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CHAPTER ONE

GENERAL INTRODUCTION

hysics is real and valid to the inquiring mind through the results of :perimental works. The laboratory is the workshop of the student, e place where he gets answers to questions in theory papers, first und knowledge of physical principles and experimental methods rough handling of apparatus designed to demonstrate the meaning id application of these principles. Some of the specific objectives e:

To acquire training in scientific methods of observation and recording of data;
To acquire techniques in the handling and adjustment of equipinent;
To become more familiar with the limitations of equipment and uncertainties of measurements;
To obtain experience in the use of graphical representation and
To take data, and develop confidence in one's ability to compute reliable answers or determine valid relations.

iis book contains general guidelines on writing reports of periments. It treats various types of graphs and explain the methods calculating errors through model practical examples. In so doing. oservations of expenment already performed in a laboratory are ioted for practice and analysis. The exercises and tests serve as odel experiments which you ought to have performed were you ven the chance. You are supposed to answer the exercise neatly in ur practical note book following the correct format.

ie following laboratory directives should be considered:

Since you have limited time for the practical class, you are strongly advised to read the instructions for the experiments carefully before the practical session.

* All breakages should be reported immediately, so that repairs/replacement could be made before the next practical class.
* The experimental report must be satisfactorily completed and submitted for grading before leaving the laboratory.

CHAPTER TWO

2.1 ERROR PROPAGATION

In Physics and engineering, the collection of information means measurement. Once measurements have been made they must be organized, evaluated and interpreted. Because of human and instrumental limitations, no measurement is absolutely accurate or exact. A measurement or experimental result is of the value if nothing is known about its accuracy. Errors are not mistakes or blunders since mistakes can be avoided and errors cannot. Errors arise because of limitations and imperfections of apparatus, imperfection of personal judgment, scale limitations, approximate theory used and fluctuations of environmental conditions.

Since such error are inevitable every experimental report should be accompanied by some indication of its reliability. These are best written by stating standard errors e.g.

(a) $g = (9.88 \pm 0.04)\ ms^{-2}$

(b) $f = (15.1 \pm 0.3)$ cm,

The standard errors are $\pm 0.04ms^{-2}$ and ± 0.3cm respectively. The standard errors are not maximum possible errors but they give a guide to the precision of the measured values. In (b) above, the standard error, $S = \pm 0.3$ indicates that on the basis of our experiment:

i. There is about 68% certainty that the focal length f, lies in the range(15.1-0.3)cmto(15.1 + 0.3)cm i.e.($f \pm S$)

ii. There is about 95% certainty that the focal length f, lies in the range(15.1 - 0.6)cm to (15.1 + 0.6)cm i.e.($f \pm 2S$)

iii. There is about 99.75% certainty that the focal length f, lies in the range(15.1 - 0.9)cm to (15.1 + 0.9)cm i.e.($f \pm 3S$).

1.3 **PERCENTAGE ERROR**

The actual error is the amount by which the experimental value differs from the true value. For example if a student measures the length of the blackboard to be 4.9 meters when the accepted value is 5 meters. The actual error in the measurement is 0.1 meter.

The relative or fractional error = $\frac{\text{Actual Error}}{\text{True Value}}$

This quantity shows the precision of the measurement. In the above case we have:

$$\text{Fractional error} = \frac{0.1}{5} = 0.02$$

In general,

$$\text{percentage error} = \frac{\text{Actual error} \times 100}{\text{Standard Value}} = 0.02 \times 100\% = 2\%$$

2.3 **PERCENTAGE DIFFERENCE**

There are cases in which we want to compare the results of two trustworthy measurements, that is we wish to find the percentage differences between the two. We do this by comparing the deviation (or difference) with the average of the two thus:

$$\text{Percentage difference} = \frac{\text{Deviation} \times 100\%}{\text{Average Value}}$$

For example, if two students measure the length of our blackboard to be 4.9 metres and 5.1meters.

$$\text{Percentage difference} = \frac{(5.1-4.9) \times 100}{5} = 4\%$$

2.4 **UNCERTAINTIES**

The accuracy with which a given measurement can be made is increased by obtaining the average of a number of independent readings.

This average is a more reliable value than just one single reading. the fluctuations.(deviations) observed is a more reliable value than just that uncertainties exists in the 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. The examples below will illustrate this. If M is the mean value of the individual reading and d is the average of the deviations from the mean, then the measured quantity is recorded as:

$$\textit{correct value} = M \pm d$$

and the percentage uncertainty in the measured quantity is given as

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

Sample Problem 1

Find (a) the correct value and (b) the percentage uncertainty in the measured distance (in cm). 68.161, 68.162, 68.161, 68.163. 68.160, 68.164, 68.161, 68.161, 68.160, 68.161.

2.4.1 **Solution**

$$\text{Mean value} = \frac{\text{Sum of all measured}}{\text{No of measurements}} = \frac{681.615}{10} = 68.1615$$

Observe that we have not approximate the value.

Mean-measured value	Deviation	Deviation
68.1615- 68.161	$+5\times10^{-4}$	5×10^{-4}
68.1615- 68.162	-5×10^{-4}	5×10^{-4}
68.1615- 68.161	$+5\times10^{-4}$	5×10^{-4}
68.1615- 68.163	-15×10^{-4}	15×10^{-4}
68.1615- 68.160	$+15\times10^{-4}$	15×10^{-4}
68.1615- 68.162	-5×10^{-4}	15×10^{-4}
68.1615- 68.164	-25×10^{-4}	25×10^{-4}
68.1615- 68.161	$+5\times10^{-4}$	5×10^{-4}
68.1615- 68.160	$+15\times10^{-4}$	15×10^{-4}
68.1615- 68.161	$+5\times10^{-4}$	5×10^{-4}
		100×10^{-4}

Average deviation. $d = \frac{100 \times 10^{-4}}{10} = 10 \times 10^{-4}$

(a) Correct value = Mean value ±Average deviation
$= 68.1615 \pm 10 \times 10^{-4}$cm

(b) Percentage Uncertainty = d/m x 100 % = $\frac{10 \times 10^{-4}}{68.1615} \times 100\,\%$

$= (1.47 \times 10^{-5})$

2.4.1 STANDARD DEVIATION METHOD

Trials	x_i/cm	deviation d_i/cm	d_i^2cm^2
1	68.161	$+5\times10^{-4}$	25×10^{-8}
2	68.162	-5×10^{-4}	25×10^{-8}
3	68.161	$+5\times10^{-4}$	25×10^{-8}
4	68.163	-15×10^{-4}	225×10^{-8}
5	68.160	$+15\times10^{-4}$	225×10^{-8}
6	68.162	-5×10^{-4}	25×10^{-8}
7	68.164	-25×10^{-4}	625×10^{-8}
8	68.161	$+5\times10^{-4}$	25×10^{-8}
9	68.160	$+15\times10^{-4}$	25×10^{-8}
10	68.161	$+5\times10^{-4}$	25×10^{-8}

$\Sigma x_i = 681.615$, $d_i = 0.00$, $\Sigma d_i^2 = 1.45x10^3$

Mean x $\sum \frac{xi}{n} = 681.615/10 = 68.1615/cm$

Standard deviation, $\sigma = \sqrt{\frac{\sum d_i^2}{n-1}} = \sqrt{\frac{1.45x10^{-3}}{9}}$

$= \pm 1.27 \times 10^{-3}$

Standard error, $S = \frac{\sigma}{\sqrt{n}} = \frac{1.27x10^{-3}}{\sqrt{10}}$

Correct value = (68. 1615 ± 0.0004)cm

2.5 COMBINATION OF ERRORS

You will sometimes have to combine the standard errors of two or more parameters in order to obtain the standard error of another parameter. The type of combination depends on the relation between the parameters.

2.5.1 ESTIMATION OF STANDARD ERRORS

As earlier stated each time a measurement is made there is a random error, hence readings are repeated several times and the mean is taken as the best value. The standard error of the means is estimated from the error in the individual readings.

2.5.2 SUM AND DIFFERENCES

Let y = x ± z and the standard errors of x and z are S_x and S_z respectively, then the error in y is given by $S_y = (S^2_x = S^2_z)$ valid for both sum and difference.

2.5.3 SUM OF SQUARES ESTIMATE

The standard error is the root-mean-square of the deviations from the mean. Let the error in the series of readings be $S_1, S_2, S_3, \ldots, S_n$;where n is the number of readings. Then the standard error of the mean is: $S = Lim\{(S^2 + S^2 + S^2 \ldots\ldots\ldots + S^2)/n)\}^{1/2}$
$n \to$

2.5.4 STANDARD DEVIATION METHOD OF ESTIMATE

First find the standard deviation of this set of readings. Thus if $x_1, x_2, x_3, \ldots x_n$ are the set of readings, the mean is given as:

$$Mean\ \bar{x} = \frac{\sum x_i}{n}$$

The deviation of individual readings are given by their departures from the mean thus,

$$d_1 = \bar{x} - x_1,\ d_2 = \bar{x} - x_2,\ d_3 = \bar{x} - x_3\ ,\ \ldots\ldots\ d_n = \bar{x} - x_n$$

The standard deviation or the mean square variation or the mean square deviation is given by:

$$\sigma = \sqrt{d_1^2 + d_2 + d_3 + \ldots\ldots d_n^2 \big/ n-1}$$

$$\sigma = \sqrt{\frac{\sum(\bar{x} - x_1)^2}{n-1}} = \sqrt{\frac{\sum d^2}{n-1}}$$

From this standard error is approximately given as $s = \dfrac{\sigma}{\sqrt{n}}$

That is, standard error, s = $\dfrac{\text{standard deviation}}{\sqrt{n}}$

2.5.5 RANGE ESTIMATE METHOD

The range, w is the difference between the highest and the lowest measured value;that is, $w = x_{max} - x_{min}$

The standard deviation, σ is approximately given as: $\sigma = \dfrac{w}{\sqrt{n}}$

and the standard error, s, can be determined by using. $s = \dfrac{\sigma}{\sqrt{n}} = \dfrac{w}{n}$

Thus for a set of n - readings(where $3 \leq n \leq 12$) one simply finds the range and divides it by the number of reading to get the standard error.

Sample Problem 2:

Using the set of data given in sample problem 1, find the standard error and the correct value of the given distance measurements. Left as exercises to the student.

Solution: Using range estimate method $w = x_{max} - x_{min}$

w = 68.164 - 68.160 = 0.004 cm, n = 10

Standard Error,s = w/n = 0.004/10 = 4×10^{-4}

Correct value = (68.1615 ± 0.0004)cm

Observe that the correct value is the same for the three methods. We encourage you to use the range estimated method regularly in class work.

2.5.6. PRODUCTS AND QUOTIENTS

(i) Let y = kx ,where k is a constant and let the standard error in x be S_x then the standard error in y will be: $S_y = kS_x$

(ii) Let y= S_z; then the usual rotation, the standard error in y is given by

$$\frac{S_y}{y} = \left\{\frac{S_x^2}{x^2} + \frac{S_z^2}{z^2}\right\}^{\frac{1}{2}}$$

$$S_y = y\left\{\frac{S_x^2}{x^2} + \frac{S_z}{z^2}\right\}^{\frac{1}{2}}$$

(iii) Let y = $\dfrac{x}{z}$ or $\dfrac{z}{x}$

The process of estimation is the same as in (ii),that is

$$S_y = y\left\{\frac{S_x^2}{x^2} + \frac{S_z}{z^2}\right\}^{\frac{1}{2}}$$

(iv) If y=kx or $\dfrac{kx}{z}$ or $\dfrac{kz}{x}$; $kS_y = ky\left\{\dfrac{S_x^2 + S_z^2}{x^2 + z^2}\right\}^{\frac{1}{2}}$

(v) If $y = kx^n$ then $S_y = yn\dfrac{S_x}{x}$

(vi) If $y = kx^n z^m$ or $\dfrac{kx^n}{z^m}$ or $\dfrac{kz^n}{x^m}$ then $S_y = y\left\{\dfrac{n^2 S_x^2}{x^2} + \dfrac{m^2 S_z}{z^2}\right\}^{\frac{1}{2}}$

2.5 ERRORS OF SLOPE

The standard error of the slope or gradient may be estimated from the scatter of the points by the formulae.

$$S_x = \frac{4w}{nR}(3 \leq n \leq 12), \text{ where } R = x_{max} - x_{min}$$

(see diagram) and w = the distance PQ drawn parallel to the y-axis and n = number of measurement.

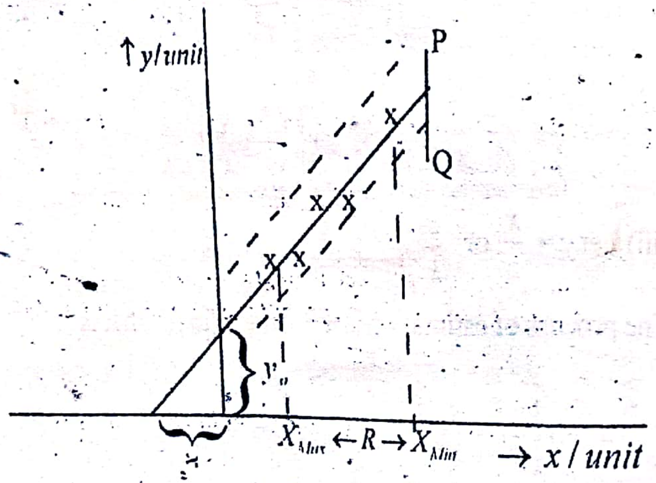


Fig 2.4

CHAPTER THREE

METHOD OF WRITING THE REPORT

Our reports must be clearly written to show exactly what has been done, why and how it has been done, the results and method of error analysis. Such a full account should enable any reader to repeat the experiment for himself, if so desired.

The report which must be neat and orderly should consist of the following headings and subheadings in the presented order. However, for easy evaluation of your work, the instructor may alter the sequence:

i. Experimental number

ii. The title or heading of the experiment should be written in block letters.

iii. Aim or objectives. The aim should specify what the experimenter intends to achieve.

iv. Diagram (if any). Only sketch diagram, block diagram etc, must be drawn where they may aid the arrangement of the devices used in the experiment.

v. Procedure (method): The procedure gives a concise account of the measurements taken in the order *in* which they were taken; and the method of analysis employed. The pronouns such as I, We, They, The group, The instructor, The demonstrator etc must be avoided. The names of instruments used in measurements of distance, time, mass, temperature, angle etc must be mentioned as the sensitivity of such measuring devices could be improved upon in a repeat-experiment to minimize error or observation.

3.1 PROCEDURAL REPORT

Example: Below is a written report for experiment on simple pendulum. One end of the given string was to the pendulum bob, the other free end was tied to the ceiling. The height of the center of the pendulum bob from the floor was measured using meter rule. The pendulum bob was tilted through a very small angle and released. Time for fifty oscillations of the bob was taken and recorded using the stop clock. The process was repeated five more times for various heights of the center of the bob from the floor. The time. T for one complete oscillation of the pendulum bob was determined. A graph of T^2 against the height. L from the floor to the center of the bob was plotted and analysed.

3.2 OBSERVATION (DATA RECORDING)

The results of all measurements taken during the experiment are recorded in a closed composite table (table fractionation is prohibited). The reading should be recorded to the correct degree of accuracy of the instruments consistently throughout the column (the same decimal places). The headings at the top of the table denote the quantities measure with their units. An example of a composite table for our simple pendulum experiment above is given below:

Trial	Height L/cm	Time for 50 Oscillations T/s			Period T/s	T^2/s^2
		t_1/s	t_2/s	t_{aveg}/s	t_{aveg}	
1						
2						
3						
4						
5						

From the table, observe that a stroke (/) has been used to demarcate the symbol of the measured physical quantity and the unit rather than parenthesis (); the importance of this may be highlighted by your instructor.

Where the reading cannot be expressed in tabular form, such as in specific heat capacity experiments, our readings must be recorded following a neat order to the correct accuracy and with appropriate units.

3.3 CALCULATIONS (IF ANY):

The Theoretical and Mathematical knowledge required to get solutions expected from the experiment must be stated in the report. Three types of calculations are involved:

3.3.1. DERIVATION OF EXPRESSIONS NEEDED FOR CALCULATION OR FOR THE GRAPH

To illustrate this we shall use our experiment on simple pendulum *determination of inaccessible heights.* The period, T, of oscillation is given as:

$$T = 2\pi\sqrt{\frac{H-L}{g}} \qquad 1.1$$

Where H is the inaccessible height from the floor. We are required to plot suitable graph to determine the inaccessible height, H.

$$T^2 = 4\pi^2\frac{(H-L)}{g} \qquad 1.2$$

Expanding: $T^2 = 4\pi^2\frac{H}{g} - 4\pi^2\frac{L}{g}$ 1.3

Re-arranging: $T^2 = 4\pi^2\frac{H}{g} - 4\pi^2\frac{L}{g}$ 1.4

Equation 1.4 permits one to plot the graph of T^2 against L. we shall expanciate on this under graphs later.

3.3.2 THE SECOND CATEGORY INVOLVES CALCULATION OF RESULTS

A typical example is found in calculations involving determination of specific heat capacity of a substance by calorimetric method. (Outside the scope of this text)

3.3.3 CALCULATION OF ERRORS

This has been dealt with in details in the previous chapter, because of time frame, we recommend Range Estimate Method for error propagation.

3.4 GRAPHS

Results of our experiment are conveniently displayed on a graph. This will be left for detail discussion later.

3.5 PRECAUTIONS

Steps taken to minimize error must be enumerated. At least three (3). Avoid all personal pronouns.

3.6 RESULT

The final result must be given with reasonable order of accuracy, that is, ($R = X \pm Y\%$) we shall assume that your result is within 68% confidence limit otherwise indicate this by writing 2σ or 3σ.

CHAPTER FOUR

GRAPHS

INTRODUCTION:

In many experiments in Physics, a quantity 'P' is observed or measured under different conditions varied by the experimenter. The value of 'P' may depend on several factors e.g. the volume of an ideal gas depends on the mass of the gas. its pressure and temperature, or the anode current of a triode depends on the filament temperature, the grid voltage and the anode voltage. It is customary of a Physicist to vary one factor say, Q at a time and to find how P depends on Q, when other conditions are kept constant.

The results of such experiments are expressed on a graph. Values of Q (or some power or function of Q) are called the independent variable and are plotted along the x-axis while values of P (or some power or functions of P) called the dependent variable are plotted along the y-axis

4.2 ADVANTAGES OBTAINED WHEN A GRAPH IS PLOTTED

i. *If P is plotted against Q the relationship between them is shown pictorially.*

ii. *Corresponding value of P and Q other than those actually observed and recorded can be read or deduced from the graph.*

iii. *A known or expected relationship between P and Q could be verified and numerical values of constants occurring in the relationship could be determined.*

v. *If the relationship between P and Q is simple but not known or suspected before the experiment, a graph enables one to discover the form of this relationship.*

4.3.1 STRAIGHT LINE GRAPH

When we plot the graph of P against Q if the graph is a straight line type, the relation between the two quantities is linear. The equation is given by

$$P = mQ + C \qquad 4.1$$

In a more generalized form, the equation of the straight line graph is given by:

$$y = mx + c \qquad 4.2$$

Where y is plotted along the vertical axis and x along the horizontal axis. See figure 4.1; m is called the gradient or slope of the graph and c is a constant called the y-intercept. That is, intercept along y-axis

Y-INTERCEPT: Is defined as the value of y when x = 0. In equation 4.2, if x = 0 and y = mx+c, the y = c $\qquad$ 4.3

X-INTERCEPT: Is defined as the value of x when y = 0. Substituting in equation 4.2, we have y = mx+c

If y = 0 $\therefore$ 0 = mx + c, then mx = -c

$$\therefore\ x = \frac{-c}{m} \text{ that is, intercept } = \frac{-c}{m} = \frac{\text{y-intercept}}{\text{gradient}}$$

Gradient or Slope (m)

$$\text{The slope } m = \frac{\text{Change in y value}}{\text{Change in x value}}$$

If the graph slope upwards or makes an acute angle with the positive x-axis (fig 4.2), the slope is positive. But if the graph slopes downwards or makes obtuse angle with the positive x-axis, the slope is negative (fig4.3). If the graph passes through the origin, then the intercept is zero and equation 2.2. becomes y = mx + 0; y = mx

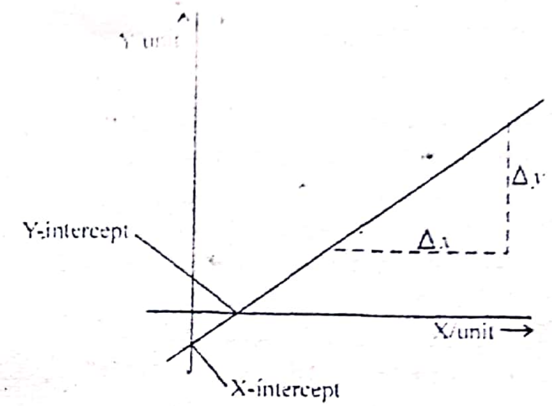


Fig 4.1

; in this case, y and x are directly proportional.

Intercept determination: In order to read the y and x-intercepts directly, both axis must start from the zero as origin. Where it is not convenient to start both axis from zero as the origin, either must start from the origin so that the other intercept could be determined. Example: If x-axis does not start from zero as origin we cannot read y-intercept directly (recall the definition of y-intercept), hence we have to determine the value of y from the equation of the graph; consider the figure 4.4 below.

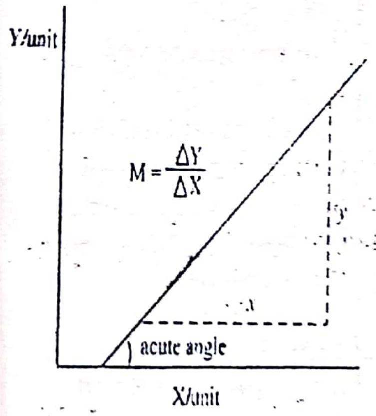


Fig 4.2

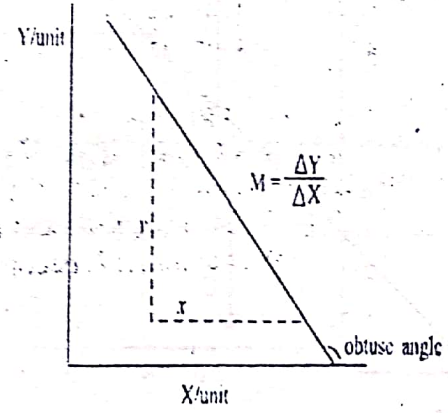


Fig 4.3

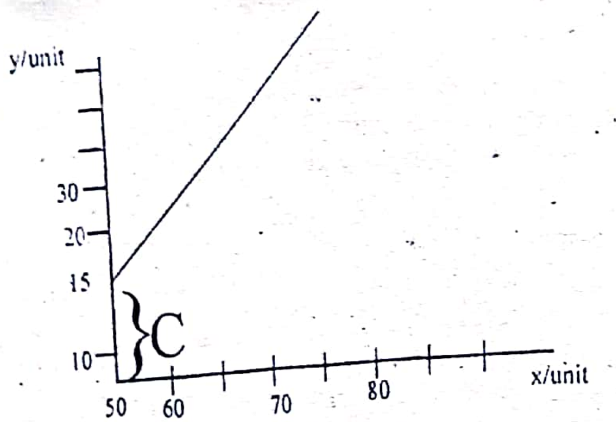


Fig 4.4

When x = 50, y = 15, the portion marked C is not the y-intercept because at that point of intersection. We shall substitute the values recorded from the graph in order to determine the y-intercept. Thus
$y = mx + c$, $\therefore$ $15 = 50m + c$
Therefore, c = y-intercept = 15-50m, where m is the determined slope.

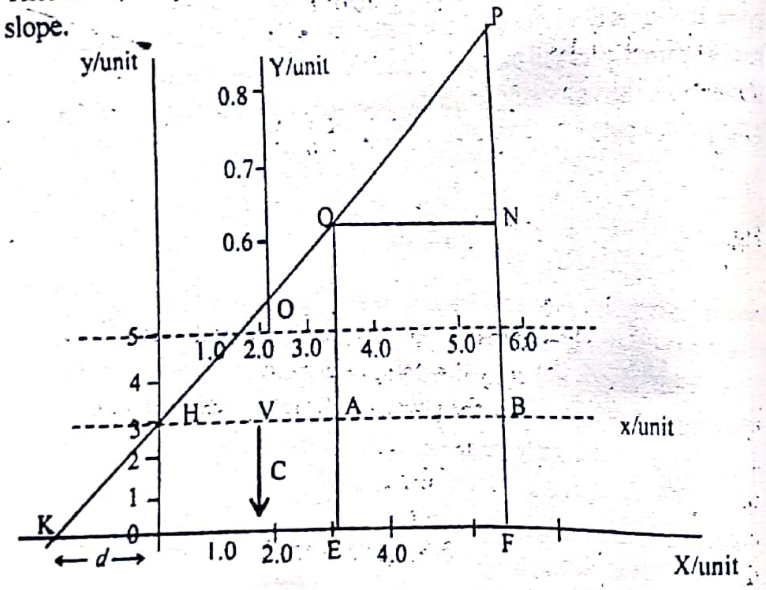


fig 4.5

AXIAL EXTRAPOLATION

Sometimes the coordinates of the axes do not start from zero as origin to avoid crowded points at the top portion of the graph. If the axes are extrapolated the slope is unaltered; but the intercepts could only be read through axial extrapolation as shown in figure 4.5. In the figure y-1 and x-1 {0 = (20,5.0) as origin} is the graph plotted by the student before realizing he has to read the intercepts; and y- and x- are the extrapolated (or true axis). Triangle PQN has been used by the student to determine the slope in the initial unextrapolated graph. Triangle PHB is now used to estimate y-intercept while triangle PKD is used to estimate x-intercept.

$$\text{Slope} = \frac{PN}{QN} = m$$

Intercept are OK (d) and OH (c) on the true axes.

(i) Y-intercept, 'c'

$$\text{The slope} = \frac{PB}{HB} = \frac{\text{y co-ordinate of P - C}}{\text{x co-ordinate of P}}$$

'c' can be calculated.

(ii) X-intercept, 'd'

$$\text{The slope} = \frac{PF}{KF} = \frac{\text{y co-ordinate of P - C}}{\text{x co-ordinate of P+d}}$$

Fig. 4.5 'd' can be calculated.

Exercise 1: (*Test 1*)

The following values of load and effort were obtained with a simple machine. (Table 4.1) copy the data; using the correct format and appropriate accuracy. Plot the graph of effort against load and

a. Read the y-intercepts.
b. Determine the slope of the graph.
c. Determine the x-intercept.
d. Write down the relationship between P and W.

Table 4.1

Load W/N	10	20	30	40	50
Effort P/N	5	7	8	11	13

FINAL COMMENTS ON STRAIGHT LINE GRAPH

The straight line graph is the simplest form of bringing out relationship between two variables even when the relationship is non-linear. The complex equation is reduced to a form which would give a straight line plot. We have already seen an example in section one (inaccessible height). There, the period T of the swinging Pendulum was given as:

$$T = 2\pi \sqrt{\frac{H-L}{g}}$$

On squaring both sides and rewriting, we obtained

$$T^2 = 4\pi^2 \frac{H}{g} - 4\pi^2 \frac{L}{g}$$

This equation is similar to the equation of a straight line graph $y = mx + c$.

The slope, $m = \frac{4\pi^2}{g}$

and it is a negative slope.

The intercept along T^2 – axis is a constant because all the elements in the expression are constants ∴

$$c = -\frac{4\pi^2}{g}$$

Note: In the example above we can determine the value of acceleration of free fall in two different ways:

(a) From the slope $\frac{\Delta T^2}{\Delta L} = \frac{4\pi^2}{g}$

knowing the slope, g, could be determined.

(b) If T^2 – axis starts from zero as origin, then L-intercept could be read directly and

$$0 = -\pi^2 \frac{H}{g} + 4\pi^2 \frac{L}{g}$$

solving L = H; hence the intercept along L-axis is the inaccessible height, H. Substituting the value of H in $c = -\frac{4\pi^2}{g} H$

C = T^2-intercept. i.e. (assuming T^2 –axis starts from zero as the origin) Then the value of acceleration of free fall, g, could be determined. This method is therefore one of the best known methods of determining acceleration of free fall, due to its dual advantage.

Exercise 2: (Test 2)

The period of oscillation of a compound pendulum about a given axis distant h from its center of gravity is given by:

$$T = 2\pi \sqrt{\frac{h^2 + k^2}{gh}}$$

Where k is a constant for the pendulum, called radius of gyration, and all the other symbols retain their usual meaning. Using the standard format of writing experimental report and your basic knowledge of the theory and practice of the experiment, plot a suitable graph; using the set of data given in Table 4.2

From the graph determine.

a. *The radius of gyration. K of the pendulum.*

b. *The acceleration of free fall, g.*

Table 4.2: Compound Pendulum:

h/cm	5	10	20	30	40	50
T/sec	2.76	2.03	1.63	1.57	1.60	1.66

4.3.2 LOG-LOG GRAPH

When the relation between variables is not linear or known such as in a log-log graph, then there is the need to reduce equation to its linear equivalent. Suppose P and Q are related by the equation: $P = AQ^n$ Where A and n are numerical constants whose values are required, the best option is to reduce the expression to a linear form by taking logarithms of both sides;

Log P = log A + nlog Q

Rearranging to make it look like the standard from: y = mx + c

We have, Log P = nlog Q + log A 4.12

Since n and log A are constant, equation 4.12 is the equation of a straight line. We shall plot the graph of log P along y-axis and log Q along x-axis.

ANALYSIS:

The slope, m = n 4.13

The log P-intercept (i.e value along log p when value along log Q is Zero) equals log A.Hence if we start log Q-axis from zero as the origin we can read the intercept along log p directly. Let the value read, be k; then k = log A 4.14

To evaluate, we shall find the anti logarithm of k; this gives the value of A.

A = anti log k 4.15

Note: Care has to be taken in plotting the logarithm graph, since the true logarithms not the conventionally tabulated logarithm of numbers smaller that unity are usually required. For instance, the number 0.5 is less than unity, and its logarithm is read from the four figure tables as 1.6990 and from the calculator as -3.010. (before proceeding let us do the conversion).

$$Log0.5 \Rightarrow \bar{1}.06990 = -1 + 0.6990$$

Performing the arithmetic operation: $Log0.5 \Rightarrow \bar{1}.06990 = -0.3010$

Having plotted the graph, (the instructor will teach you the two methods of plotting the logarithm graph on linear graph sheet as well as on logarithm graph sheet). If the intercept reads -2.73, we shall find the antilog of -2.73. To do this, we shall reverse our former process; Antilog of -2.73 = anti log + 0.2700 ==>anti log 3.2700; from this value A could be determined.

Class Work

Using Table 4.3 below, plot the graph of logP against logQ. Find from the graph the slope, m, and the intercept along logP-axis.

Table 4.3

Q	1	2	3	4
P	3	12	27	48

Exercise 3: (Test 3)

Using the table below (Table 4.4.) plot a suitable graph, for a relation $P = KQ^x$ where K and x are unknown, (Do not reproduced the table but derive the equation for the straight line graph to show the suitability of your graph).

Table 4.4

P	0.4	0.14	0.017	0.05
Q	1.0	2.0	3.0	4.0

a. From your graph, determine the value of K and x.

b. Using the determined values, write down the relation between P and Q.

Exercise 4: (Test 4)

In an experiment with a cooling calorimeter, the following results were obtained (Table 4.5).

Table 4.5 Cooling correction:

Rate of fall of temperature Q/°c min⁻¹	5.6	3.5	2.3	1.7	1.3	0.8
Excess temperature over Environmental temperature P/°c	79.4	56.2	39.8	31.6	25.0	18.0

Assuming that the law of cooling is given by the formula: $Q = aP^n$

a. Find the value of a and n.

b. Using the values, write down the relation between the rate of cooling and the excess temperature over the room temperature.

4.7.1 A VARIABLE AS AN INDEX (LOG-LINEAR GRAPH)

Suppose P and Q are again related by an equation of the form

$P = ax\,10^{bQ}$

Reduce it to the form $y = mx + c$ by taking logarithm of both sides. We can plot the graph of log P against Q since a and b are constants. We can plot this on a log-linear graph paper (semi-logarithmic graph paper) or on purely linear graph paper. The slope, M of the graph is the value of "b" and the value of "a" could be determined from the intercept along the log P-axis.

Exercise 4: (Test 4.1)

Express the following physical formulae in the form of the equation of a straight line graph and indicate:

a. The suitable graph to be plotted.

b. What the intercept corresponds to, and

c. What the slope corresponds to

(i) $P = ae^{bQ}$ 2.20

Where e = 2.718 is the base of the Napierian (Natural) Logarithms

(ii) $P = Qe^{-bQ^2}$ 2.21

Exercise 4: (Test 4.2)

Andrade's formula for the variation of the viscosity of a liquid with the absolute temperature T/Kelvin is given is:

$N = Ae^{b/T}$

Using Table 4.6. Find the value of the constants A and b for water. (report completely using relevant literature in the Library).

Table 4.6: Variation of Viscosity with temperature.

Temperature θ/°C	0.00	20.0	40.0	60.0	80.0
Viscosity/Poises	[illegible]	[illegible]	0.0065	0.0074	0.0036

4.8 NONLINEAR GRAPHS

If the relation between P and Q is not linear more points are required to plot the graph than that of a straight line graph. The most important type of the non-linear graph is that in which the independent variable is time. In such a case the gradient measures the rate of change with time of the dependent variable and these vary from point to point along the smooth curve.

4.8.1 GRADIENT OF NON-LINEAR GRAPHS

In order to measure the gradient of a curve at a given point, a tangent is drawn to that point and the slope of the tangent is determined as usual. To draw the tangent at the given point, say d, in figure 4.6, we shall mark the point on the curve and then draw a straight line through the marked point just touching the curve at the marked point. The line which must not cross or cut the curve but just touch the curve at the given point is called *tangent*.

The tangent must be conveniently long to provide a large right angled triangle required for the determination of the gradient (fig.4.6). The tangent forms the hypotenuse, while the two adjacent sides are parallel to the axes. Slope, m at d = $\frac{\Delta P}{\Delta Q}$

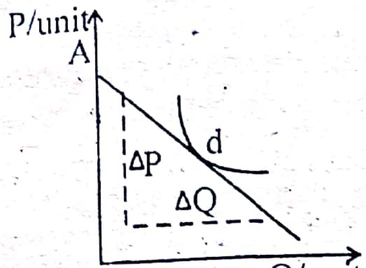


fig 4.6

Exercise 5: (Test 5)

Table 4.7 shows a set of readings obtained in a cooling calorimeter experiment; plot the graph of the temperature in ^{0}C against the time in minute.

1. Draw a smooth curve, also draw at least 5 tangents to the curve at 5 different temperatures of your choice. Determine the gradient at each point. (use space point).
2. Draw another graph with your selected temperatures along y-axis and determine the corresponding gradients along the x-axis. Find the gradient of the resulting straight line. Comment on your result.

Table 4.7

Time in sec	0	60	120	180	240	3 00	360	420	480	540
Temp. in ^{0}C	45	33	26.1	21.7	19.1	17.4	16.5	15.1	14.0	12.6

4.9 AREA UNDER GRAPHS

When the graph of P against Q is plotted, the Product PQ has a definite physical meaning. For example, if P is velocity and Q is time, the product PQ represents the area of the velocity-time graph and gives the total distance traveled. Also if P is force and Q is distance, the product PQ represents the work done.

We can employ calculus to determine this area

(Beyond the scope of this book), but it is suggested that we count the total number of squares under the graph provided we have used graph paper thus:

i. Count all the full squares and record as one each.

ii. All portions which are larger than half-square should also be counted and record as one each.

iii. All portions which are exactly half squares should be counted and record as ½ each

iv. All portions which are less than half-square should be neglected or record as zero.

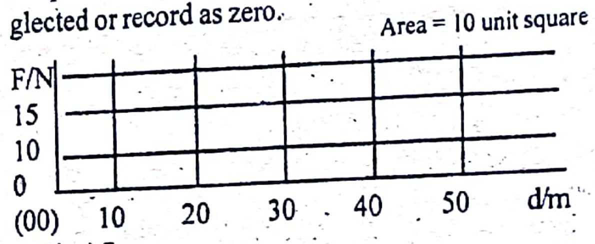
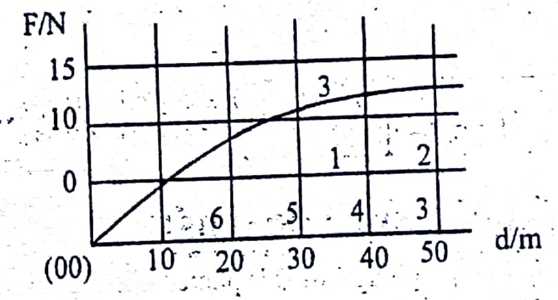


Fig 4.7

In figure 4.7 there are 10 unit squares (count these). The total area under the graph is the total work done assuming the force is constant.

Figure 4.8 represents a case in which the applied force is not uniform.



Note The total number of unit square is about 7.5 = 375 joules. In computing areas using this observation method, two important precautions must be taken,

i. The intersection of the axes must be at zero as the origin and must be indicated (not assumed).

ii. The area under discussion must be that between the curve and the correct axis.

Exercise: (Test 6)

Plot the velocity time graph for the following motion (Table 4.8) and find:

a. The acceleration at time, t = 2 sec.

b. The total distance traveled in the last 2 seconds.

Table 4.8

Velocity/ms-1	15	2.9.5	36	38	35
Time/sec	0	1	2	3	4

CHAPTER FIVE

EXPERIMENT 1: DETERMINATION OF MOMENT OF INERTIA OF A BAR USING A BIFILAR SUSPENSION

APPARATUS:

Cylindrical metal bar, AB. two heavy stands and clamps, two lengths of thread, two split corks. stopwatch, metre rule, balance reading to ± 0.1g, vernier calipers

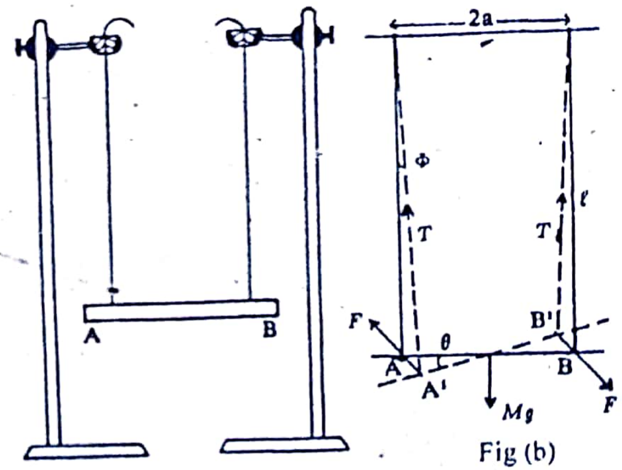


Fig (a)

Fig (b)

METHOD:

Suspend the metal bar horizontally by means of vertical strings of equal lenght, L, arranged symmetrically on either side of the centre of gravity. Set the bar into torsional oscillations through displacing its ends by equal small amounts with the centre remaining stationary, and measure the period "T" of oscillations for different lengths L,of the strings, keeping their seperation fixed.

Weigh the bar and measure its length L and radius r.

RESULTS:

L (cm)	Time for n oscillations (s)			Mean time of oscillation (s)	Period T (s)	T^2 (S^2)
	i)	ii)	iii)			

Mass of bar, M = g
Length of bar, L = cm = m
Diameter of bar, 2r = cm = m
Therefore, mean radius of bar "r" = cm = m
Gradient of graph = ±
Therefore, moment of inertial of bar = ± kgm^2

THEORY:

Let θ be the angular displacement of AB in the horizontal plane, and ψ be the corresponding displacement of the strings in the vertical plane. if θ is small, then:

$$AA^1 = a\theta \simeq l\psi \qquad (1)$$

Considering the vertical equlibrium of the bar, we have:-

$$Mg = 2T\cos\psi \simeq 2T \qquad (2)$$

The horizontal components of the tensions acting perpendicularly on AB are each T sin ψ. The exert a restoring couple = 2aT sin ψ on AB. If I = moment of inertia of bar about vertical axis through its centre of gravity, the equation of motion of the bar is

$$I\ddot{\theta} = 2aT\sin\psi \simeq -2aT\psi$$

Using equation (1) and (2), this become

$$I\ddot{\theta} = -\frac{Ma^2g}{l} \qquad (3)$$

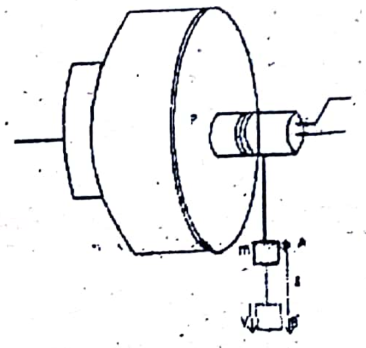
This represents simple harmonic motion of period "T"

$$T = 2\pi\sqrt{\frac{IL}{Ma^2g}}$$

Plot the graph of T^2 as ordinate against L and deduce I from the slope. Estimate the standard error in I from the scatter in the graph. Compare the measured value of I with that calculated from the formula

$$I = M\left(\frac{r^2}{4} + \frac{L^2}{12}\right)$$

EXPERIMENT 2: DETERMINATION OF THE MOMENT OF INERTIA OF FLYWHEEL



APPARATUS:

Flywheel of standard pattern supplied with wall support. A weight attached to a length of fine cord which is wrapped round the axle, the free end being passed through a hole in the axle. The length of cord is adjusted so in the axle. The length of cord is adjusted so that when the weigth reaches the ground, the cord detached itself from the axle. Callipers, stopwatch, meter rule.

METHOD:

The weight m is allowed to fall through a measured distance (s) to the ground(s), and the time of descent (t) is taken by a stop-watch. The number of revolutions (n) of the wheel during this time is taken by observing a mark made on the circumfrence of the wheel at p.

The further revolutions (N) made by the wheel also counted by reference to the mark p. The experiment is repeated two or three times for the same distance "s" and average values of n, t and N are taken. The value of m is obtained by weighing and the radius r of the axle found by using callipers.

RESULTS:

Radius of axle (r) = m
Mass (m) = kg
Distance (s) = m
t = Distance s Average t = s
n = Distance rev Average n = rev
N = Distance rev Average N = rev.

NOTE:

The cord should be a small diameter compared with the axle, otherwise the value of r used above must be taken as the sum of the radii of axle and cord.

THEORY:

Let the mass of the suspended weight be m and let the moment of inertia of the flywheel be I and the radius of the axle r. Then when the mass descends a distance AB =s, it loses potential energy = mgs and during the same time it acquires kinetic energy = $\frac{1}{2}mv^2$ due to its velocity V at B, Then by the principle of the conservation of energy. Let the opposing frictional couple be F and if the wheel makes n revolutions while m falls from A and B then

$$Mgs = \tfrac{1}{2}mv^2 + \tfrac{1}{2}Iw^2 + F2\pi n \quad (1)$$

Suppose that after the mass is released at B the wheel makes a further N revolutions before being brought to rest. The work done against friction during these N revolutions is equal to the kinetic energy of the wheel at B.

i. e. $2\pi NF = \tfrac{1}{2}Iw^2$ (2)

Substituting for F in 1 from 2 we have

$$Mgs = \tfrac{1}{2}mv^2 + \tfrac{1}{2}Iw^2 + \tfrac{1}{2}Iw^{2n}/N$$
$$= \tfrac{1}{2}mv^2 + \tfrac{1}{2}Iv^2/r^2 + \tfrac{1}{2}Iv^2/r^2wn/N$$
$$= V^2/2\,(m + {}^{1}/r^2\,(1 + n/N)$$

Now since the acceleration is constant, the velocity of M at B is is twice the average velocity during the fall from A to B, that is,

$V = \frac{1}{2}s/t$ Thus, $Mgs = \frac{4s^2}{2t^2} = [m + I(1+n/N)]$

From which $I = Mr^2\,(gt^2/2s - I)\,(N/N+n)$

NOTE:

An interesting alternative, if somewhat less exact, method for obtaining the moment of inertia of the flywheel is as follows:
A small mass m is attached to the edge of the wheel (e.g. by a little soft wax), and the system followed to execute oscillations of small amplitude. The time for 20 (say) of these oscillations is taken and the moment of inertia of the flywheel, the restoring couple come into play on displacing the wheel a small angle θ from the equilibrium position is

$$MgR\sin\theta = MgR\theta \text{ (since } \theta \text{ is small)}$$

The equation of motion resulting on releasing the wheel is $-MgR\theta = I'\ddot{\theta}$, where $I'\ddot{\theta}$ is the moment of inertia of the system $= I + MR^2$

Hence we have $\ddot{\theta} + \frac{(MgR)}{I + MR^2}\cdot\theta = 0$

The motion thus being simple harmonic of periodic time.

$$T = 2\pi\sqrt{\frac{I + MR^2}{MgR}}$$

(1) The above arrangement ignores the work done against rolling friction, which in any case is small and may be disregarded. The student should carry out the experiment, varying M until consistent values of I are obtained.

EXPERIMENT 3: PRINCIPLES OF MOMENT

AIMS: To determine

(1) The mass of a meter rule,
(2) The upthrust of a liquid and
(3) The density of a solid using the principles of moments of a force.

APPARATUS:

Meter rule, Knife edge, String, beaker, water, vernier calliper and 0.1kg mass

THEORY:

If the relationship between Y and Z is given by

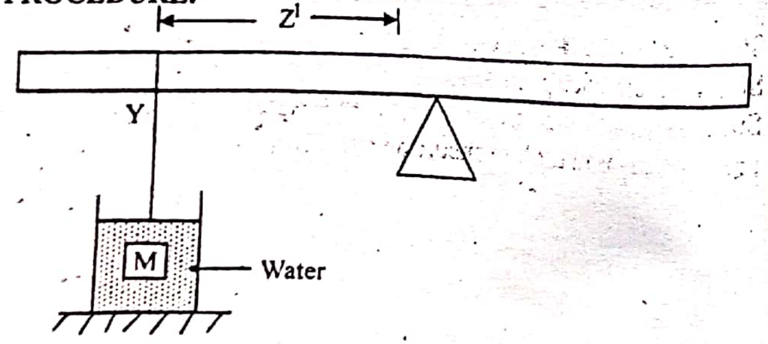
$$Y = Z\left(\frac{M}{M_r}+1\right)+C$$

and the relationship between Y and Z' (When the mass is totally immersed in water) is

$$Y = Z'\left(\frac{M}{M_r}-1\right)+C$$

Where M is the mass provided and M is the mass of the meter rule and U is the upthrust of the liquid.

PROCEDURE:



Balance the meter rule onthe knife-edge and record the reading corresponding to the centre of gravity of the metre rule.

With the string provided, suspend the given mass at point Y, 5cm from the free end of the meter rule and balance the arrangement on the knife-edge. Measure the distance Z between the knife-edge and point Y. Repeat the experiment for the mass hung at point Y = 10, 15, 20, 25, 30cm marks respectively.

Half fill a beaker with water and record this initial volume of water as V'. Repeat the above experiment with the mass totally immersed in the half - filled beaker of water and record Z'. Also, read and record the increase in volume of water as V_1. Tabulate your result as appropriate. Using the vernier calliper, determine the diameter of the given mass.

RESULTS:

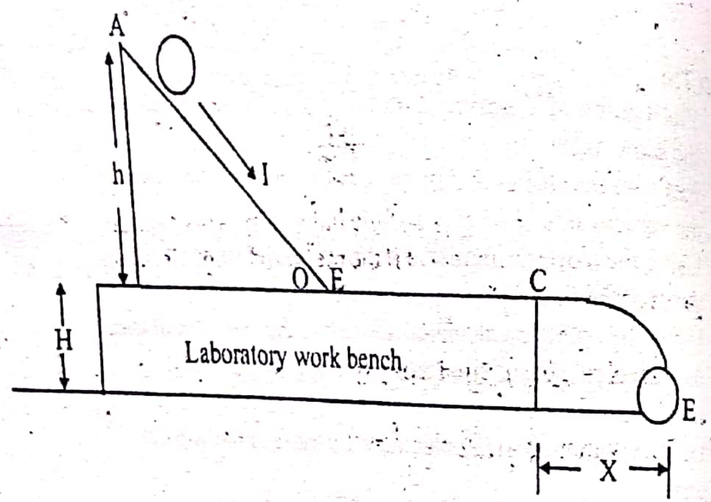
1. Plot a graph of Y against Z and Z', using the same scale and the same axes
2. Evaluate the slopes and intercepts of the two graphs along the vertical axis.
3. Using the slopes, calculated the mass metre rule and the up thrust of the liquid.
4. Using the upthrust calculated above and the diameter of mass provided,calculated the density of the mass provided.
5. Evaluate $V' - V_1$
6. Using your result in (5), calculate the mass of the weight provided
7. State the law of floatation
8. State Archimedes principles
9. State the possible sources of error in this experiment and the precautions you took to ensure accurate results.

EXPERIMENT 4: KINEMATIC PRINCIPLES

AIM: To determine the height of the laboratory work bench and the acceleration due to gravity using kinematic principles

APPARATUS: Inclined plane, spherical balls, carbon paper and plain typing paper, vernier callipers and stopwatch.

PROCEDURE: Set up the apparatus as shown below.



Using a metre rule, measure the distance BC = 50cm. vary h such that $\theta = 10°$. Mark out the point A on the inclined plane and measure AB and record as L. Allow a spherical ball to roll down the plane from point A. Such that it moves through the path AB - BC - CE. Place a sheet of typing paper and a carbon paper at point E so that at impact, the ball makes an impression on the plain paper. Using a metre rule, measure the distance X, from the foot of the table to point E. Using a stopwatch measure the time taken for the ball to roll from point A to point E. Keeping the distacne AB and BC constant throughout, repeat the experiment for $\theta = 30°, 50°$ and $70°$. in each case read and record h, θ, t and X. Tabulate your results as shown below.

RESULTS:

AB = l =

BC =

h (cm)	θ°	t_1(s)	t_1 (s)	t (s)	X_1	X_1	Xmean	l^2-h^2	h(l^2-h^2)

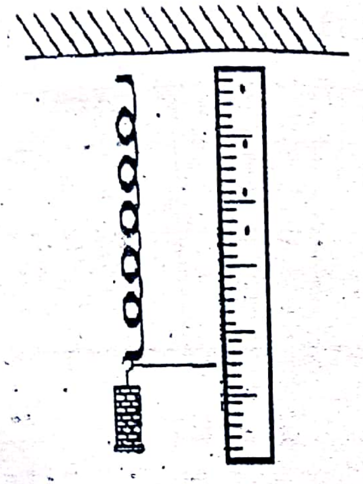
DATA ANALYSIS:

1. Plot a graph of X against h(l^2-h^2)
2. Evaluate the slope of the graph
3. Given that the slope $S = \dfrac{20H}{7l^2}$,

   Calculate H, the height of the laboratory work bench.
4. Calculate the error in H if the measured height is 93.50± 0.05cm.
5. If $X = \dfrac{20H\, l\, \sin\theta \cos^2\theta}{7}$;

   Show that $X = \dfrac{20Hh\,(l^2-h^2)}{7l^2}$
6. State the possible sources of errors in this experiment
7. Mention the precautions you took to ensure accurate results

EXPERIMENT 5: A SPIRAL SPRING EXPERIMENT



APPARATUS:

Spiral spring to which a light pointer is attached by plastcine at its lower end, rigid stand and clamp, metre rule, scale-pan and weights stop-watch.

METHOD:

Experiment 1: To verify Hooke's law and to find the extension per G of added load. The spring, with scale-pan attached is firmly clamped and the meter scale placed vertically so that the pointer moves lightly over it. Loads are added to the scale-pan and the corresponding extensions of the spring are noted. The scale readings are also taken when unloading the spring, and the mean extension thus obtained. A graph of extension against load is plotted from which the extension (N) per unit load is found.

Experiment 2: To determine the acceleration of gravity and the effective mass (M) of the spring. A load is added to the pan which is set in vertical vibration by giving it a small additional displacement. The Periodic time (T) is obtained by timing 20 vibrations. This is repeated with different loads and a graph of T_2 against load is plotted, from whcih G and M are found.

NOTE:

The mass of the scale-pan should be included in the load in this experiment.

RESULTS:

Experiment 1:

Load M. (kg)	Extenstions		Mean Extension
	Load increases	Load decreases	

Experiment 2:

M (kg)	Time for 20 Vibrations (S)	T (S)	T^2 (S^2)

From Fig. 3.2 with extension expressed in $g = 4\pi^2 nM$ from Fig 3.3. M = AC meters and load in kg for SI units

$$n = \frac{BC}{AC} = mkg^{-1}$$

$$\therefore g = \frac{4\pi^2 nM}{T^2}$$

$$\therefore g = \frac{4\pi^2 nAC}{BC} \quad ms^{-2}$$

From Fig. 3.3 m = OD kg.

THEORY:

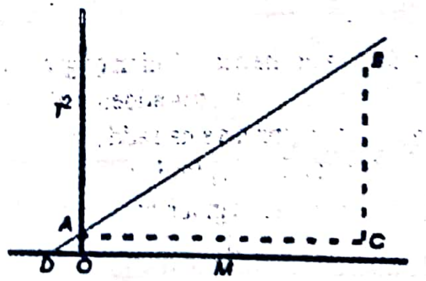


Fig 3.3

A spiral spring subject to extension by an applied load conforms to Hooke's law, which state that, the stress is proportional to the strain i.e. the load is proportional to the extension it produces. If a graph is drawn, after the initial loading where some force is required to seperate them turns of the spring which are pressed against each other, a straight line is obtained of extension against load. From this portion, the extension (n) in cm per gramme of load can be obtained from the gradient:

$$n = \frac{BC}{AC}$$

If now, a mass M is attached to the spring, and the spring be extended a further distance x, a restoring force of $^{x}/_{ng}$ is called unto play. The spring, and the spring on being released executes vertical oscillations, the equation of motion of the mass being

$$Mx = \frac{-x}{n} g \quad \text{or} \quad \frac{x + gx}{Mn} = 0$$

The motion is thus simple harmonic and the periodic time T is

$$T = 2\pi\sqrt{\frac{Mn}{g}}$$

The above analysis assumes the spring to be weightless. The load M must be increased by an amount in equal to the effective mass of the spring.

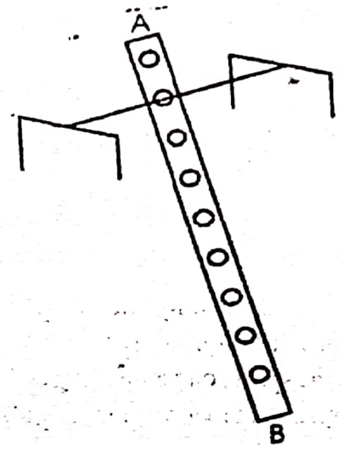
Then $$T = 2\pi\sqrt{\frac{(M+m)n}{g}}$$

If a graph of T^2 against M gives the effective mass (m) of the spring

NOTE:

From considerations of the kinetic energy for the vibrating spring it can be shown that m $= ^1/_3$ mass

EXPERIMENT 6: DETERMINATION OF THE ACCELERATION OF GRAVITY BY MEANS OF A COMPOUND PENDULUM



APPARATUS:

The usual pendulum for this experiment is a metal bar about a metre long drilled with holes at regular intervals and supported by a knife edge through these holes. If this is not available a metre rule can be used with small drilled at 4 - cm intervals. A knitting needle passes through these holes, and supports the rule on the two rigidly held razorblade edges. Stop-watch.

METHOD:

The needle is first inserted through the hole nearest the end A of the bar, and the time for 20 vibration of small amplitude is taken by the stop watch.

This is repeated for each point of suspension along the rule. From the observation made a graph is plotted of the periodic time (T) against the distance (d) of th suspension from the end A of the rule. By drawing horizontal lines on this graph through given values of T, the corresponding means values of the length (L) of the simple equivalent pendulum can be obtained.

An average value of $1/T^2$ can be obtained from these results for use in computing "g".

THEORY:

The diagram represents a rigid body suspended by a horizontal axis through O. On being displaced through a small angle θ from the vertical position a restoring couple, - Mgh sin = - Mghθ

Thus: Mgh = Iθ (where I is the moment of inertia about the axis through O). The motion is thus simple harmonic and the periodic time (T) is

$$T = 2\pi\sqrt{\frac{I}{Mgh}}$$

Writing I_G for the moment of inertia about the c.g then $I = I_G + Mh^2$ (by theorem of parallel axis), $I_G = Mk^2$. Where K is the radius of gyration about the c.g, that is

$$T = 2\pi\sqrt{\frac{K^2+h^2}{gh}}$$

Since the periodic time of a simple pendulum is given by

$$T = 2\pi\sqrt{\frac{l}{g}}$$

;the period of the rigid body is the same as that of simple pendulum of length

$$l = h + \frac{K^2}{h}$$

This is known as the length of the simple equivalent pendulum. The expression for l may be written as a quadratic in h,

thus: $h^2 - hl + k^2 = 0$. This gives two values of h (h_1 and h_2) for which the body has equal time for vibration. From the theory of quadratic equations, $h_1 + h_2 = l$ and $h_1h_2 = k^2$. Thus, if a distance k^2 is measured along the axis from G on the side remote from O, a point O the centre of oscillation) is obtained, and the distance Oo' = length

of the simple aquivalent pendulum. The periodic time about O' is clearly the same as that about O, i.e the centres of suspension and oscillation are interchargeable. A graph of T against d will by symmetrical about a line through the c.g (for which T is infinite) as shown, and a horizontal line draw through a given value of T will cut the graph in four points. The length l of the simple aquivalent pendulum. For this value of T will be the distance from the 1st to the 3rd or the 2nd to the 4th of these point then.

$$g = \frac{4\pi^2}{T^2}$$

NOTES:

1. The roots of the quadratic at the bottom are

$$h = \frac{1}{2} \pm \frac{1}{2}\sqrt{l^2 - 4k^2}$$

The least value of l for real roots in 2k when h $l = h_2 = \frac{l}{2} = k$

and the time is then a minimum $= 2\pi\sqrt{2\frac{k}{g}}$ The radius of gyration can be found directly from the graph or alternatively $k = \frac{EF}{2}$ can be found from the relation $k = \sqrt{h_1h_2} = \sqrt{AHxHC}$

2. Having found k as above, the moment of inertia of the body about the c.g. can be determined, having obtained its mass by weighing, $I_G = Mk^2$

3. The radius of gyration (and hence the moment of inertia) of a rigid body can be obtained very readily by suspending it at a given distance (h) from its c.g on the same axis as a simple pendulum. the length (l) of the simple pendulum is adjust so that both pendulums swing together. Then, $l = \frac{K^2}{h}$ from which k can be found.

RESULTS:

d (cm)	Time for 50 vibration(s)	T(s)

Result from graph

T(s)	T^2 (s^2)	Mean	$1/T^2$

EXPERIMENT 7: COEFICIENT OF STATIC AND DYNAMIC FRICTION FOR WOOD

AIMS: To determine

(1) The coefficient of static friction μs

(2) The Coefficient of dynamic friction μk of wood.

APPARATUS:

Inclined plane, beam balance, a smooth wooden block with hook light inextensible string, scale pan or mass hanger, and slotted weights

PROCEDURE:

Using the beam balance, weigh the wooden block and record its mass M_2 place the block on the flat horizontal plane. Tie the mass hanger or scale pan to the hook of the block of wood using the light inextensible string. Pass the string over a pulley such that the scale pan floats in space while the block remains stationary. Gently add the given weights one at a time of the mass hanger until the block just beings to move. Record the total mass of the slotted weights at the instant the block just beings to move. Repeat this process for five more times and find the average. Record the average mass as M_2. In each case determine the force F required to move the block of wood (Note that the block must be returned to its initial position each time) Plot a graph of force F as a function of normal reaction to the weight of slides and the added load.

(a) Repeat the process above for five various weights placed on the wooden block. Gently tap the block after adding a slotted weight to the scale pan. The block must move with constant velocity after tapping, if not, add more slotted weights to the scale pan. In each case measure the total weight M_1 = (Note that $M_1 = M_1 + M^1$ where M^1 is the mass of the added weights). Evaluate F, in each case and tabulate your results.

(b) Let the wooden block rest on the inclined plane at some angle to the horizontal. Continue to increase the angle a little at a time until you obtain the largest angle at which the block remains at rest on the surface (that is, just about to slide). Measure and record this angle.

QUESTIONS:

1. Find the tangent of this angle
2. Find the component of the weight of the slider along the X - axis
3. Find the component of the weight of the slider along the Y-axis
4. Find the quotient obtained when your result in (2) is divided by the value in (3)
5. Compare your result in (1) above with your result in (4)
6. Determine the uncertainty in your results.

(c) Place a known mass on the slider and repeat the process. Measure the angle of repose.

RESULTS:

Tabulate your result as shown below.

1. *Horizontal plane*

Number of trials	Mass of slide + slotted weight	Mass of hanger + slotted weights	Static Friction μs
1			
2			
3			
4			
5			

2. *Inclined plane*

Number of trials	Mass of slide + slotted weights	Angle of inclination θc	Dynamic Friction μk
1			
2			
3			
4			
5			

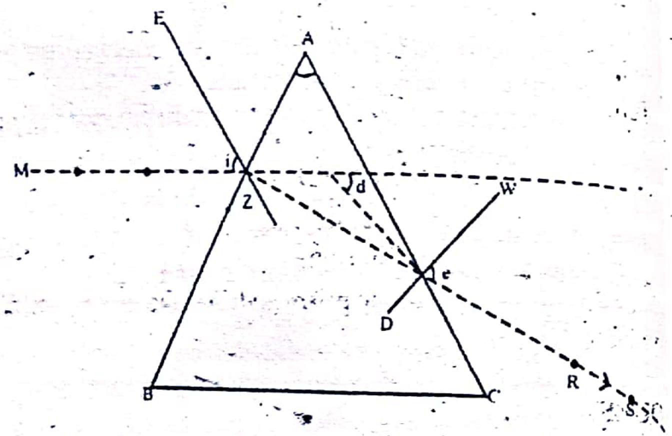
FURTHER QUESTIONS

1. Calculate the coefficieent of static and dynamic friction
2. Has the angle of repose change?
3. Why has it changed or why has it not change?
4. State the precaution you took to obtain accurate result

EXPERIMENT 8; DETERMINATION OF THE REFRACTIVE INDEX OF A PRISM

APPARATUS:

Prism, 4 optical pins, protactor, sheet of paper, drawing board two square pin



PROCEDURE:

Pin the sheet of paper to the drawing board using the two squ pins. Place the glass prism on the sheet of paper and trace outl ouline ABC. Remove the prism and measure the angle of prism. Draw a normal to the side AB at X. Draw the line at MX at an ang of 35° to the normal. Place pins P and Q on the line to represent t incident ray. Replace the glass prism and place pins R and S to be line with the images of P and Q as seen through the prism. Remo the prism, join the position of pins R and S produce it to meet li MX at Z. Draw the normal ΔW. Measure and record the angle emergence and the angle of deviation d. Repeat the experiment fo I = 40, 45, 50, and 60° in each case evaluate d-e.

Tabulate your readings as shwon below.

Angle of incidence °	Angle of deviation d°	Angle of emergence e	d - e

Angle of the prism A= ....

THEORY:

When a ray passes through the prism symmetrically (when angle of deviation is minmum and the angle of incidence is equal to the angle of emergence), then the refractive index of the glass prism with respect to air is

$$\mu = \frac{\sin\left(\frac{A + D}{2}\right)}{\sin\left(^{A}/2\right)}$$

Where A is the angle of the prism and D is the angle of minimum deviation

QUESTIONS:

i. On the same scale and axes, plot the graph of D against I and e against i. From the graph of D against I, read off the angle of minimum deviation and the corresponding angle of incidence. Draw a line from the origin of the graph O to touch the graph of e against i (at T. Find the slope of the line OT)

ii. Using the value of the angle of minimum deviation and the angle of prism A, calculate the refractive index of the prism.

iii. Plot a graph of (d - e) on the vertical axis against I on the horizontal axis starting both scale from the origin. Calculate the slope of the graph and read off it's intercept on the vertical and horizontal axis I, I_2 respectively.

Evaluate $In = \frac{T_1 + T_2}{O}$

State four precautions you took to arrive at an accurate result.

EXPERIMENT 9: DETERMINATION OF THE FOCAL LENGTH OF AN INACCESSIBLE CONVERGING LENS BY NEWTON'S METHOD

APPARATUS:

Converging lens <F~ 15cm> mounted inside a short cardboard tub with open ends illuminated aperture of light box, white screen, optic bench or metre rule, stands for lens and light box, plane mirror.

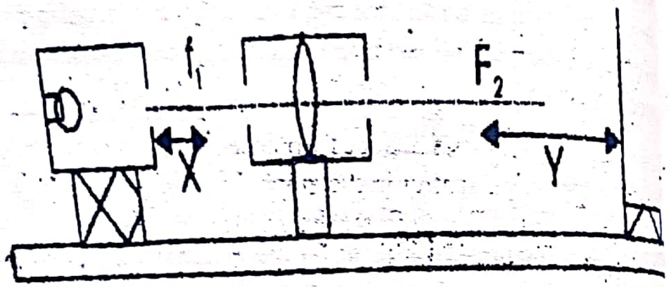


Fig 75

METHOD:

Mount the cardboard tube around the middle of the optical bench, shown in figure 75 and, with the aid of the light box and plane mirr determine the position on the optical bench of the self conjugate poi F_1 and F_2 on either side of the lens.

With the illuminated aperture at a measured distance x from F determine the distance y of the screen from F_2 at which a clear ima of the aparture is focussed on the screen. Repeat the experiment f other values of x.

RESULTS:

Scale reading for F_1(cm)	Scale reading for F_2(cm)	x(cm)	y(cm)

F = ± cm

THEORY:

The points F_1 and F_2 are respectively the 1st and 2nd principal foci of the lens, and their distance from the lens centre is F, the focal length.

If u and v are the object and image distance respectively,

u = x + f and v = y + f.

When these are substituted into the lens formula, we have

$$\frac{1}{y+f} + \frac{1}{x+f} = \frac{1}{f}$$

$$xy = f^2$$

Plot y against 1/x and deduce f from the slope. estimate the standard eror in f from the scatter in the graph. Explain briefly how the self conjugate points F_1 and F_2 are determined.

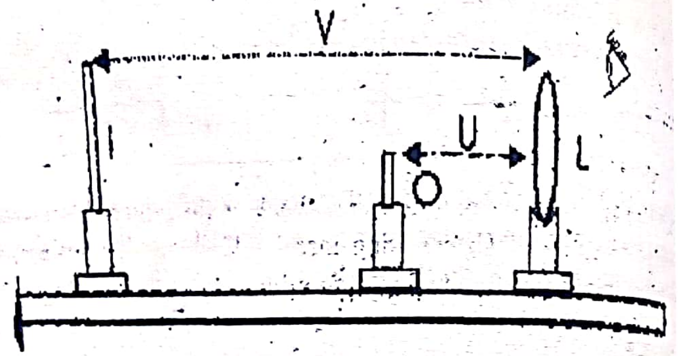
NOTE:

The Experiment can also be done using pins instead of the illuminated object and screen. since the method does not require knowing the location of the lens centre, it is suitable for determining the focal length of a converging thick lens or a converging lens combination.

EXPERIMENT 10: DETERMINATION OF THE FOCAL LENGTH OF A CONVERGING LENS BY LOCATION OF VIRTUAL IMAGES

APPARATUS:

Converging lens <f ~ 15 - 25cm>, optical bench or metre rule, optical pins, holders for lens and pins.



METHOD:

Mount the lens and pins in the holders and align them on the optic bench (or a long the metre rule) with the lens near one end, as shown in fig. 64 move the object pin until a fairly magnified, erect (virtual) image is seen, and adjust the heights of the pins O and I until the composite illustration in figure 54 (a) is seen.

Move the search pin I until there's no parallax between it and the image of O. It is necessary to readjust the heights of the pins to retain the composite picture. measure the object and image distance u and v. Repeat the experiment for other object distances.

RESULTS:

u (cm)	v (cm)	v/u

THEORY:

Using the real-is-positive sign convention, we have

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

that is $\frac{v}{v} + 1 = \frac{v}{f}$

Plot the graph of v/u as ordinate agasinst v and deduce the focal length f from the slope. Estimate the standard error in f from the scatter on the graph.

NOTE:

Use the u - v diagram as a quick check on the reasonableness of each reading taken. The resulting lines should all roughly pass through a small region around x whose coordinates are (f, f) as shown in figure 65.

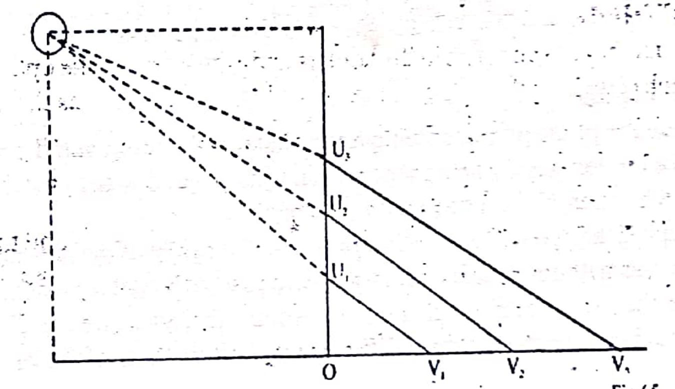
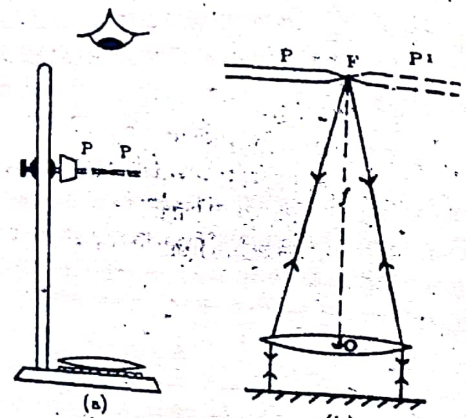


Fig 65

EXPERIMENT 11: DETERMINATION OF THE FOCAL LENGTH OF A CONVERGING LENS BY THE SELF CONJUGATE METHOD

APPARATUS:

Converging lens (f~10-25cm), optical pin pierced through a co[rk], retort stand and clamp for mounting pin horizontally, plane mi[rror] and metre-rule.



(a) (b)

METHOD:

Place the plane mirror face up on the base of the retort stand, a[nd] place the converging lens on the mirror. Clamp the cork-and pin wi[th] pin p horizontal and its tip on the axis of the lens.
Keeping the eye well above the pin, adjust the height of the pin un[til] it moves without parallax with its inverted image P. At this positio[n] both the pin and its image are of the same size. Measure the dis[tances] between the pin tip and the top and bottom faces of the lens.

Repeat the experiment twice and find the mean value of OF, th[e] distance between the pin tip and the optical centre of the lens.

RESULT:

Trial	Distance from pin to lens top (F_1) (cm)	Distance from pin to mirror face (f_2)(cm)	Mean distance (f) (cm)

Therefore, focal length (f) = 1 cm.

THEORY:

Referring to figure 61 (b), a beam of light incident on the lens from the tip f of the pin emerges as a parallel beam which is reflected normally by the mirror to form an image at F. F is the self-conjugate point; is therefore a principal focus of the lens; and its distance from the centre of the lens is the focal length f.
Estimate the standard error in f from the range of values of F.

EXPERIMENT 12: DETERMINATION OF THE FOCAL LENGTH OF A DIVERGING LENS USING (A) A CONCAVE MIRROR, (B) A CONVERGING LENS

APPARATUS:

Diverging lens (f ~10cm), Concave mirror (f~15cm) optical pi[...] optical bench, stands for lens, mirror and pins.

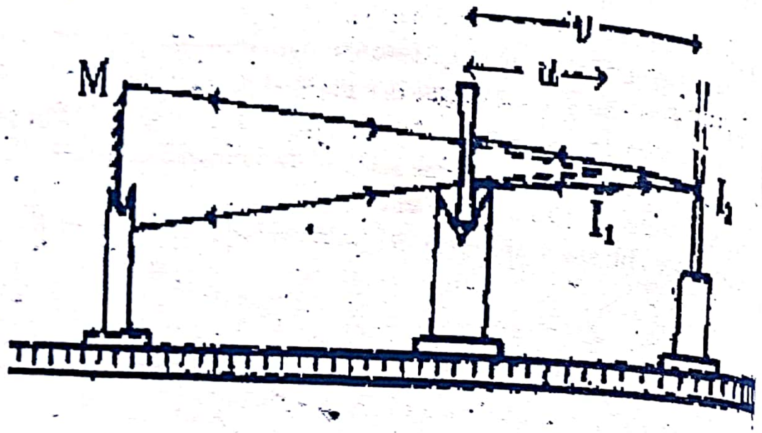


Fig 68

METHOD (A):

Mount the concave mirror M with axis horizontal on the optical bench and use the pin to locate its self-conjugate point I. This is the centre of currature of the mirror. Leaving M unmoved, insert the diverging lens between M and I, at a measured distance u from I, and adjust the pin poistion to locate the new self-conjugate point I_2 to the lens. Repeat the experiment for various distances between the mirror and lens.

RESULTS:

u (cm)	v (cm)	v/u

THEORY:

The concave mirror serves to produce a real image I. Hence, the focal length of the lens is givne by:

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

or $$\frac{v}{u} + 1 = \frac{v}{f}$$

Plot v/u as ordinate against v and deduce f from the slope. Estimate the standard error in f. from the scatter in the graph. What determines the maximum value of u in this experiment.

APPARATUS(B):

Diverging lens, Converging lens (f ~25 cm), two optical pins, optical bench, stands for lenses and pins.

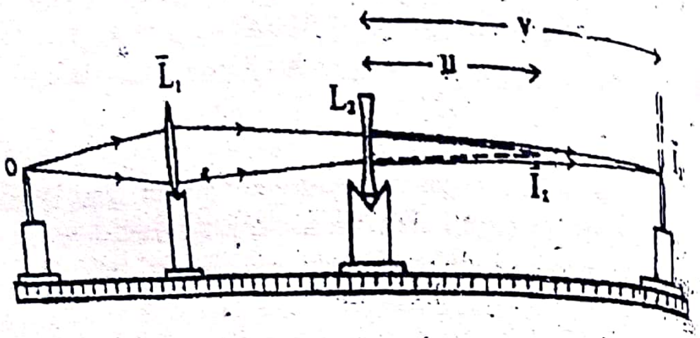


Fig. 69

METHOD (B):

Mount the converging lens with axis horizontal on the optical bench, and use one of the optical pins to locate the real magnified image position I. Of the other pin O used as object.

Leaving L_1 unmoved, interpose the diverging lens L_2 between L_1 and L_2 at a measured distance u from I, and without moving pin O, adjust the position of the search pin to locate the new image I_2 of O. Measure the distance v from I_2 to the diverging lens.

Repeat the measurement for various distances u between I, and the diverging lens.

RESULTS:

u (cm)	v (cm)	v/u

THEORY:

Here the converging lens serves to produce a real image I_1 which serves as a virtual object for the diverging lens. I_1 and I_2 are clearly conjugate points for the diverging lens, and f is given by:

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

or $$\frac{v}{u} + 1 = \frac{v}{f}$$

Plot v/u as ordinate against v and deduce f from the slope. Estimate the standard error in f from the scatter in the graph. Compare the values of f obtained from both experiments.

NOTE:

The experiment can also be done using an illuminted object and screen in place of the object and search pins.

THE SPECTROMETER:

As the name implies, this is essentially an instrument for making measurements on spectra. The spectrometer also provides one of the most accurate means of determining the refractive index of a materials available in the form of a triangular prism. The essential components of a spectrometer are obtained below.

1. The Collimator produces a parallel beam of light from a light source. The collimator consists of a slit of adjustable width at one end of a tube of adjustable length and a converging lens at the other end.
2. A rotatable table on which a light disperser (e.g. a prism or diffraction grating) is placed.
3. The telescope receives the dispersed light and focusses the rays on to cross-wires in the eye piece. The optical axes of the collimator and telescope meet on the axis of rotation of the table, and a scale provided with two verniers enables the angle of rotation of

the telescope to be accurately measured.

ADJUSTIMENT OF THE SEPCTROMETER:

1. Adjust the eyepieces of the telescope until the cross-w seen distinctly.

2. Take the spectrometer outside, direct the telescope at a object and, using the adjustment screw, focus the image of th The telescope is then set to focus parallel light, and there sho be no parallax between the image and the crosss-wire.

3. Take the spectrometer back to the laboratory and po telescope towards the illuminated slit of the collimator, taki not to distrub the telescope setting. Adjust the length of the col tube until the image of the slit is as sharp as possible. The col is then producing parallel light. Narrow down the slit to a fine

4. Level the prism table to be accurately perpendicular to its rotation. This is done by adjusting the screws S_1, S_2 and S_3 images of the slit reflected in turn by two faces of the prism i telescope, are central in the field of view of the telescope.

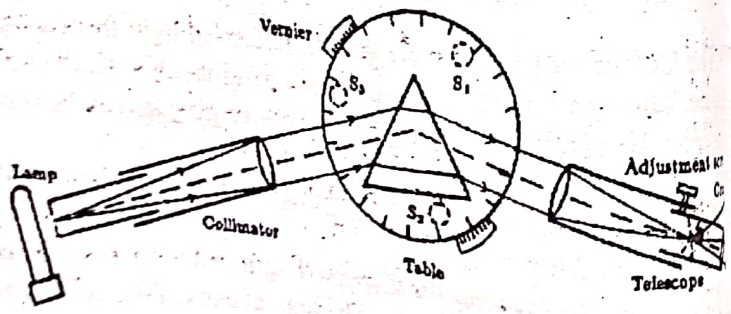


Fig. 70

EXPERIMENT 13: DETERMINATION OF THE FOCAL LENGTH OF A CONVERGING LENS BY THE DISPLACEMENT METHOD

APPARATUS:

Converging lens (f ~ 15cm), illuminated aperture of light box, white screen, optical bench or meter rules stands for lens and illuminated object.

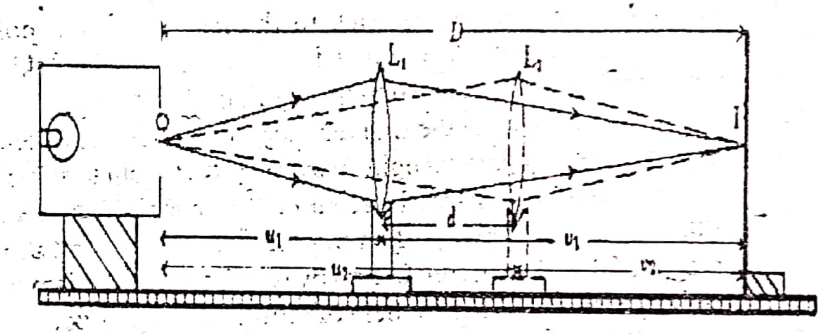


Fig. 76

METHOD:

Find the rough focal length F of the lens by focusing a distant object on a wall. Mount the light box, lens and screen, in that order, on the optical bench with the illuminated aperture and the screen at a measured distance D{> 4f} apart. Adjust the lens to a position L_1 at which a clear, magnified image of the aparture is thrown on the screen and note the postion of the lens holder on the optical bench. Without altering D, move the lens to a new position L_2 at which a clear, diministed image of the aperture is thrown on the screen. Measure the distance d between the two lens positions.

Repeat the experiment with D taking different values.

RESULTS:

D (cm)	Position of L_1, x_1 cm	Position of L_2, x_2	d = $(x_2 - x_1)$ (cm)

f = ± cm

THEORY:

Let u_1 and u_2, v_2 be the object and image distances cor[illegible] the lens positions L_1 and L_2. Since O and I are obviou[illegible] points we have

$U_1 = V_2$ and $U_2 = V_1$

Since $U_1 + V_1 = D$, and $V_1 - V_2 = V_1 - U_1 = d$,

we have $U_1 = \frac{D - d}{2}$ and $V_1 = \frac{D + d}{2}$

Substituting these into the lens formula, we have

$$\frac{2}{D - d} + \frac{2}{D + d} = \frac{1}{f}$$

Or $D^2 - d^2 = 4fD$.

Plot $\{D^2 - d^2\}$ as ordinate against D, and deduce F fro[illegible]

Estimate the standard Error in F from the scatter in the[illegible]

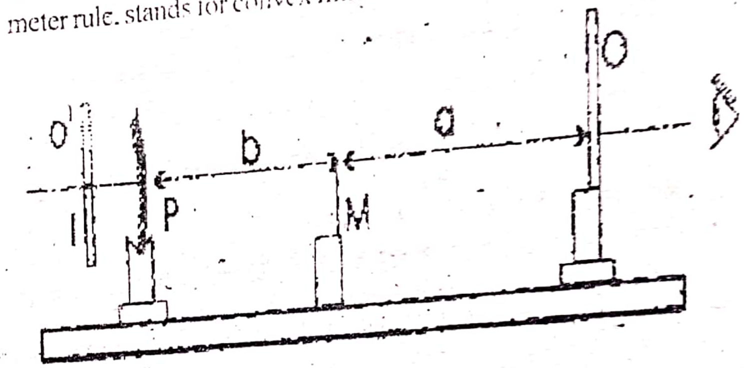
NOTE:

Since the distances D and d can be measured accurately,[illegible] provides an accurate method of determing F.

EXPERIMENT 14: DETERMINATION OF THE FOCAL LENGTH OF A CONVEX MIRROR USING (A) A PLANE MIRROR (B) A CONVERGING LENS.

APPARATUS (A):

Convex mirror, mounted plane mirror, optical pin, optical bench or meter rule, stands for convex mirror and pin.



METHOD (A):

Set up the apparatus shown in figure 59. the plane mirror is placed between the pin and convex mirror is adjusted to cover the lower half of the latter. With the pin O at a measured distance {a + b} from the covex mirror, adjust the position of the plane mirror M until there's no parallax between the image I and the dimisnihed image O of pin O in the convex mirror. Measure the distance b. Repeat the experiment for other values of the distance {a + b}

RESULTS:

a (cm)	b (cm)	u = a + b (cm)	v = {a - b} (cm)	$\frac{v}{u}$

f = ± cm

THEORY:

For a given position of M,

Object distance u for the convex mirror. = a + b,

Image distance v for the convex mirror = MI - PI = a - b

From the mirror formular we have

$$\frac{v}{u} + 1 = \frac{v}{f}$$

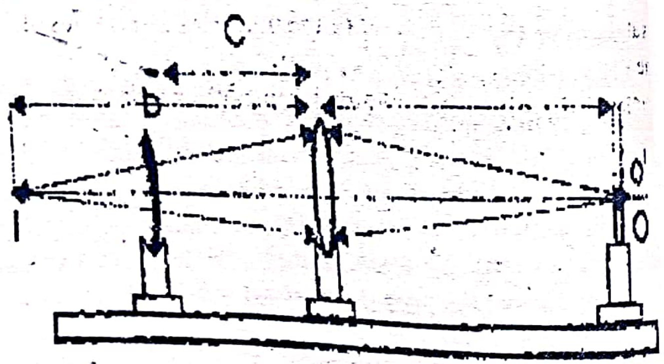
Plot the graph of $\frac{v}{u}$ as ordinate against v and deduce f fro slope. Estimate the standard error in f from the scatter in the

NOTE:

Since the images are vitual, the image distances v are all nega

APPARATUS (B):

Convex mirror, converging lens {f~25cm), 2 optical pins, bench or metre rule, stands for mirror, lens & pins.



METHOD (B):

Mount the object pin O; lens and search pin I in that order on optical bench; and with the object pin at a measured distance a from the lens, locate its real image by the method of no parallax the search pin. Measure the image distance b.

Insert the convex mirror between I and the lens. and adjust its position until the new image O formed coincides with the object pin O. Measure the distance c between the mirror and the lens. Repeat the experiment for various distances between the object and lens.

RESULTS:

a (cm)	b (cm)	r = b - c (cm)

Mean, r = ± cm

Therefore, F = ±cm

THEORY:

Since O is a self-conjugate point for the lens, the light rays between the lens and mirror must be reflected from the mirror normally. Thus, I is at the centre of curvature of the mirror, and the radius of curvature v is equal to b - c.

Compare the values of f obtained from both experiments.