A Laboratory Manual of

Experiments in Physics

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A LABORATORY MANUAL OF EXPERIMENTS IN PHYSICS

PREFACE TO SIXTH EDITION

The two senior authors are glad to welcome as coauthor in this edition Professor T. A. Rouse, who has been much interested in and concerned with the preparation of the last several revisions of this manual.

The changes in the present revision are the most extensive of any since those of the third edition. Thirteen outmoded or seldom used experiments have been dropped and seven new ones added. Several other experiments have been completely or partly rewritten and a great many minor improvements have been made. Most of the added experiments have to do with the more recently developed fields of physics. There is always a nice question as to how much material of the sort one usually associates with advanced or at least second-year texts can be included in a general physics course. However, in view of the intimate relationship of some of the instruments and techniques used in these experiments to the striking new developments in physics—matters in which literally everyone is interested—it is difficult to see how they can be left out of any physics book which makes any pretense of being up to date. It may be added that, since these experiments will be of interest mainly to the better students, it has not seemed necessary to include as much detail in describing the procedure. In other words, the student is expected to rely more on his own ingenuity.

In preparing this revision we have, for the first time, made a serious effort to get in touch with every instructor using this manual in his classes and ask for criticisms. The result has been a veritable flood of welcome suggestions, and, while it has proved possible to incorporate only a fraction of them, they have all been given careful consideration. We take this opportunity to express our thanks to these many friends for such evidences of their interest and good will.

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PREFACE TO THE THIRD EDITION

In the preparation of the present edition of this manual the book in its previous form has been completely rewritten and almost forty per cent of new material has been added. All the best of the former experiments have been retained, however, with only relatively minor changes in procedure so that laboratories accustomed to the former edition will experience no inconvenience with the present one; but most of the descriptions have been recast. A particular feature is the brief digest of the underlying theory which accompanies each experiment and serves to bridge the gap between formal class work and laboratory exercises. The instructions are somewhat more specific and clear-cut than formerly, but we have kept continually in mind the dangers of being over-specific. The aim has been to strike a satisfactory mean between the one extreme of giving directions so sketchy that the student is unable to make headway, and the other of providing cookbook-like instructions which leave nothing to his ingenuity.

Since the book is designed for use with both general and technical courses, it will be found to contain a rather wide variety of experiments ranging from relatively simple ones to those of a more exacting nature. Nearly one-fourth of the experiments are new, and a number of these make use of improved forms of apparatus which have recently been developed and put on the market. We feel sure that these new experiments, as a whole, will come to be regarded at least as highly as any of the older ones. In general it will be found that they are slightly more involved than the others, but they are usually divided into parts so that the instructor can make a suitable selection for a particular class of students. In the same way a choice may be made of the questions and problems. The occasional question marked as difficult by an asterisk may serve to stimulate the outstanding student.

It is not easy to avoid a certain amount of local color in a manual. This has been reduced to a minimum, but in those few cases where it has been necessary we have frankly specified that certain instructions are for University of Wisconsin students. To adapt the book to the needs of the average user, almost all of the apparatus called for is standard and each experiment is accompanied by a statement of the apparatus requirements. In the few instances where special equipment or assembly is required, we have tried to make the arrangement clear so that it can be duplicated if desired. All the new experiments have been tested with many groups of students and we hope that this has resulted in the elimination of inaccuracies and ambiguities, but we shall be glad to have any such as remain called to our attention.

We wish to acknowledge our indebtedness to the following apparatus and instrument companies for the use of illustrations or other material: Central Scientific Company, Gaertner Scientific Corporation, General Electric Company, Leeds and Northrup, and the W. M. Welch Scientific Company. We also wish to express our thanks to the staff of physical laboratory instructors of the University of Wisconsin, and particularly to Dr. T. A. Rouse and L. T. Earls, for continuous assistance during the preparation of the book.

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INTRODUCTION

1. Initial Instructions. Laboratory work in physics is designed to familiarize the student with the fundamental laws and principles of the subject and to acquaint him with the methods of making physical measurements. The success of experimental work depends upon the exercise of thoroughness and care and upon the originality and ingenuity of the experimenter. It is quite possible—and, in fact, frequently the case—that two students will perform the same experiment in the same way with identical apparatus and yet obtain widely different results, owing to the fact that one exercises care and originality while the other merely follows the instructions mechanically. So while specific directions are given for each experiment, it cannot be too strongly impressed on the student that satisfactory experimental work means more than the mere following of such instructions. It means that the student should at each stage of the procedure know just *what* he is doing and *why* he is doing it.

Accordingly, before beginning an experiment the student is asked to read carefully through the instructions and, as far as possible, to *familiarize himself with the theory.* In many cases it will be desirable to look up the subject in a general text. Descriptions of particular instruments, special technique, etc., will be found in Appendix I and should always be read when they apply to the experiment.

2. Measurements. Data. All measurements are to be recorded directly in the laboratory notebook, or on data sheets if so directed by the instructor (he may also ask that a carbon copy of the data sheet be left with him). If, as is customary, two students work together on an experiment, each must keep his own complete record of the data. The date, student's name, and partner's name should head the data sheet for each experiment. If any data entered in a student's record is actually the work of his partner, credit and responsibility should be shown by having the partner initial such data.

The data should contain *all* the measurements and must never be altered nor recopied. Do not make erasures; if a mistake is made, cancel with a line and write the correct value nearby. Establish the habit of tabulating the data in a well-organized manner. In many cases it will be useful to rule the paper so that this tabulation can be done neatly. Each student should take his turn at reading the instruments, and care should be taken to state the units in which the measurements are made.

At the conclusion of the experimental work the instructor will initial the data sheets if the work has been satisfactory and file his copy. Unfinished data must not be taken from the laboratory.

While many of the measurements made in the physical laboratory are within the scope of everyday experience (*e.g.*, the use of a rule in measuring lengths), there are certain requirements in scientific work which may be new to the student but with which he must become acquainted at the earliest opportunity. The first of these is the number of determinations to be made in any particular measurement. It is a fundamental law of laboratory work that a *single* measurement is of little value because of the liability not only to gross mistakes but also to smaller errors. Accordingly it is customary to repeat all measurements so that the total number of observations of a particular quantity is seldom less than 3 and in some cases even 10 or more. The average of these readings is obviously of a greater probable accuracy than any one could possibly be alone. The number of readings to be taken is usually specified in the earlier experiments, but it is expected that the student will soon accustom himself to this requirement and will always take his measurements in sets of three or more, whether this is explicitly specified or not.

Requirements of accuracy demand that each measurement be made as carefully as possible, and to fulfill this requirement it is universal practice in physical measurements to estimate the reading of a scale to tenths of the smallest division. Thus if a scale is divided into millimeters, as is the ordinary meter stick, the reading will be expressed in tenths of a millimeter, *e.g.*, 4.3 mm., 27.42 cm. In case the reading falls exactly on a scale division, the tenths are expressed by 0, *e.g.*, 6.0 mm., 48.50 cm.

3. Reports. The nature and extent of the final written report which is to accompany the data sheet will be specified by the instructor. The following outline lists suggestions:

1. Name and number of experiment. Name and number of student and partner.
2. Object of the experiment (to be stated in the student's own words).
3. Apparatus used, with diagram; give numbers of apparatus when possible.
4. Description of how the experiment was performed.
5. Method of deducing results from original data.
6. Summary of results; be sure to specify units and, where possible, place side by side with the results standard values as given in physical tables, for purposes of comparison.
7. Curves, if required.
8. Physical interpretation of results and answers to questions (unless already answered on the data sheet).
9. It is also frequently possible and profitable to include a discussion of sources of error.

When an experiment has been completed, the student should talk the matter over with the instructor in order that any difficulties may be cleared up. Later the instructor will make a more careful survey of the report. If returned to the student for correction, such corrections should be made at once. Good laboratory work involves writing up and completing the experiment as soon as possible after taking the data. *In general, full credit cannot be allowed for experiments in which there is unnecessary delay in the submission of the completed report.*

The answers to the questions on each experiment constitute one of the most important parts of the finished work. These should in every case be written, generally at the end of the report. Also it is wise, as a rule, to sketch out the answers on the data sheet and talk them over with the instructor at the time the measurements are completed. Questions or problems marked with an asterisk are more difficult than the others and, needless to say, are for the ambitious student who wants to make his work as complete as possible.

4. Computations. Significant Figures. All but the simplest computations should be made with either slide rule or logarithms. Simple log tables will be found in Appendix II, and half an hour's study of the instructions preceding them should render it possible for even the student without previous experience with logarithms to use them.

When an equation involving a number of quantities is to be solved, write the equation first in symbolic form; then rewrite it, substituting experimentally determined quantities; finally write it a third time, reducing all quantities to simple numbers of one and two digits and powers of 10. This enables one to locate the decimal point readily and facilitates checking over computations. *Do not fail to state the units in which the result is obtained.*

No matter to how many decimal places the computation may be carried, the accuracy of the result cannot exceed that of the data. If three successive measurements with a meter stick give 48.25, 48.23, 48.22 cm., as the length of a certain rod, the average might be expressed as 48.2333333 cm. But as the meter stick is divided only to 0.1 cm. and the next figure is obtained by estimating tenths, the result should not be expressed to more than two, or at most three, decimals. By the term "significant figures" is meant those figures in a result which are trustworthy and have some significance. Obviously, the figures after the third decimal place in the length just mentioned are of no value and so are not significant figures. The position of the decimal point in no way affects the number of these figures; this number is determined entirely by the accuracy of the data. Suppose three significant figures are to be retained in the following numbers: 1,763,298.23 and 0.0003628. Then they should be written 1,760,000 and 0.000363 (or, better, 1.76×10^6 and 3.63×10^{-4}).

In ordinary laboratory work it is usually unnecessary to have more than four significant figures in the result, but the following rules may prove useful:

1. In addition and subtraction do not carry the result beyond the first column which contains a doubtful figure.

2. In multiplication and division the number of significant figures in the result should be one greater than the smallest number of trustworthy figures contained in any factor used in obtaining the result.

These rules give the number of significant figures which should appear in the result, the last figure being always in doubt; but, in computing, it is better to carry one more figure than they specify. The following examples illustrate the principles just mentioned:

$$4{,}567 + 1.48 + 0.0764 = 4{,}568.6$$
$$13.28 \times 2.06 = 27.36$$
$$0.0735 \times 0.002 = 0.00015$$
$$189{,}324{,}500 \times 66 = 12{,}500{,}000{,}000 = 125 \times 10^8$$

5. Errors. Absolute accuracy is, of course, unattainable in laboratory measurements. Every result, no matter how carefully obtained, has a certain "probable error" which depends on the number of measurements, their concordance, and some other factors. It should be the aim of the student to make his measurements with the greatest accuracy attainable with the given apparatus; in no case, however—except by accident—will his results agree exactly with the true values of the quantities measured.

Errors are commonly listed as either *absolute* or *relative.* If a length of 400 cm. is measured as 398 cm., the absolute error is 2 cm., while the relative error is $2/400$ or 0.5 per cent. If quantities are to be added or subtracted, it is the actual or absolute error which is of importance; if multiplied or divided, the relative or percentage error. In the latter case the relative error of the separate quantities determines the error of the final result, and for this reason small quantities should be measured with special care to keep the percentage error low. This is particularly true when a quantity is squared or raised to some higher power, in which case the relative error of the result is multiplied by this power. Thus in experiments on torsion the radius of the wire appears raised to the fourth power. This means that if the wire is 1 mm. in diameter and the absolute error of its measurement is 0.01 mm., this relative error of 1 per cent causes an error of 4 per cent in the final result.

An indication of the trustworthiness of a result is given by the consistency of the individual measurements. If these show only a small variation or deviation from the mean value, the accuracy of the final result may be taken as correspondingly high. As an example consider the following series of readings.

Readings, cm.	Deviations, cm.
17.304	0.047
17.483	0.132
17.266	0.085
17.325	0.026
17.379	0.028
5)86.757	5)0.318
17.3514	0.0636

The arithmetic average, 17.3514, is obtained as indicated. The deviation of each reading from the average is given in the second column. The average deviation is 0.0636 cm. This is frequently called the "average error." In relative form it is 0.0636/17.3514 = 0.0035 or 0.35 per cent.

6. Averaging. Method of Differences. Since experimental values involve errors, some averaging process is desirable in order to lessen the final error. A result which is based on a large number of readings is more accurate than one based on one or two readings. When several readings are taken separately, the most nearly correct value of the quantity is the ordinary arithmetic average. It is to be noted that this is used only *when the readings are wholly independent of each other*. For example, if several measurements are made of the diameter of a wire, the most dependable value to take would be the arithmetic mean of the individual determinations.

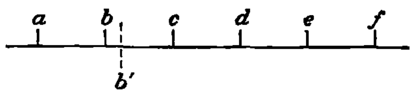

FIG. 1-1. Illustration of "method of differences."

Under certain circumstances this method is not satisfactory. This may be seen from the following discussion: If the average width of a board on the floor of a room is desired, several methods may be followed. The obvious way would be to measure the total width of a certain number of boards and divide this total by the number of boards included. The result is dependent only on the two end readings; it would be more accurate if a number of readings were involved.

Another method which at first appears more accurate is to lay a scale across the floor, note the reading on the scale at the edge of each board, subtract these readings in order to find the width of each board, and then find the ordinary average of these differences.

In this case, however, the arithmetic average does not give the best result obtainable from the data. In order to see its failure let the successive readings on the scale be a, b, c, d, e, f, as illustrated in Fig. 1-1.

These readings are steadily increasing across the scale. The width of the first board is then *b-a*; the width of the second is *c-b*; etc. If the arithmetic average be taken, we should add the differences and divide by their number:

$$\begin{array}{c} b-a \\ c-b \\ d-c \\ e-d \\ \underline{f-e} \\ f-a \end{array}$$

Thus when the successive differences are added, the intermediate readings are eliminated leaving only *f-a*. This is precisely the result obtained in the foregoing method and shows the final result to be dependent only on the end readings. The intermediate readings are therefore wholly useless and may be in error by any amount without influencing the result. Suppose, for instance, that a large error had been made in the second reading and that this reading is represented by b' instead of *b*. Obviously the observed width of the first board is $b'-a$ and that of the second board is $c-b'$, but the sum of the two differences is *c-a* just as before. Hence the reading at b' has no effect upon the result.

There is, however, a way of averaging—sometimes called the "method of differences"—which makes use of these intermediate readings. Divide the readings into two equal groups, *a*, *b*, *c* and *d*, *e*, *f*. Subtract the first reading in group A from the first in group B, *i.e.*, (*d-a*); then subtract the second in group A from the second in group B, *i.e.*, (*e-b*); etc. Thus:

$$\begin{array}{c} d-a \\ e-b \\ f-c \end{array}$$

Each of these differences represents three of the desired intervals. If the differences are added, no readings will be eliminated, and the sum will represent nine of the desired intervals. Finally, a single interval (in this example the width of one board) is found by dividing the total by the number of intervals represented. The effect of this method is to make each reading the beginning point or the end point of some difference (using in the example three differences with three boards in each) and thus make the final result depend upon all readings instead of only two.

As an illustration this method of averaging will be applied to the following data taken to determine the period of vibration of a certain pendulum:

Observation	Vibration	Time			Differences			
		h	m	s		vib.	m	s
1	0	2	35	50	Fifth-first..................	400	13	19
2	100		39	9	Sixth-second...............	400	13	21
3	200		42	29	Seventh-third..............	400	13	21
4	300		45	48	Eighth-fourth..............	400	13	22
5	400		49	9	Total....................	1,600	53	23
6	500		52	30			or	
7	600		55	50			3,203sec.	
8	700		59	10				
					∴ Period is 3,203/1,600 = 2.002sec.			

It is to be noted that this special method of averaging is to be used only when the average of a number of *successive differences* is desired. For all other cases the ordinary arithmetic average is satisfactory.

7. Plotting of Curves. In the plotting and discussion of curves the following terms are frequently used:

The *abscissa* is the distance OA (Fig. 1-2) measured along the horizontal line OX. This line is called the axis of abscissas or X axis.

The *ordinate* is the distance OB measured along the vertical line OY, the axis of ordinates or Y axis. These two distances OA and OB are called the *coordinates* of the point P.

The *origin* is the point O, the intersection of the two axes. This point is called the origin only when the magnitudes plotted on the two axes have their zero values at this point.

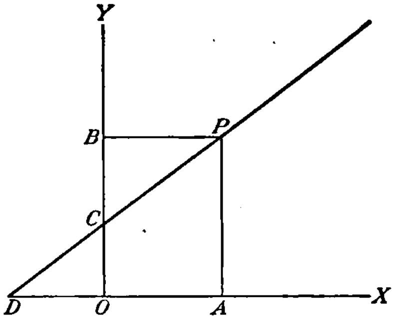

FIG. 1-2. Coordinates, intercepts, and slope.

An *intercept* is the distance measured from the origin along one of the axes to the point at which the curve meets the axis. Thus OC is the Y intercept and OD the X intercept for the curve in Fig. 1-2.

The *slope* of a curve is a measure of the angle which the curve makes with the X axis. It is the trigonometric tangent of this angle; thus in the figure the slope is AP/DA.

The following general rules should be observed in plotting curves:

a. Choice of Scales. Use, in general, only standard 15- by 20-cm. coordinate paper, or paper ruled 20 lines per inch. Choose such scales that the curve will extend nearly the full length of the sheet in both directions, but make them convenient; *i.e.*, have each division equal to 1, 2, 5, 10, etc., units. The scales need not be the same for both axes. Label the main divisions, the numbers increasing from left to right and from bottom to top. It is customary to plot the independent variable as abscissa and the dependent as ordinate.

b. Plotting. Locate experimental points by small, sharp dots. Draw around each point a small circle in ink; crosses are also frequently used. Draw a smooth curve, first in pencil and then in ink, passing through (or near) as many of the points as possible, but do not make it irregular to get in all the points and do not draw the final line *through* the circles (note the way in which the curves in Fig. 1-3 are interrupted at the circles). The curve should indicate the average trend of the data. It should never be

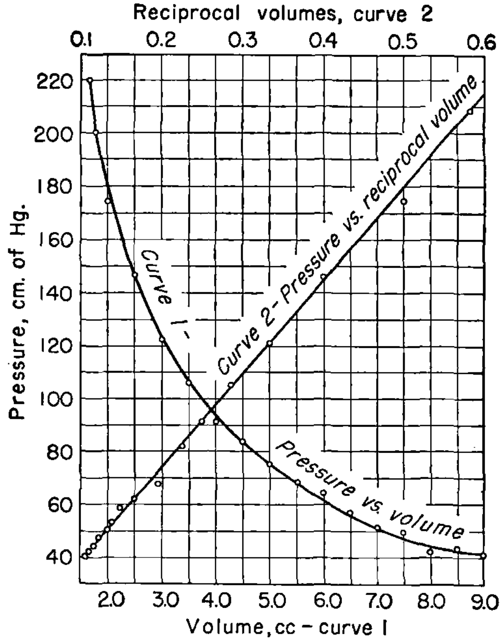

FIG. 1-3. Typical graphs.

merely a series of straight lines connecting the points, except in certain types of calibration curves.

c. Labeling Curve and Coordinates. Letter the title of the curve and number of the experiment on the sheet, also your name. Along each axis label the coordinates, stating the *quantity* plotted and the *units* in which it is expressed (see Fig. 1-3). When two or more curves are on one sheet, use different colors of ink if possible for the different scales and corresponding curves, or else use dotted or broken lines.

d. Interpretation of Curves. This means to state what physical law or conclusions may be drawn from such a curve. For instance, if a curve of distances covered by a falling body plotted against squares of the times should come out as a straight line passing through the origin, the conclusion would be that the space covered by a falling body is directly proportional to the square of the time.

8. Graphical Analysis of Data. Empirical Equations. Sometimes in a physical problem the dependence of one quantity upon another can be deduced theoretically, and sometimes it must be arrived at experimentally. The mathematical relationship between two quantities may be determined experimentally by observing a series of values of one of them corresponding to various arbitrary values of the other (all other factors being kept constant) and then subjecting the data to some kind of analysis. An equation established in this way is called an *empirical* equation. One of the most convenient and fruitful means of treating experimental data is graphical analysis.

In the graphical analysis of experimental data, the straight line assumes a fundamental role since it can readily be recognized, whereas the exact nature of a nonlinear graph is often difficult to identify. If the data yield a straight line when plotted in any one of several ways, the form of the equation can be deduced and the numerical value of the constants obtained from the graph. In making such an analysis, three types of graphs are of particular importance: *viz.*, *Cartesian*, *logarithmic*, and *semi-logarithmic* graphs.

Cartesian Graphs. In a Cartesian graph the successive values of one quantity are plotted against the corresponding values of the other on rectangular coordinate paper in which each axis is graduated uniformly (Fig. 1-3). The simplest relationship between two variables x and y is a linear one expressible by an equation of the form

$$y = A + Bx, \tag{1}$$

where A and B are constants. The graph of Eq. (1) on Cartesian paper is a straight line (Fig. 1-2) with a slope equal to the constant B and a y intercept equal to the constant A. Thus, if a linear relationship is suspected, its existence will be confirmed or denied by the form of the curve resulting from a Cartesian graph of the data.

Logarithmic Graphs. A logarithmic graph is one in which the logarithm of one quantity is plotted against the logarithm of the other. This may be done either on Cartesian paper or on specially ruled logarithmic paper, which will be described later. This type of graph is useful in demonstrating the existence of a *power function, i.e.*, a relationship in which one quantity is proportional to some power of the other. The mathematical statement of a power function is

$$y = Cx^n, \tag{2}$$

where C and n are constants. Taking the logarithm of both sides of Eq. (2) yields

$$\log y = \log C + n \log x. \tag{3}$$

Comparison of Eqs. (1) and (3) shows that, if the relationship sought is of the type expressed by Eq. (2), a logarithmic graph of experimental data yields a straight line, the slope of which is the value of the constant n; the numerical value of the constant C is obtained from the intercept on the $\log y$ axis.

Semilogarithmic Graphs. A semilogarithmic graph is one in which the successive values of one quantity are plotted against the logarithms of the corresponding values of the other. This type of graph may also be made upon Cartesian paper or upon specially prepared semilogarithmic paper. The semilogarithmic graph is used in testing for an *exponential function* of the form

$$y = k10^{nx}, \tag{4}$$

or, since $10 = e^{2.3026}$, the equivalent expression

$$y = ke^{2.3026nx}, \tag{5}$$

where k and n are constants and e is the base of the natural system of logarithms. In this discussion only logarithms to the base 10 are considered.

An alternative way of writing Eq. (4) is

$$\log y = nx + C, \tag{6}$$

where $C = \log k$. Comparison of Eqs. (1) and (6) shows that, if the relationship is of the exponential form represented by Eq. (4), a graph of $\log y$ versus x is a straight line of slope n.

Logarithmic and Semilogarithmic Paper. The plotting of logarithmic and semilogarithmic graphs is facilitated by the use of specially ruled paper called, respectively, *log* and *semilog* paper. On the former, the graduations of both coordinate axes are proportional to the logarithms of the consecutive numbers instead of to the numbers themselves. On semilog paper, one axis bears a uniform scale and the other a logarithmic scale. Consequently, when data are plotted on either of these papers, the values of the quantities are plotted directly, and it is unnecessary to look up the logarithms.

Figure 1-4 is an example of a logarithmic graph plotted on log paper to the scale of common logarithms. On log paper the origin is the point $x = 1$, $y = 1$ instead of $x = 0$, $y = 0$, as in the case of Cartesian paper. Consequently, the *intercepts* are measured from the origin along the lines $x = 1$ and $y = 1$. On logarithmic paper like that illustrated in Fig. 1-4, the graduations from 1 to 10, 10 to 100, and 100 to 1,000, respectively, are called *cycles*. If the data to be plotted lie within one cycle, they can be plotted as in Fig. 1-4; if the values extend over more than one cycle, multiple log paper, which contains two or more complete cycles for each coordinate, must be used. In logarithmic plotting the origin cannot be located arbitrarily but must be at the beginning of a cycle. If the range of the data is such that the origin does not appear on the graph (as in Fig. 1-4), it may be located by attaching one or more additional sheets and continuing the calibrations along the axes. If the cycle distance is the same on both axes (as in Fig. 1-4), the slope of a curve on log paper is the ratio of any vertical distance to the corresponding horizontal distance measured

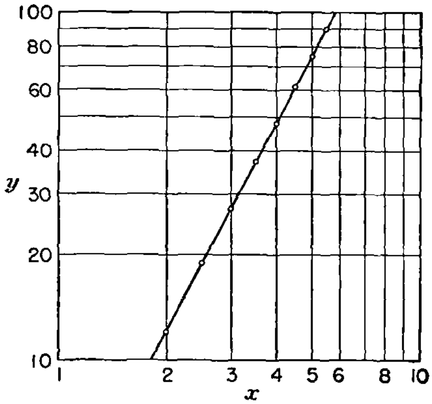

Fig. 1-4. Typical logarithmic graph, $y = 3x^2$.

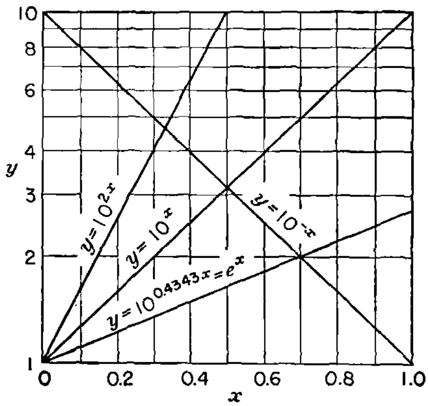

Fig. 1-5. Typical semilog graphs.

with the same uniform scale. It can, therefore, be measured with an ordinary ruler. If the two cycle distances are not the same, the ratio of the corresponding vertical and horizontal distances (apparent slope) must be multiplied by the ratio of the cycle distance on the x axis to that on the y axis to give the slope.

Figure 1-5 shows several curves plotted on semilog paper to the scale of common logarithms. On semilog paper the origin is at the point $x = 0$, $y = 1$. Thus, the constant C in Eq. (6) is determined from the intersection of the curve with the line $x = 0$. Inspection of Fig. 1-5 shows that a range of values on the logarithmic scale such as 1 to 10, 10 to 100, 100 to 1,000, etc., corresponds, respectively, to a range of 0 to 1, 1 to 2, 2 to 3, etc., on the uniform scale. In each case the corresponding range of values is called a cycle. From this definition, it follows that the measurement of the slope obeys the same conditions as were described for logarithmic graphs.

Summary. When one quantity is plotted against another, a straight line on Cartesian paper indicates a linear function represented by Eq. (1); on log paper it indicates a power function of the type of Eq. (2), the value of the exponent being yielded by the slope; and on semilog paper it indicates an exponential function such as represented by Eq. (4).

9. General Laboratory Rules.

1. Be punctual; habitual tardiness will be counted as absence.
2. Absences must be made up. If possible, this should be done under the student's own instructor. In any case, the student should be sure that the instructor enters the credit on his work card.
3. Follow the laboratory bulletin board.
4. Credit will not be given for experiments which have not been regularly assigned or for which the data sheets have not been initialed by an instructor. Full credit will not be allowed when there is unnecessary delay in submitting the completed report on the experiment.
5. *Under no circumstances may a student use data in the taking of which he has not had a part.* This is particularly applicable when a student is absent and his partner performs the experiment alone. Such data must not be used in any way by the absent student.
6. Students are asked not to move apparatus about the room without permission. Special cooperation is asked in keeping apparatus and laboratory in as good shape as possible.