King Abdul-Aziz University
Faculty of Science
Physics Department

PHYS 281
General Physics Laboratory

Student Name:

ID Number:

Introduction

Advancement in science and engineering has emphasized the microscopic world, that is the world of atoms and its parts. This required that scientist develop individual initiatives to see, to question and, if possible, to find out why! This process is not a straight forward procedure but demand a gradual and direct introduction to the fundamentals methods of analysis.

The objectives of a physics laboratory, such as PHYS 281, are not just verification of known laws or the blind substitution of data into a formula. The physics laboratory should bridge the gap between idealized laws discussed in textbooks and the real world. In order to achieve this, the student must master some fundamental tools that would aid his/her curiosity. Nonetheless, the mastery of such tools depends on the attitude of the student toward the laboratory work.

Objectives

The objectives of this laboratory are:

1. To introduce the student to the significance of the experimental approach through actual experimentation.
2. To apply the theories to real-life problems to develop a better understanding.
3. To introduce the student to the methods of data analysis used in science and engineering.
4. To develop an "error conscience" so that the engineer and scientist will at least be aware of the relative worth of all measurements, whatever their type.
5. To familiarize the student, by direct contact, with a great many basic instruments and their applications.
6. To make the student realize that such tools as graphing, use of algebra and calculus, etc. are of fundamental importance.
7. To impress on the student that even an experiment which is apparently unimportant to his/her professional future may contribute directly to the student's mental development because of the analytics and mathematics involved.
8. To improve the student's ability of self expression through report presentation.
9. To give the student direct contact with the instructor, and thus the advantages of close direction and personal discussion of ideas and methods.

Laboratory Operation

1. Assignments

   Each student will work in a team. Laboratory assignment requires the performance of an experiment in the laboratory and the presentation of the data, computations, etc. must be completely worked out in the laboratory worksheets. All the work should be written up in a report and handed to the instructor for inspection and grading no more than the next scheduled laboratory meeting.

2. Data check

   At the completion of the experiment, the laboratory worksheets are to be presented to the instructor to be checked and signed. This permits obvious errors to be found.

3. Student's responsibility toward equipment

   Most equipment is sensitive and expensive. Therefore, apparatus must be treated with respect. Students must leave their tables and apparatus in good order: i.e. weighs put away, instruments returned to cases, water emptied, scrap paper picked up, etc.

The Report

Most experimental work, records of the work done, data taken, and observations made in the laboratory are kept in the laboratory worksheets. The final reports are abstracted from such worksheets and this is the method that your laboratory lab work should be presented to your instructor.

The laboratory report has generally eight parts:

1. Purpose of the experiment and preliminary discussion.
2. Sketch
3. List of apparatus
4. Procedure
5. Data
6. Computation outline
7. Graphs and results
8. Discussion and Conclusion

Errors in laboratory work

Physics is an exact science, but the pointer readings of the physicist's instruments do not give the exact values of the quantities measured. No measurement in science is absolutely accurate. The value of physical quantities such as a length, a time-interval or a temperature, are accurate within a limit. The closer these limits, the more accurate the measurement.

The difference between the observed value of any physical quantity and the 'standard' value is called the ***error of observation***. Such errors follow no simple law and, in general, arise from many causes.

Classification of errors

An error which tends to make an observation too high is called a ***positive error*** and one which makes it too low is called ***negative error***. Errors can be grouped in two general classes, ***systematic*** and ***random***.

Systematic error

Systematic errors always produces an error of the same sign. Such errors can be subdivided into three groups.

(i) Instrumental error: it is caused by faulty, poorly made or improperly calibrated instruments. For example, a stop watch, that does not run at the proper rate, will cause an instrumental error. A spring balance, which is not properly calibrated, will cause an error to the mass of the body weighed by it. An ammeter or voltmeter is accurate in limited sense. The dial instruments have zero errors i.e., the pointer does not indicate zero when not in use.

(ii) Personal error: it includes errors of judgment, errors in reading instruments, writing down the wrong figures, mistakes in arithmetic or using a calculator. An error, due to parallax, come under this category.

(iii) External errors: these are usually caused by conditions over which the observer has no control. Examples are:

   a. Change in atmospheric pressure in Boyle's law experiment
   b. Change in room temperature in velocity of sound experiment

Random errors

In random errors positive and negative errors are equally probably. As an example, we can take the measurement of the diameter of a cylinder. Even if the readings are taken with utmost care, the values of the diameter slightly differ from one another. The best value is obtained by taking their arithmetic mean. The observed values of the diameter will be found to lie on both sides of this mean value. The factors causing such types of errors are unknown are variable. The errors are assumed to be a matter of chance. Therefore, positive and negative errors are equally probably. The effect of such errors, on the experimental result, can be made quite small by taking a large number of observations. However, a large number of observations have no effect on systematic errors.

Some personal errors are regarded as random errors. If a person takes two sets of observations for 50 full oscillations of a pendulum, the measured time for the two sets will not be the same. In this case, errors may be minimized by taking several sets of independent observations.

Probable error

If *n* observations are taken, the probable error (P.E) is given by

$$P.E. = 0.6745\sqrt{\frac{\sum d^2}{n(n-1)}}$$

The quantity $\sqrt{\sum d^2/n(n-1)}$ is called the standard deviation from the arithmetic mean.

Let us suppose the ten readings of the vernier calipers are as shown in table 1 below.

$\therefore\ P.E. = 0.6745\sqrt{(2810 \times 10^{-6})/10 \times 9}\ cm = 0.119\ cm$

The diameter of the cylinder = 2.507 ± 0.119 cm.

Table 1: Vernier caliper readings

No. of obs.	Diameter (cm)	Arithmetic mean (cm)	Deviation d(cm)	d^2	Σd^2
1	2.52		+0.013	169×10^{-6}	
2	2.53		+0.023	529×10^{-6}	
3	2.50		-0.007	49×10^{-6}	
4	2.49		-0.017	289×10^{-6}	
5	2.50	2.507	-0.007	49×10^{-6}	2810×10^{-6}
6	2.51		+0.003	9×10^{-6}	
7	2.53		+0.023	529×10^{-6}	
8	2.49		-0.017	289×10^{-6}	
9	2.48		-0.027	729×10^{-6}	
10	2.52		+0.013	169×10^{-6}	

Percentage error

In most cases it is desirable to express the error in percentage of the quantity measured. Examples:

(a) A meter rule graduated in *mm* is used to measure the length of a string. The possible error in judging the position of each end of the string against the meter rule is 1 *mm*. Thus the maximum possible error is 1 *mm*. If the length of the body is, say, 72 *cm*, the possible error is 0.1 *cm* in 72 *cm*. So the possible percentage error (P.P.E.) = (0.1/72) × 100 = 0.14. The P.P.E. in measuring a length of 7.2 *cm* on the same rule will be (0.1/7.2) × 100 = 1.4.

(b) A thermometer, capable of reading to 0.1°C, is used to measure a temperature-rise of, say, from 20.5°C to 31.7°C. Each temperature has a possible error of 0.1°C. The possible error in rise of 11.2°C is 0.2°C. Thus the possible percentage error is (0.2/11.2) × 100= 1.8, say 2%.

(c) An ammeter, whose scale divisions are 0.1A, indicates a current of 3.2 amp. The maximum likely error in any scale-measurement is taken to be half of the value of 1 scale division. In this case, as two readings of the pointer are involved, the possible error is 2 × 0.05 A. The possible percentage error is thus 2 × (0.05/3.2) × 100 = 3.1 which, when rounded, gives 3%.

Combination of errors

Most experiments involve the measurement of a number of quantities. The final result is affected by the errors of all the measured quantities. The method of combining the individual errors is illustrated by the following examples:

(a) The possible error, in the sum or the difference of two quantities or readings, is given by the sum of the separate possible errors.
The percentage error in a quantity z which is related to the quantities x and y as $z=x \pm y$ is given by

% error in z = % error in x + % error in y.

(b) The percentage error in a quantity, which involves product or quotient of some quantities, is given by the sum of the percentage errors in each of the quantities.
(i) The percentage error in the volume V of a rectangular box of length l, breadth b, and height h is given by
% error in V = % error in l + % error in b + % error in h.

(ii) The percentage error in density (density = mass/volume) is given by
% error in density = % error in mass + % error in volume.

(c) When a quantity appears in a formula to a higher power, the percentage error is multiplied by the power to which the quantity is raised.
(i) The percentage error in the volume V of a sphere of diameter d is given by, ($V = 4/3\pi r^3 = 4/3\pi (d/2)^3 = (n/6)d^3$)

% error in V = 3 × % error in d.

(ii) The percentage error in the volume of a cylinder of diameter d and height h is given by ($V = \pi (d/2)^2 h = \pi d^2 h/4$)

% error in V = 2 × % error in d + % error in h.

(iii) The percentage error in the resistivity ρ of the material of a wire of resistance R, length l and diameter d is given by ($\rho = RA/l = R\pi d^2/4l$)

% error in ρ= % error in R + 2 × % error in d + % error in l.

(iv) The percentage error in the value of g, the acceleration, due to gravity measured by a simple pendulum is given by ($T=2\pi\sqrt{l/g}$ or $g=4\pi^2 1/T^2$)

% error in g = % error in l + 2 × % error in T.

Measurements - Worksheet

1. **Investigate some parameters we can measure in the lab and the instruments required for these measurement. Fill in the below table showing the different instruments in the lab and the parameter it measures.**

Parameter									
Instrument									

2. **Use the paper rulers 1,2 and 3 respectively to evaluate the following:**

   a. Measure the length of the pen.

   b. What is the minimum and maximum value in each ruler.

   c. Comment on the differences in the readings of paper rulers.

   d. Which is the best ruler for measurement and why?

3. **Look at the different measuring devices in front of you and answer the following questions.**

   1. **The ruler, vernier caliper and micrometer:**
      a. What is the physical quantity measured by each of them?

      b. What is the measuring unit of each of them?

      c. What is the value of the major mark?

      d. What is the value of the minor mark?

      e. Using the different object in front of you, take some measurements by using each of them?

      f. Calculate the percentage error of each measurement you perform.

2. **The thermometer:**

   a. What is the physical quantity measured by thermometer?

   b. What is the measuring unit of a thermometer?

   c. What is the value of the major mark?

   d. What is the value of the minor mark?

   e. Hold the shiny tip of the thermometer in your hand and take the measurements of your body. Does your reading give the normal body temperature (37^o)? If not explain why?

   f. Calculate the percentage error of your reading.

3. **The mass balance:**

   a. What is the physical quantity measured by a balancing scale?

   b. What is the measuring unit of a balancing scale?

   c. How many scales does the balancing scale in front of you have?

   d. In the front scale, what is the value of the major and minor marks?

   e. In the middle scale, what is the value of the major and minor marks?

   f. In the rear scale, what is the value of the major and minor marks?

   g. Take some measurement using the balancing scale and the object around you.

   h. Calculate the percentage error of each measurement you perform.

4. **The stop watch:**

   a. What is the physical quantity measured by a stop watch?

   b. What is the measuring unit of a stop watch?

   c. What is the value of the major marks?

   d. What is the value of the minor marks?

   e. Using the stop watch, measure the number of pulses you heart makes in one minute. Does your pulse rate falls in the normal heart pulse rate?

   f. Calculate the percentage error of your measurement.

5. **The dynamometer:**

   a. What is the physical quantity measured by a dynamometer?

   b. What is the measuring unit of the dynamometer?

   c. What is the value of the major and minor marks in the dynamometer?

   d. Take some measurements by using the dynamometer and some objects in the lab.

   e. Calculate the percentage error of each measurement you perform.

6. **The ammeter**:

   a. What is the physical quantity measured by an ammeter?

   b. What is the measuring unit of an ammeter?

   c. What is the value of the major marks?

   d. What is the value of the minor marks?

   e. What is the maximum possible error in your reading

7. **The voltmeter:**

   a. What is the physical quantity measured by a voltmeter?

   b. What is the measuring unit of a voltmeter?

   c. In the top scale or the voltmeter reading screen, what is the value of the major and minor marks?

   d. In the bottom scale of the voltmeter reading screen what is the value of the major and minor marks?

   e. Explain how and why do you choose one scale over other?

   f. What is the maximum possible error for each scale.

Measurements

To measure lengths or angles accurately up to a fraction of the smallest division provided on the scale a device called vernier is used. A vernier is an auxiliary scale that slides along the main scale. The length of one division of the vernier scale is not equal to the length of one division of the main scale. The smallest length which can be measured with a vernier scale is called the LEAST COUNT.

The least count = 1 main scale division-1 vernier scale division. In general, (*n* -1) divisions of the main scale are equal to n divisions on the vernier. Thus 1 division of vernier scale = (*n* -1/*n*) divisions of mainscale.

Hence,

$$The\ least\ count = 1\ main\ scale\ division - 1\ vernier\ scale\ division$$

$$= \left(1 - \frac{n-1}{n}\right)\ main\ scale\ division$$

$$= \frac{1}{n}\ \ main\ scale\ division$$

Exercise:

Find the value of the least count in the following cases:

(a) 10 vernier scale divisions are equal in length to 9 main scale divisions as in Fig 1a (1 main scale division = 1 *mm*).
(b) 20 vernier scale divisions are equal in length to 19 main scale divisions (1 main scale division = 1 *mm*; 1 main scale division = 0.5 *mm*).
(c) 50 vernier scale divisions are equal in length to 49 main scale divisions. (1 main scale division = 1 *mm*).
(d) 30 vernier scale divisions are equal to 29 main scale divisions (1 main scale division = 1 degree of angle).

Readings:

To use a vernier instrument proceed as follows:

(a) Find the value of one main scale division.

(b) Find the least count of the vernier

(c) Read the main scale just before the ZERO MARK on the vernier scale.

(d) Find the number of the vernier mark, which coincides with a mark on the main scale.

Examples:

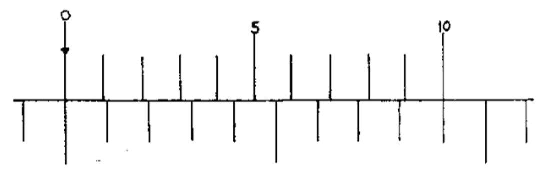

Figure 1a

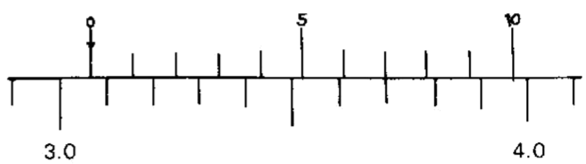

Figure 1b: Ordinary vernier

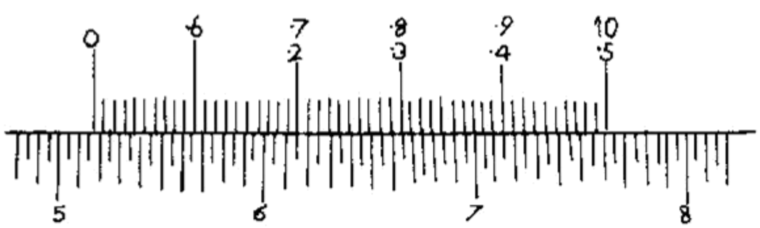

Figure 1c: Vernier used in travelling microscope

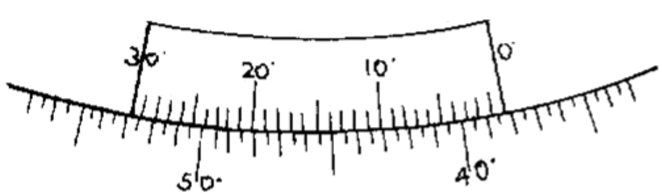

Figure 1d: Angular vernier used in spectrometer.

Fig. no.	Main scale reading (A)	Vernier coincident	Vernier coincident × least count (B)	Total (A+B)
1b	3.0	7	0.07	3.07 cm
1c	5.15	21	0.021	5.171 cm
1d	38°	14'	14'	38° 14'

VERNIER CALLIPERS

It is an instrument which is used for measuring the linear dimensions of bodies. It consists of a rule furnished with two jaws (Fig. 2) projecting at right angles to the rule. One jaw is fixed and the other is attached to a slider which can slide backwards and forwards on the rule. The rule is divided into millimeters. The sliding jaw is also provided with short scale called a vernier. The vernier scale has 10 divisions which are equal to 9 divisions on the rule i.e. to 9 *mm*.

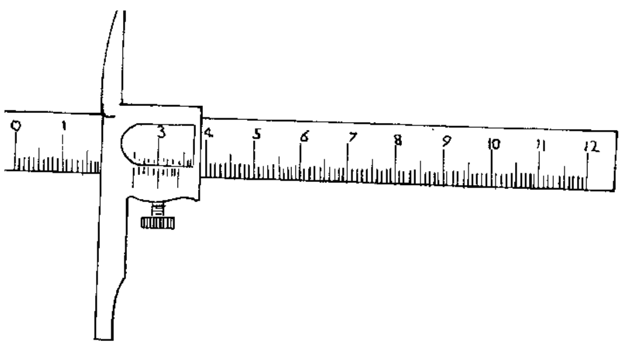

Figure 2

Thus 1 vernier division = 9/10 *mm*.

The least count = 1 main scale division - 1 vernier division

= (1-9/10) = 1/10 = 0.1 *mm*

When the jaws are brought together the zero mark on the vernier should coincide with zero on the rule, if not correction must be applied to readings obtained with the callipers.

To measure the length of an object, it is placed between the two jaws and the sliding jaw is adjusted till it makes contact with one end of the object when the other is in contact with the fixed jaw. Take the reading of the vernier as explained before.

THE MICROMETERS CREW GAUGE

It is an instrument for measuring the linear dimensions of small objects. It works on the principle that when a perfect screw moves in a fixed nut, the motion of translation of the screw is directly proportional to the amount of rotation given to it.

One jaw A (Fig. 3) is fixed, and the jaw B is on a screw thread. The scale S is graduated in millimeters, and round the rim D is a scale divided into 50 or 100 equal divisions. This scale turns as the screw head is turned by means of the knob E. When the screw head is rotated the jaw B advances and there is a gap between the jaws A and B. This gap is measured on the horizontal scale. The distance between the jaws A and B for one complete turn of the screw head is called the PITCH of the screw. When the jaws are closed, the 0 (zero) mark on the rim scale (D) coincides with 0 (zero mm) mark on the horizontal scale S.

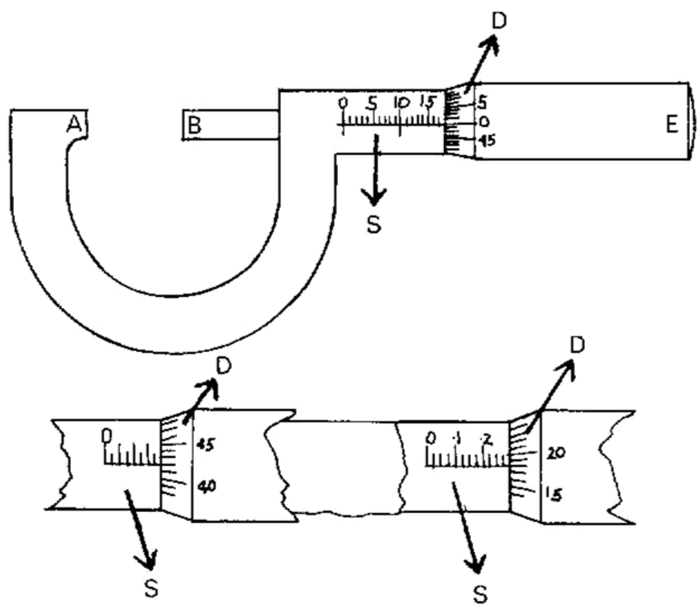

Figure 3

PROCEDURE

For using the micrometer proceed as follows:

(i) Rotate the knob E by 10 complete turns and note the reading on the horizontal scale S.

$$Pitch = \frac{The\ reading\ on\ scale\ S}{Number\ of\ complete\ rotations} = say, 0.5\ mm$$

$$Vernier\ constant = \frac{Pitch}{Number\ of\ divisions\ on\ the\ rim\ D}$$

$$= \frac{say, 0.5}{say, 50} \qquad = 0.01\ mm$$

(ii) Turn the screw head E so that the jaws are closed.

(a) If the 0 (zero) mark on the rim scale coincides with the horizontal line of the scale S, there is no ZERO ERROR.

(b) If it is not, record the zero error, that is the number of divisions the screw head has to be turned to bring the 0 mark on the rim scale to the horizontal line. The zero error may be positive or negative. If the zero mark stands, say 4 divisions above the horizontal line we must add 4 × .01 = 0.04 *mm* to the final reading. If the zero mark stands, say 3 divisions, below the horizontal line, we must subtract 3 × .01 =0.03 *mm* from the final reading.

(iii) Rotate the screw head so that the specimen can be inserted firmly between the two jaws. Note down the readings on the horizontal scale and on the rim scale. Care should be taken not to rotate the screw head too hard.

Readings

Pitch= mm.

Vernier constant = mm.

Zero error = mm

Reading on the scale S	Reading on the rim scale	Vernier constant (mm)	Total (mm)	Corrected for zero error (mm)

Graphs - Worksheet

1. **Look at the three different tables below. Can you determine the type of relation between the parameters *x* and *y* in each table?**

Table A:

x	1	2	3	4	5	6	7	8	9	10
y	2	4	6	8	10	12	14	16	18	20

Table B:

X	1	2	3	4	5	6	7	8
y	1	8	27	64	125	216	343	512

Table C:

x	0	30	60	90	120	150	210	240	270	300	330	360
y	0	0.5	0.8	1	0.8	0.5	-0.5	-0.8	-1	-0.8	-0.5	0

2. **In an experiment we studied the relation between the mass (*m*) and the weight (*w*) for some objects. In each step we changed the mass and measured the weight experimentally. The results of these measurements are shown in the following table**:

m (kg)	1	2	3	4	5	6
w (N)	10	20	30	40	50	60

From the above table answer the following questions:,

a. What is the weight of a 4.35 kg object?

b. What is the mass of a body that has a weight equal to 27.5 N?

c. Is the above table enough to find accurate answers for parts a and b?

d. How can you better visualize the results of this experiment and the relation between its parameters?

e. Use a graph paper to plot the data by choosing a suitable scale. What are the independent and dependant variables?

f. What scale will you use for the *x* and *y* axes? What are the values of the major and minor marks in both axes? Remember to label the axes correctly.

g. Repeat parts a and b. Are your answers different from the previous ones? Explain.

h. Calculate the slope of the resulting line. What does this slope represent?

3. Using the below table, plot the graph that represent these data. Make sure you take the below points into consideration:

a. Correctly determine the dependant and independent data.
b. Determine the values of the major and minor marks in both axes.
c. Place the title of each axes and its measurement unit.

Table 1:

t(s)	**0.1**	**0.15**	**0.2**	**0.3**	**0.45**
v(m/s)	**0.49**	**0.61**	**0.93**	**1.25**	**2.19**

Table 2:

m(kg)	**2**	**4**	**5**	**7**	**8**
Δx (m)	**0.245**	**0.53**	**0.625**	**0.888**	**1.095**

Graphs

Wherever possible, the results of an experiment should be presented in graphical form. A graph provides the best means of averaging a set of observations. A graph gives an immediate visual picture about the dependence of one variable quantity on the other. In plotting the results, the dependent variable should be plotted as ORDINATES on the Y axis and the independent variable as ABSCISSAE on the X axis. The use of a graph to obtain readings between experimental points is called INTERPOLATION. The extending of a graph to obtain values outside the experimental range is called EXTRAPOLATION. One should be cautious in doing extrapolation.

The most satisfactory 'shape' of a graph is the straight line. This is done more accurately, and deductions from such a graph are more reliable than with curved graphs. If the relationship between two quantities is not a simple linear one, the quantities plotted are so chosen that the graph of the equation is a straight line. Some of the methods of doing this are described below:

In equation of the form

$y=ax^2$ or $y=bx^3$

if y is plotted against x, curves are obtained. The resulting graph may be a straight line if y is plotted against x^2 or x^3.

The time-period of a simple pendulum is given by $T=2\pi\sqrt{l/g}$.

If T is plotted against 1, a quadratic curve is obtained. The equation can be converted to the form $T^2 = 4\pi^2 \cdot l/g$ to give a straight line between l and T^2.

The curve, between the pressure p and the volume V of a given mass of gas at constant temperature, is an inverse curve as the relation between them is expressed as

pV = k , where k is a constant.

The equation can be written in the form

$$p = k \cdot \frac{1}{V}$$

The graph of p, when plotted against $1/V$, is a straight line.

POSITIONING A STRAIGHT LINE THROUGH EXPERIMENTAL POINTS

One can convert the working formulae to yield a straight line but he cannot make the straight line to pass through all the points obtained from the experiment. The line passing through most of the points and about which the points not lying on the straight line are most evenly spaced, is known as the 'line of best fit'. This line passes through the *centroid* of the experimental points (Fig. 4). The centroid is the point with co-ordinates $(\bar{x}, \bar{y})$, where $\bar{x}$ is the average value of the x coordinates and $\bar{y}$ is the average value of the y coordinates of all the plotted points. If the points are not very unevenly spaced on the graph, the point on the line equidistant from the first and last points plotted may be taken as the centroid.

A straight line is now drawn through the centroid in such a way that the number of points on the two sides of the line is the same. It is worth mentioning here, that the best straight line is obtained by the method of least squares.

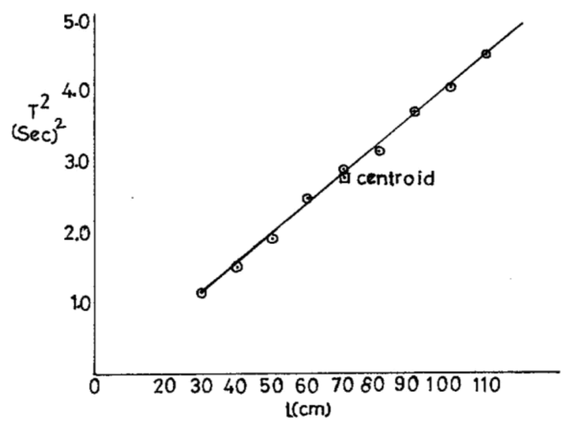

Figure 1b

Figure 4

Error of the slope of a graph

(a) Where the result of an experiment is derived from the slope of a graph, the accuracy of the result is judged by the possible error in the slope of the graph. This is done by drawing the lines of the greatest and the least slope passing through the centroid. The maximum possible error in the slope may now be estimated from these three lines. For example, if the slope of the best straight line is m and the greatest and the least slopes be m_1 and m_2 respectively then the maximum possible error in the slope is $m_1 - m$ or $m - m_2$, whichever be greater.

(b) Errors in reading the position of points on the graph can also cause an error in the slope. If millimeter graph paper is used, a point can only be located to the nearest half of a millimeter. The resulting error in terms of scale units can thus be calculated.

Choice of scales

While plotting a curve a proper choice of scales plays an important role. Usually a student learn it by practice. The plotting of *h*, the excess pressure above the atmospheric pressure against the volume enclosed in a tube is discussed here: fig 5a, 5b and 5c show the results obtained when the points are plotted on a graph with three different scales.

In fig. 5a the scale was so chosen that the intersection of the graph on the negative side of Y axis was obtained. In doing so the points got crowded in a small region of graph and the selection of the best straight line became more difficult.

In fig. 5b the scale was expanded to use the whole paper. The scale, then was so large that small errors in the measurements got enlarged. Again, the task of positioning the best straight line became difficult.

In fig 5c the scale was chosen so that the errors were neither suppressed nor enlarged.

Note: the scale should be chosen to fit in with the subdivisions of the graph paper. If one big division of a graph paper is subdivided into ten small divisions then taking 3 or 7 divisions for 10 of the quantity to be plotted should be avoided. A proper choice would be 2 or 5 divisions for 10.

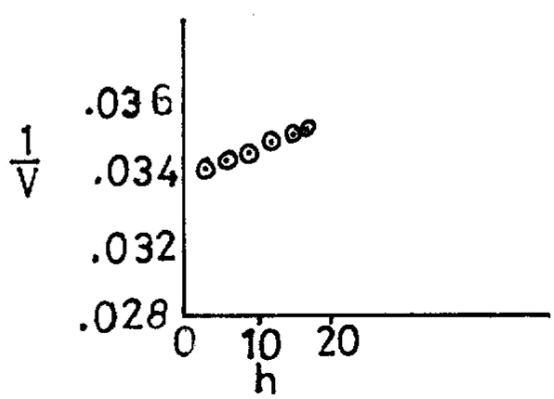

Figure 5a

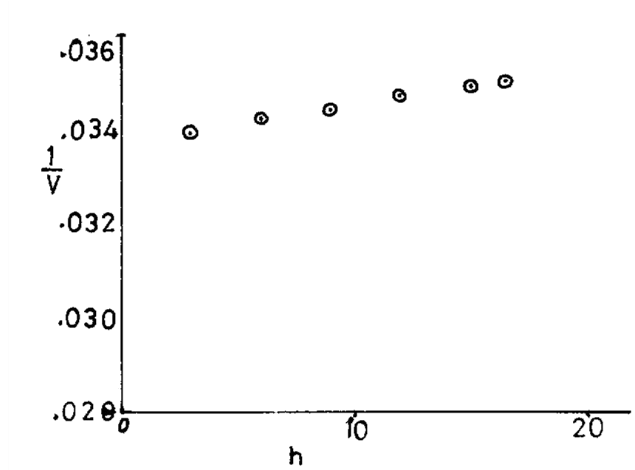

Figure 5b

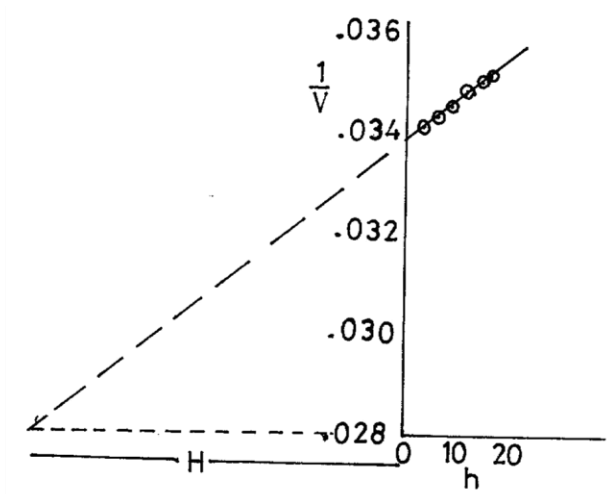

Figure 5c