Part One

Laboratory Experiments in Medical Physics

Introduction

1. Laboratory Objectives.

The laboratory is the workshop of the student, the place where he gets a firsthand knowledge of physical principles and experimental methods through the handling of apparatus designed to demonstrate the meaning and application of these principles. Some of the more specific objectives are: (1) to acquire training in scientific methods of observation and recording of data; (2) to acquire techniques in the handling and adjustment of equipment; (3) to get an understanding of the limitation and strengths of experimentation; (4) to obtain experience in the use of graphical representation; and (5) to take data, and develop confidence in one's ability to compute reliable answers, or determine valid relationships. When one develops the skill of computing answers from experimental data which check with known values of the desired quantities, he acquires the confidence needed to perform an experiment and determine some quantity or relationship which was previously not known to anyone.

2. Development of character and Sense of Responsibility.

The physics instructor makes his evaluation of these traits such as character、attitude, honesty and dependability of students from observations of the student's performance in class and in the laboratory. The laboratory is a place for serious thought and investigations, and the following suggestions should help you to develop the above mentioned traits.

a. Be prompt in arriving at your station of work and be well prepared concerning the principles of the experiment. If, for some good reason, you are late or absent, report the matter to the instructor.

b. Work quietly and attempt to make the most careful observations possible by adjusting the equipment so it will give its best possible performance.

c. Be honest in making and recording observations. Record data as indicated by your equipment and not as you thought it was supposed to be, if they differ. If your results seem to be outside the limits predicted by the experimental uncertainties, recheck your measurements and computations. If this does not give the answer, make the best possible explanation for the discrepancy.

d. Have the entire procedure well in mind and perform the various steps in the order that will make the best use of your time. Cooperate with your partner in such a way that each of you gets experience in manipulating the equipment. Then each of you computes your results independently so as to check on the accuracy of your work.

e. Always remain at your assigned station and do not disturb other people in the class concerning any part of the experiment. Do not disturb other equipment that may be in the room but not a part of your present experiment.

f. Always abide by any precautions that your instructor may have given you regarding the proper handling of the equipment. Delicate equipment may be easily damaged.

3. Preparation for the Actual Laboratory Work.

The efficiency of performance in the laboratory depends largely on the preparation made before the experimental work begins. This preparation may consist of a careful individual study of the principles involved and a general idea of the procedure to be followed, or, your instructor may give a lecture on the experiment. In the lecture period which may, or may not, immediately precede the laboratory work, the instructor will state the purpose of the experiment, discuss the underlying theory in the "Introduction" section, and outline the experimental approach for obtaining the necessary data. He may also suggest techniques that should be used to get the best performance from the apparatus. The details of how to perform the experiment will be found in the "Procedure" section.

4. Checking Out Apparatus.

A list of apparatus is given with each experiment, and the items listed as special apparatus will usually be checked out of the storeroom by the student. Perhaps only one student will sign for the equipment issued, but all students working as a partnership will be held equally responsible for its care. Check each item of the equipment received and make sure that you have all articles required and that all are in good condition. Also check apparatus already on the table and compare with the items listed under general apparatus. Report any irregularities to the instructor or his assistant at once.

5. Materials which the Student Will Supply.

Equipment which is not considered as general laboratory apparatus will be needed at various times. These items consist of graph paper, straight edge, protractor, slide rule, and watch with sweep second hand. You should always have your textbook available for reference purposes.

6. Performance of the Experiment.

Before beginning the experimental work you should always read the entire procedure so as to get a general idea of what is to be done. You should always arrange and adjust the apparatus to give the best performance possible and then make and record readings as precisely as the apparatus will permit. Always estimate on significant figure beyond the smallest graduation on the instrument being read.

Data should never be recorded on scrap paper and then transferred to your record form. If, after you have recorded a reading, you decide that it is in error and should be discarded, mark through it and record the corrected reading below it. Always record the proper unit beside the number or at the heading of a column when a whole column of readings use the same unit.

Do not hesitate to discuss any details of the experiment with the laboratory instructor during the laboratory period. You may want to question certain procedures or suggest improvements in the method. A good question may be more important than a good answer.

7. Report of Experimental Work.

The form of the report required will be designated by the instructor in the course. In any case the original data should be presented in neat form, such as that suggested at the end of each experiment in this manual. The data should be followed by sample calculations showing the method of obtaining the results. If the experiment requires several computations of the same type, only one of each type need be shown in the report.

When all calculations have been made and curves (if any) plotted, the student should study the results and draw some conclusions concerning what relations are indicated and what physical principles are demonstrated. Many of the questions at the end of each experiment are intended to stimulate thought and to guide the student in drawing conclusions concerning the results. These questions are to be answered in discussion style and the answers so worded that the reader can ascertain the question from the answer.

8. Proficiency in the Laboratory.

This will be determined by the neatness of the report, accuracy, conduct in the laboratory, technique in operating equipment, ability to grasp the fundamental principles demonstrated by the experiment, answers to the questions at the end of the experiment, and answers given to any quiz questions that may be asked on the laboratory work.

9. Questions concerned with the experiment.

The questions which follow each experiment are designed to aid the student in making more careful observations and to train him to analyze these observations and interpret the results. Many of them are questions which the student cannot answer unless he has been a careful observer. The author believes that the answers to these questions give a very clear indication of the student's grasp of the experiment, and are a very important part of the report handed in to the instructor.

Errors and Significant Figures

1. Errors and uncertainties in measurement.

Because of human and instrumental limitations no measurement is absolutely accurate or exact. A measurement or experimental result is of little value if nothing is known about its accuracy. If we are concerned about the reliability of a certain measurement, we must know something about the probable errors and uncertainties that were involved in obtaining it. There are many types of errors which enter into measured quantities and there are several ways of classifying them. One way is to classify them as (a) errors in calibration of the instruments, (b) errors inherent in reading the scale, (c) errors inherent in the insensitivity of the indicator to changes, and (d) errors due to fluctuations in the environment which affect the experiment.

a. Errors in the Calibration of the Instruments.

These errors may result from an instrument being used under conditions different from those for which the calibration was made. If a measuring tape is calibrated to be used at 20℃, indicated measurements made at 30℃ will not be the correct values. Some very delicate instruments must have the calibration checked at periodic intervals. Instruments may also be worn by use to such an extent that accurate settings cannot be made. One must also choose an instrument which is calibrated to give the precision required in the measurement. For example, an ordinary meter stick would not be appropriate for measuring the diameter of a small wire, which may be on larger than the smallest division on the stick.

b. Errors Inherent in Reading the Scale.

A student's personal bias is often responsible for inaccurate results. When a series of trials are to be made for a certain measurement, students very often assume the first trial to be about correct and attempt to make all the others agree with it, thus giving more significance to the first reading than any of the succeeding ones. Other personal errors are introduced because of insufficient care being used in adjusting instruments, inaccurate estimations of fractional divisions, and parallax.

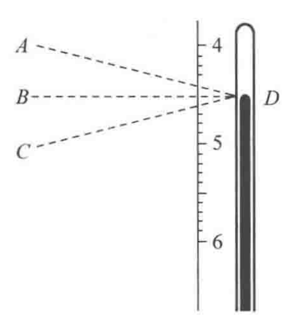

Figure A Errors in scale Readings due to parallax

The apparent distance between two objects will depend on the position of the eye. Two objects may appear to be in line when viewed with one eye but out of line when viewed with the other eye or when the head is moved to one side. This apparent change in position due to sidewise motion of the eye is called *parallax*.

If one is attempting to read the position of the mercury level in a tube near a scale (see Figure A) the line of sight must always be perpendicular to the scale. If one should sight along the line *AD*, he would read 4.4; if along line *CD*, he would read 4.6; the correct reading is 4.5, as read along the line *BD*.

The chance of error due to parallax between scale divisions and the object being measured may be reduced to a minimum by placing the measuring scale as near as possible to the object being measured. A meter stick should always be placed edgewise against the object being measured, in order to reduce such errors.

Other problems associated with reading instruments might come under the heading of *random fluctuations*. As one attempts to read a voltmeter connected across some circuit element in the *A.C.* power line, the needle may fluctuate back and forth while one attempts to get a reading. The same situation exists in attempting to read the scale on a count rate meter connected to a Geiger tube. Methods of handling statistical fluctuations will be discussed in connection with the appropriate experiment in this book.

c. Errors Inherent in the Insensitivity of the Indicator to Changes.

In some experimental setups one indicating portion of the equipment may not show sufficient response to changes in other indicating parts. When a certain amount of weight is added in one place, friction in the connecting links may prevent a scale indicator from showing the proper response. It may be that some instrument is slow in responding to a change in temperature and readings must not be made too quickly. The usual laboratory thermometer, calibrated in one degree divisions, could not be expected to show sufficient response to a temperature change of 0.01 degree.

d. Errors Due to Fluctuations in the Environment.

If one is attempting to read an instrument out in the open where the adjustment is affected by gusts of wind an accurate reading would be difficult to obtain. These types of errors, due to changes in the environmental conditions, can only be reduced through proper control of such conditions as temperature, humidity, noise background, vibration, stray electric fields, wind, and so forth. Sometimes these are beyond the control of the experimenter.

e. Percentage Error.

The error in a measurement is the amount by which the student's experimental value differs from the accepted value listed in some official record, such as a handbook. It should be clearly understood that the amount of the error is not a true index of the precision of the measurement. For example, suppose someone measures the distance between two streets to be 390 m, while a professional surveyor's record shows the distance as 400 m. In another case, a person estimated the width of a table as 1.8 m when it should be very near 2.0 m. The absolute error in the first case is 10 m, and in the latter case, 0.2 m. Which one would you say did the best job in his measurement? The one who measured the table made an error of 0.1 m in each meter measured. On this basis, he would have made an error of 40 m in the street measurement. The fractional error, which is the ratio of the absolute error to the accepted value, is the quantity which shows the precision of the measurement. In the above cases we have the following:

First case, fractional error $= \frac{10\ \text{m}}{400\ \text{m}} = 0.025 = 2.5$ parts in 100, or 2.5%

Second case, fractional error $= \frac{0.2\ \text{m}}{2.0\ \text{m}} = 0.10 = 10$ parts in 100, or 10%

In general, percent error $= \frac{\text{absolute error}}{\text{accepted value}} \times 100\%$

f. Percentage difference.

There are cases in which we want to compare the results of two equally trustworthy measurements, that is, to find the percentage difference between the two. For example, suppose two measurements of a length give 4.0 cm and 4.2 cm, respectively, the exact value not being known. The percentage difference is found by comparing the deviation (or difference) with the average of the two. Hence, we have

Percentage difference $= \frac{4.2 - 4.0}{4.1} \times 100\% = 0.049 \times 100\% = 4.9$ percent.

g. Estimated Uncertainties.

The accuracy with which a given measurement can be made is increased by obtaining the average of number of independent readings. This average is likely to be scale being read and deciding by what fraction of a more reliable value for the measurement than just one single reading. These fluctuations (or deviations) in the individual readings indicate that uncertainties do exist in experimental measurements. The average deviation may be obtained by finding the absolute value of the difference between the mean and the individual values and then averaging these deviations. If M is the mean value and d is the average of the deviation from the mean, then the measured value of the quantity Q should be recorded as

$$Q = M \pm d$$

For example, suppose one measures the length of a small body for five times and gives the results as follows:

$x_1 = 3.41$ cm, $x_2 = 3.43$ cm, $x_3 = 3.45$ cm, $x_4 = 3.44$ cm, $x_5 = 3.42$ cm

So the mean value would be

$$M = \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$= \frac{1}{5} \times (3.41 + 3.43 + 3.45 + 3.44 + 3.42)\ \text{cm}$$

$$= 3.43\ \text{cm}$$

The deviation for each time would be

$$d_1 = |3.41 - 3.43|\ \text{cm} = 0.02\ \text{cm}$$

$$d_2 = |3.43 - 3.43|\ \text{cm} = 0.00\ \text{cm}$$

$$d_3 = |3.45 - 3.43|\ \text{cm} = 0.02\ \text{cm}$$
$$d_4 = |3.44 - 3.43|\ \text{cm} = 0.01\ \text{cm}$$
$$d_5 = |3.42 - 3.43|\ \text{cm} = 0.01\ \text{cm}$$

The average value of deviation would be

$$d = \Delta x = \frac{1}{n}\sum_{i=1}^{n} d_i = \frac{1}{5} \times (0.02 + 0.00 + 0.02 + 0.01 + 0.01)\ \text{cm} = 0.01\ \text{cm}$$

The measured value of the length can be expressed into this form:

$$d = x \pm \Delta x = M \pm d = (3.43 \pm 0.01)\ \text{cm}$$

The percent uncertainty is equal to $\frac{d}{M} = \frac{0.01}{3.43} \times 100\% \approx 0.3\%$

If only one reading is made, one may estimate the uncertainty by examining the scale division a reading could be in error. This may vary from 0.1 to 0.5 of the smallest scale division.

The percentage uncertainty, in terms of the above symbols, is expressed by the relation

$$\text{Percentage uncertainty} = \frac{d}{M} \times 100\%$$

2. Significant figures.

The digits required to express a number to the same accuracy as the measurement it represents are known as significant figures. If the length of a cylinder is measured as 20.64 cm, this quantity is said to be measured to four significant figures. If written as 0.0002064 kilometers, we still have only four significant figures. The zeros preceding the 2 are used only to indicate the position of the decimal point. The zero between the 2 and 6 is a significant figure, but the other zeros are not. If the above measurement is made with a meter stick, the last digit recorded is an estimated figure representing a fractional part of a millimeter division. ***All recorded data should include the last estimated figure in the result, even though it may be zero.*** If this measurement had appeared to be exactly 20 cm, it should have been recorded as 20.00 cm, since lengths can be estimated by means of this instrument, to about 0.01 cm. When the measurement is written as 20 cm it indicates that the value is known to be somewhere between 19.5 cm and 20.5 cm, whereas the value is actually known to be between 19.995 cm and 20.005 cm.

By referring again to the 20.64 cm measurement, the possible error in this measurement is ±0.005 cm and was recorded as being nearer to 20.64 than to 20.63 or 20.65. Hence, the error is less than one part in two thousand.

Now suppose the diameter of the cylinder is measured with the same instrument and recorded as 2.25 cm. This number has only three significant figures, and hence is known to only one part in a little more than two hundred. From this we see that the number of decimal places does not indicate the precision of the measurement.

Now suppose we wish to find the volume of this cylinder as given by the relation

$V=\pi r^2 h$. The radius r = 1.125 cm, four significant figures being retained because the original number has been reduced by the process of dividing by 2, thus giving rise to a larger percentage error from deviations in the third significant figure. The accuracy of the original measurement will determine when it is best to include an additional figure in such cases.

If we underline the doubtful figures in the number representing r and find r^2, the multiplication is as shown below.

$$
\begin{array}{r}
1.1\underline{25} \\
\times 1.1\underline{25} \\
\hline
\underline{5625} \\
\underline{2250} \\
11\underline{25} \\
11\underline{25} \\
\hline
1.2\underline{65625}
\end{array}
\qquad\qquad
\begin{array}{r}
20.6\underline{4} \\
\times\ 1.2\underline{7} \\
\hline
1\underline{4448} \\
41\underline{28} \\
206\underline{4} \\
\hline
26.\underline{2128}
\end{array}
$$

The result is shown to be 1.265625; but if the doubtful figures are carried through the process of multiplication and only one of them kept in the final result, the result of r^2 is recorded as $1.2\underline{7}$.

If the first 6 in the result is doubtful, the other four figures are worthless in the result and should be discarded. In like manner the product r^2h has a value of $26.\underline{2}$ when we include only one doubtful figure. It should be noted that this final product contains no more significant figures than does the factor having the fewest significant figures, namely, 1.27, which has three.

The next step is to multiply by π, the value of which that you have most probably been using is 3.1416. This multiplication is being left as an exercise for the student under the supervision of the instructor and supplemented by his discussion.

First multiply the result of r^2h as given above by 3.1416, showing all the steps in the multiplication and indicating the doubtful figures, and record the final result so as to retain only one doubtful figure. Now multiply the value of r^2h by 3.14 and record the final result as containing one doubtful figure. How do the two results compare? What rule would you suggest concerning the number of digits to use for π in multiplication processes such as this? If the diameter of a certain circle is $9.8\underline{1}$ cm, with only one doubtful figure, what should be used as the value of π in obtaining the circumference of the circle? Check the validity of your answer by multiplying $9.8\underline{1}$ by 3.14, then by 3.142, and finally by 3.1416. If you keep only one doubtful figure in the final result, how many significant figures of π are required, and how many significant figures are in your answer? Note that 9.81 is almost as large as 10.00, a number having four significant figures. Hence, one must carry enough digits in π to avoid introducing more uncertainty into the answer.

Now take the diameter of the cylinder as $3.2\underline{8}$ cm instead of $2.2\underline{5}$ cm and calculate the volume by following the doubtful figures through the multiplication process. If one doubtful figure is retained in the result, how many significant figures appear in your answer? Is this number any different from what you expected?

a. Significant Figures in Division.

Your result from the first calculation of the volume should be $82.\underline{3}$ cm^3. Now suppose the cylinder weighed $784.\underline{7}$ g and we wished to find the weight per unit volume. We should find the quotient of $784.\underline{7} \div 82.\underline{3}$. By adding sufficient zeros to carry out the division in the usual manner we obtain 9.534629 g/cm^3 as the weight per unit volume. If the effect of the doubtful figures in both numbers is followed through, it should be noted that the number $9.5\underline{3}$ has as many significant figures as we are justified in keeping.

b. Significant Figures in Addition.

Suppose it is desired to find the sum of the numbers in the first column at the right. Nothing is known about the $71\underline{0}$ to the right of the decimal point. Hence, addition of digits to the right of the decimal point is meaningless. The numbers should be recorded as shown in the second column.

$81.57\underline{2}$		$8\underline{2}$
$71\underline{0}.$	⇒	$71\underline{0}$
$0.0\underline{3}$		0
$+\ 24.\underline{3}$		$+\ 24$
		$81\underline{6}$

c. General Rules for Computations with Experimental Data.

(i) In addition and subtraction, do not carry the result beyond the first column which contains a doubtful figure.

(ii) In multiplication and division, carry the result to the same number of significant figures that there are in that quantity entering into calculation which has the least number of significant figures. If the first digit of this quantity is 7 or more, then for safety purposes, it should be considered as having one additional significant value.

(iii) In dropping the figures which are not significant, the last figure retained should be increased by 1 if the first figure dropped is 5 of more.

Graphical Representation of Experimental Data

From an examination of the tabulated values of a number of measurements of related quantities it is often difficult to grasp the relationship existing between the numbers. A method widely used to discover such relationships it the graphical method, which gives a pictorial view of the results and makes it possible to interpret the data by a quick glance.

1. Independent and Dependent Variables.

In any experimental study of cause and effect the aim is to vary just one condition at a time (the cause) and to observe the corresponding values of another quantity (the effect) which is suspected of being related to the first. The existing relationship is most easily interpreted from the graph if the first of these quantities, the independent variable, is plotted on the abscissa scale (x-axis) and the dependent variable, is plotted on the ordinate scale (y-axis). Very often the values to be potted are all positive and only the first quadrant of a rectangular coordinate system will be needed. In such cases the origin should be shifted to the lower left-hand comer of the sheet of cross section paper. When possible draw the axes inside the margins of the graph paper along the first or second large square. This gives more space to write in the scale and also furnishes guide lines for lettering the names of the variables being plotted (Figure B).

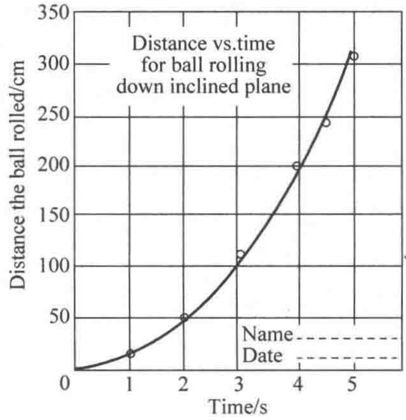

Figure B A sample graph showing the general form that should be used for curve plotting in general

2. Choice of Scale.

Choose a size of graph that bears some relation to the accuracy with which the plotted data are known. In general, the curve should fill most of the sheet if the data are known to three significant figures. If the data are known to only two significant figures, a large graph gives a false impression of the precision of the measurements.

Note the range of values of the independent variable(x quantity), and the number of spaces along the x-axis. Choose a scale for the main divisions on the graph paper that are easily subdivided and such that all the range of values may be included. Subdivisions such as 1, 2, 5, and 10 are best, but 4 is sometimes used; Never use 3, 7, or 9, since these make it very difficult to read values from the graph. The same procedure should be used for the ordinate scale, but the divisions on the ordinate and abscissa scales need not be alike. In many cases it is not necessary that the intersection of the two axes represent the zero values of both variables. If the values to be plotted are exceptionally large or small, use some multiplying factor that permits using a maximum of two or three digits to indicate the value of the main division. A multiplying factor such as $\times 10^{-2}$ or $\times 10^{-6}$ placed at the right of the largest value on the scale may be used.

3. Labeling.

After you have decided which variable is to be plotted on which axis, neatly letter the name of the quantity being plotted together with the proper unit (see Figure B).

Abbreviate all units in standard form. Then write the numbers along main divisions on the graph paper, using an appropriate scale as explained in the preceding paragraph. The title should be neatly lettered on the body of the graph paper, but it is usually best to do this after the points have been plotted so the title will not interfere with the curve. Explanatory legends should also be shown.

4. Plotting and Drawing the Curve.

Use a sharp pencil and make small dots to locate the points. DO NOT write the coordinates of the points on the graph paper. Your table of data shows these. Carefully encircle each point with a circle about 2 mm or 3 mm in diameter. In drawing the graph it is not always possible to make all of the points lie on a smooth curve. In such cases, a smooth curve should be drawn through the series of points so as to follow the general trend and thus represent an average. Suppose the plotted points show a straight line trend such as shown in Figures C and D. To draw the straight line which best represents the relationship which produced the series of points, proceed as follows. First, cover the lower half of the points and draw a faint sharp cross at the centroid of the points in the top half of the series. Next cover the top half and mark a cross at the centroid of the lower group. Then draw a line straight through the two crosses and it will represent a true average. If the series of points appear to represent a function which is not a straight line, the points should lie on both sides of the curve along all parts of the curve.

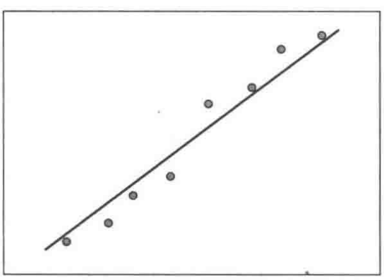

Figure C Incorrect method of fitting a straight line to a series of points

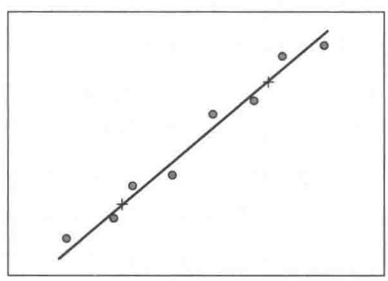

Figure D Correct method of fitting a straight line to a series of points

When more than one curve is drawn on a graph, and it is desirable to distinguish the points associated with one curve from those associated with another, crosses (×), triangles (△), squares (□), and circles(○) may be used.

5. Analysis and Interpretation of Graphs.

One of the principal advantages afforded by graphical representation is the simplicity with which new information can be obtained directly from the graph by observing its shape, and intercepts.

The shape of a graph immediately tells one whether the dependent variable increases or decreases with an increase of the independent variable. It also shows something of the rate of change. If the points lie along a straight line there is a linear relationship between the variables. If the variables are directly proportional to each other, they approach zero simultaneously and the line passes through the origin. Curves which are straight lines and do not pass through the origin do not indicate direct proportion.

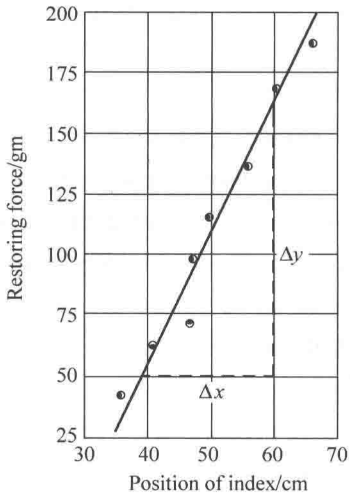

Figure E Analysis for stiffness constant of spring

6. Slope.

In discussing the slope of a graph we must distinguish between physical slope and geometric slope. The geometric slope is usually the angular inclination of the line with respect to the x-axis. In plotting physical data there may be an enormous difference in the size of the units on the two axes. The physical slope is found by dividing Δy by Δx (see Figure E), using for each the scales and units that have been chosen for those axes. The unit of the slope will be the ratio of the units on the respective axes. With the physical slope, one is not usually concerned at all with the angle the line makes with the x-axis; the tangent of the angle has no meaning.

7. Intercepts.

Significant information is often revealed by the intersections of the graph with the coordinate axes. This is true for other types of curves as well as for straight lines. The true interpretation of the intercept can be obtained only if the scales used begin at zero. In many cases there are no data available for drawing the curve to the axes. If the plotted points indicate the trend of the curve, one may be justified in extrapolating the curve to the intercept desired. Extrapolation is accomplished by extending the curve in the desired direction by a dotted line, rather than a solid line, thus indicating that data are not available for this portion of the curve. Intercepts obtained by extrapolation may serve as clues to aid in the theoretical interpretation of the phenomena being observed.

Experiment 1

Measurement of Small Length

Special Apparatus. Vernier caliper, micrometer caliper, metallic thread, small circular band, iron ball, cylinder.

The purpose of this experiment is to leam the use of the vernier caliper and the micrometer caliper in measuring length and to understand the principle of the caliper vernier and the micrometer caliper.

Introduction

1. Vernier Caliper.

When using a meter stick it is necessary to estimate the tenths of millimeters (the fractional parts of the smallest scale divisions). The vernier is a device which assists in the accurate reading of the fractional part of a scale division. The vernier caliper (Figure 1-1-1) consists of two scales: one is the fixed main scale of the instrument, and the other, called the vernier scale, is arranged to slide along the fixed scale.

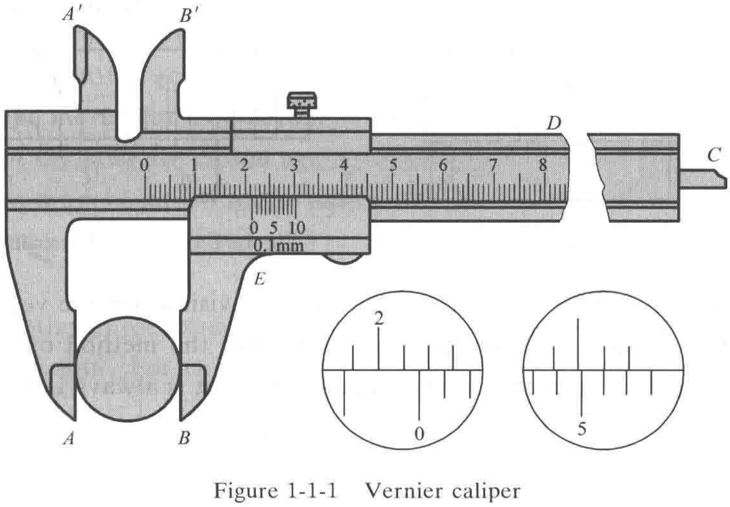

Figure 1-1-1 Vernier caliper

In the figure above, the principal divisions on the main scale D represent centimeters, and are further divided into tenths of centimeters, or, millimeters. The vernier, or movable scale E, contains ten divisions, each of which is nine-tenths as long as the smallest main-scale division. Hence the ten divisions on the vernier scale have the same length as nine divisions on the main scale (Figure 1-1-2). The scales in Figure 1-1-1 would appear as in Figure 1-1-2 if the jaws of the instrument were closed. It should be evident that the distance between the jaws of the instrument (Figure 1-1-1) is at all times the same as the distance between the zero marks on the two scales.

In Figure 1-1-2 it may be seen that both the zero and the ten marks on the vernier coincide with some marks on the main scale. The first mark beyond the zero on the vernier is one tenth of a main-scale division short of coinciding with the first line beyond the zero on the main scale. This difference between the lengths of the smallest divisions on the two scales represents the ***least amount*** of movement that can be made and read accurately and is called the ***least count*** of the instrument. If the vernier scale is moved 1/10 mm, the next mark beyond the zero coincides with a main-scale mark (Figure 1-1-3). If moved until mark two coincides with a main-scale division, the total distance moved is 0.2 mm. Thus it is seen that we can get an accurate setting for tenths of a millimeter and not have to estimate them as on a meter stick.

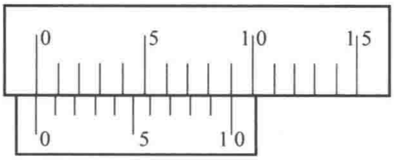

Figure 1-1-2 Vernier scale setting

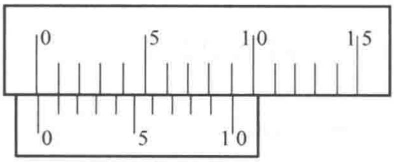

Figure 1-1-3 Vernier scale setting

In Figure 1-1-4 we see that the zero on the vernier lies between the 6 mm and 7 mm marks, and since the second mark on the vernier scale makes coincidence, the fractional distance is 0.2 mm, and the complete reading is 6.2 mm, or 0.62 cm. By similar reasoning, the reading in Figure 1-1-5 may be seen to be 3.7 mm or 0.37 cm.

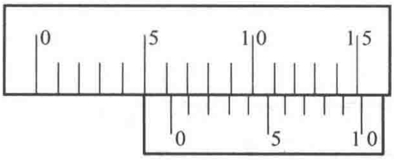

Figure 1-1-4 Vernier scale setting

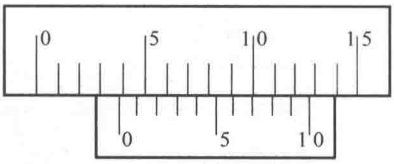

Figure 1-1-5 Vernier scale setting

Nearly all vernier calipers have the length of n divisions on the vernier scale equal to the length of $n-1$ divisions on the main scale, and the method of determining the reading is similar to that described above. The least count is always $1/n$ of the length of the smallest main scale division. For example, in Figure 1-1-1 the least count is 1/10 of 1/10 mm, or 0.01 cm.

2. Micrometer Caliper.

The micrometer caliper is an instrument designed for the accurate measurement of small distances, such as the diameter of a wire or the thickness of a thin sheet. The jaw *B* (Figure 1-1-6) is the end of a screw passing through the cylindrical nut carrying the scale *S*. The object to be measured is placed between the jaws *A* and *B*, and the head *H* which carries the screw is advanced toward the zero end of the scale until contact is made with the object by both jaws. Correct pressure of the jaws is best determined by turning the ratchet *R* until it begins to slip. The distance the screw advances when turned through one ratchet *R* until it begins to slip. The distance the screw advances when turned through one revolution is called the ***pitch of the screw***. The type most commonly used in the laboratory has a screw with a pitch of 1/2 mm. Hence if the divisions on the scale *S* are millimeter divisions, the head will make two revolutions while advancing between two marks, a distance of 1 mm.

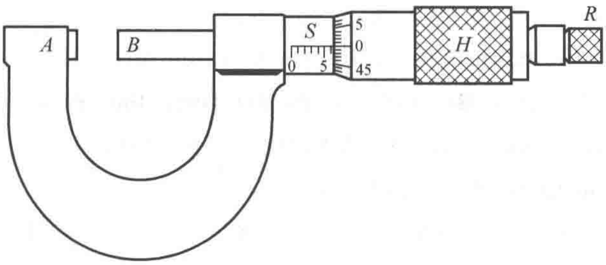

Figure 1-1-6 Micrometer caliper

From Figure 1-1-6, the position of the head on the scale indicates that the jaws have been opened by an amount greater than 6 mm. Since the scale on the revolving head indicates a reading of zero, we know that the head has been turned through one complete revolution since passing the 6 mm mark. Hence the reading is 6.50 mm, or 0.650 cm. Examination of the scale on the head shows that it contains 50 divisions, thus making the value of the smallest division on the head equal to 1/50 of 1/2 mm, or 0.01 mm. Careful examination of the reading and the position of the head *H* with respect to the space between two marks on the scale *S* will always make it possible to determine whether the head has made more than one revolution since passing the last mark visible on the scale *S*. If, when the jaws are closed against each other, the reading on the scale is not zero, a correction must be added to, or subtracted from, each reading made. This is an example of a systematic error which will occur in each measurement unless a correction is made.

There are another three examples as shown in Figure 1-1-7. For (a), the micrometer caliper shows 4.185 mm. For (b), the correct reading is 4.685 mm, not 4.185 mm. For (c), the correct reading is 1.975 mm, not 2.475 mm.