universally recognized as the fundamental units of length, mass, and time, reducing a measurement to absolute units consists simply in reducing all lengths involved to centimeters, all masses to grams, and all times to seconds. The measurement is then often said, for short, to be expressed in C.G.S. (Centimeter-Gram-Second) units.

QUESTIONS AND PROBLEMS

1. The Effel Tower is 335 m. high. What is its height in feet?

2. A freely falling body, starting from rest, moves 490 cm. during the first second of its fall. Express this distance in feet.

3. A man weighs 160 lb. What is his weight in kilograms?

4. How many kilograms of butter may be bought for $1 if a pound of butter costs 30 ¢?

5. Find the number of millimeters in 5 km. Find the number of inches in 3 mi.

6. Find the number of square rods in a field 200 ft. on a side. Find the number of square meters in a field ·3 km. on a side.

7. There are 231 cu. in. in a gallon. How deep must a tank be made which is 4 yd. long and 4 ft. wide if it is to hold 1500 gal.? What must be the depth of a tank which is to hold 6000 l. if it is 4 m. long and 1.5 m. wide?

CONSTRUCTION OF STANDARDS

12. Measurement of length. Measuring the length of a body consists simply in comparing its length with that of the standard meter bar kept in Paris. In order that this may be done conveniently, millions of rods of the same length as this standard meter bar have been made and scattered all over the world. They are our common meter sticks. They are divided into 10, 100, or 1000 equal parts, great care being taken to have all the parts of exactly the same length. The method of making a measurement with such a bar is more or less familiar to every one.

13. Measurement of mass. Similarly, measuring the mass of a body consists in comparing its mass with that of the standard cylinder of platinum, the kilogram of the Archives. In order that this might be done conveniently, it was first necessary to construct bodies of the same mass as this kilogram and then to make a whole series of bodies whose masses were $\frac{1}{2}$, $\frac{1}{10}$, $\frac{1}{100}$, $\frac{1}{1000}$, etc., of the mass of this kilogram; in other words, to construct a *set of weights*.

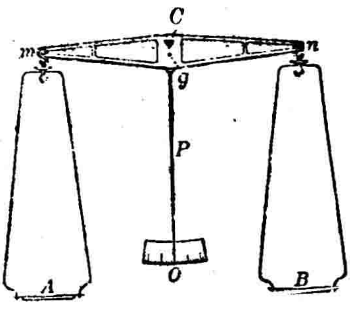

FIG. 3. The simple balance

14. Method of duplicating the standard kilogram. To obtain masses exactly equal to the standard kilogram the method of procedure is as follows. The standard cylinder is placed on one pan A of a balance (Fig. 3),— an instrument which consists essentially of a beam ***mn***, supported on a knife edge *C*, and carrying two pans *A* and *B*. Any convenient objects, such as shot, paper, etc., are then added to the pan *B* until the beam balances in the horizontal position, a condition which is indicated by the coincidence of the pointer *P* with the mark *O*. The standard is then removed from *A* and replaced by the body which it is desired to make equivalent to it. If the pointer is now found to come back exactly to the mark *O*, the body is considered to have a mass of one kilogram. If the pointer does not return to *O*, the body is altered (filed away or added to) until coincidence between *P* and *O* is exact.

15. Method of making a set of weights. To obtain bodies of mass equal to half a kilogram, it is only necessary to take two pieces of metal as nearly alike as possible and file them down together, always keeping them exactly equal to each other, until the balance shows that the two together are exactly equivalent to the standard kilogram. In this way sets of weights may be made which contain any desired masses, e.g. 500 g., 200 g., 100 g., 50 g., 10 g., 1 g., .1 g., .01 g., .001 g., etc.

16. Method of weighing a body of unknown mass. With the aid of such a set of standard weights, the determination of the mass of any unknown body is made by first placing the body upon the pan *A* and counterpoising with shot, paper, etc., then replacing the unknown body by as many of the standard weights as are required to again bring the pointer back to *O*. The mass of the body is equal to the sum of these standard weights. This is the rigorously correct method of making a weighing, and is called the *method of substitution*.

If a balance is well constructed, however, a weighing may usually be made with sufficient accuracy by simply