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PRACTICAL PHYSICS

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PRACTICAL PHYSICS

for degree students

Dr. Giasuddin Ahmad

and

Md. Shahabuddin (M.Sc., M.A)

HAFIZ BOOK CENTRE

PRACTICAL PHYSICS
for degree students
(B. Sc. Pass, Honours and Engineering Students)

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FOURTH EDITION
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HAFIZ BOOK CENTRE

PREFACE TO FIRST EDITION

The "Practical Physics for Degree Students" is designed to cover the syllabi of the B.Sc. Pass and Subsidiary and B. Sc. (Engineering) examinations of the different Universities of Pakistan. Our long experience in teaching physics and conducting practical classes has acquainted us with the various difficulties that the students face in performing experiments. In this textbook attempts have been made to guide the students so that they may proceed to record data systematically and then correlate them to get the results. Subject matter of the book has been presented in a simple manner so that the students may independently perform the experiments without the help of the teachers. At the end of each experiment relevent questions and their answers have been provided, thus clarifying the theoretical aspect of the experiment. Tables are provided at the end of each experiment. However, it should be remembered that they are purely suggestive and there is nothing special about any particular form of tabulation. Tables of physical constants and logarithmic and trigonometrical tables have been provided at the end of the book for ready reference.

In writing this book we consulted different books on practical physics specially those by Watson. Worsnop and Flint, Allen and Moore, S Datta, K. G. Majumdar, Roy Choudhury, Ganguli, H. Singh, J Chatterjee and K. Din. Various theoretical books have also been consulted.

We like to thank Professor K. M. Saha, M.Sc. Head of the Department of Physics, E. P. University of Engineering and Techonlogy, Dacca, for his keen interest in the book and his constant encouragement and guidance. We also like to thank our colleagues Mr. T. Hossain. M. Sc. and Mr. Asadullah Khan. M. Sc. for their various helps rendered during the preparation of this book.

We gratefully acknowledge the debt we owe to Mr. Nurul Momen. M. Sc. (Dac), M. A. (Columbia) for many valuable and constructive suggestions.

We also like to thank Mr. Hassan Zoberi of M/S. Zoberi and Pearl for his active co-operation in bringing out this book. Thanks are also due to Mr. Anwar Ali of the Department of Physics who helped us in getting the manuscript typed within a short time.

The book has been hurried through the press and as such some printing mistakes might have crept in inspite of our best efforts. We shall gratefully welcome any suggestion which may help to improve the book.

E. P. University of Engineering and
Technology. Dhaka.
Ist January, 1969

Giasuddin Ahmad
Md. Shahabuddin

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OF
ADVANCED PRACTICAL PHYSICS

CHAPTER 1

INTRODUCTION

1.1 IMPORTANCE OF LABORATORY WORK

A student of physics should realise that the laboratory work, popularly known as practical classes, is no less important than the theoretical lectures. In performing an experiment in the laboratory, one is required to revise thoroughly the ideas and the principles involved in the experiment which were explained by the teachers in the theoretical classes, possibly long ago. Thus practical classes serve as a sort of revision exercises of the theoretical lectures. Moreover, laboratory work makes a student methodical, accurate, diligent and trained to rules of discipline.

The overall aims of the physics practical programme are to help the students learn

a to experiment *i.e.* measure unknown quantities and draw conclusion from them.

b. to write scientific (or technical) reports and papers and

c. to use specialized methods of experimental measurement.

1.2 ERRORS IN MEASUREMENTS

In determining a physical constant in the laboratory, it is necessary to measure certain quantities which are related to the constant in a formula. Measurement of these quantities involves various errors which are enumerated below.

(a) **Personal Errors:** When recording an event, the same person at different times and different persons at the same time record it differently. This is due to the personal qualities of the workers. For example, different time keepers in a sport are found to record different times of start and finish. Inexperienced observers or observers not in a normal state of health make errors of varying magnitude. Such errors may be eliminated by taking mean of several observations.

(b) **Constant or Systematic Errors:** Errors which affect the result of a series of experiments by the same amount is called the *constant error*. Faulty graduation of an instrument, which is used in verifying certain physical laws, introduces a constant error. In determining the value of g by simple pendulum, the length of which is measured by a faulty scale, the value obtained from a series of observations would differ by a constant amount from the true value. Such errors are eliminated by different methods.

(i) In some experiments errors are previously determined and corrections in the readings are made accordingly. Thus, these errors cannot affect the final resul. Examples of these errors are the *zero-error* in measuring instruments such as screw gauge, slide callipers, end-errors in a meter bridge etc.

(ii) In some experiments error is allowed to occur and then eliminated with the help of the data recorded during the experiment. In determining specific heat of solid or liquid by the method of mixture, the loss of heat by radiation is allwed to occur and then this loss is corrected for.

(iii) There are cases in which errors are eliminated by repeating the experiment under different conditions. Thus in an experiment with meter bridge in finding the null point, a tapping error is introduced owing to the fact that the pointer which indicates the position is not exactly situated above the fine edge of the jockey which makes contact with the bridge wire. This is eliminated by obtaining two balance points after interchanging the resistance coils.

(c) **Accidental Error:** There are errors over which the worker has no control. Inspite of all corrections and precautions taken against all possible known causes, some errors due to unknown causes occur which affect the observations. Such errors are called *accidental errors*. Errors in such cases are reduced by taking a number of observations and finding their mean. By applying the theory of probabilities, it can be shown that if the mean of four observations instead of a single observation be taken, the accidental error is reduced to $\frac{1}{\sqrt{4}}$ or $\frac{1}{2}$ of the error that comes in with single observation.

(d) **Errors of Method:** The formula with which the result is calculated may not be exact and hence inaccuracy creeps in the calculated result. Care should be taken to see that the basis of calculation is exact and accurate.

(e) **Parallax Errors:** When a reading is taken along a scale, straight or circular, the line of sight must be at right angles to the surface of the scale. Due to carelessness in this respect an error in reading is inevitable. This error in reading due to looking at wrong direction is called error due to parallax. In order to avoid such errors the scale, straight or circular, is often placed over a mirror. An image of the object is formed in the mirror by reflection and the reading of the object is taken without difficulty.

(f) **Level Errors:** Instruments like a balance, spectrometer, dip circle etc, require levelling before use. These instruments are generally provided with levelling screws. Using a spirit level and by adjusting the screws, levelling is done.

(g) **Back-lash Error:** It occurs when one part of a connected machinery can be moved without moving the other parts, resulting from looseness of fitting or wear. Generally this error develops in instruments possessing *nut and screw* arrangements. With continued use, the screw and the nut wear away due to friction and the space within the nut for the play of the screw increases more and more. The result is that when the screw is turned continuously in one direction, the stud at the end of the screw moves as usual; but when rotated in the opposite direction the stud does not move for a while. The error introduced on reversing the direction of turning is called *back-lash error*. This is avoided by turning the instrument, before taking any reading, always in the same direction.

(h) **Probable Error:** Probable error means the limit within which the true value of the constant probably lies. If x be the arithmetic mean of a set of observations and a the probable error, then the true value is as likely to lie within the range $x \pm a$ as outside it. If the observed values of the same quantity u be $x_1, x_2 \ldots\ldots x_n$, then m, the arithmetic mean of these values, may be taken to be the nearest approach to the correct value of u. Let us now determine the limits within which the errors of u may lie. If d be the arithmetic mean of the numerical values of the deviations of individual observations given by $d_1 = (x_1 - m)$, $d_2 = (x_2 - m)$, ... $d_n = (x_n - m)$, then d will give the mean error and for all practical purposes, $u = m \pm d$.

The probable error may be calculated as follows:

(i) Calculate the arithmetic mean.

(ii) Find the difference between the observed values and the arithmetic mean. It is called the deviation*d*.

(iii) Calculate the average value of the deviation without taking their signs in consideration. Call this value δ the average deviation.

(iv) Divide δ by $\sqrt{n-1}$ where n is the number of observations. $\alpha = \delta / \sqrt{n-1}$ is the average deviation of the mean. The probable error is 0.8 times this value.

Example: Suppose that in determining the resistance of a wire with a meter bridge the following vales are obtained in ohms.

(i) 8.9, (ii) 9.3, (iii) 8.2, (iv) 9.1, (v) 8.8, (vi) 9. The arithmetic mean is 8.9. The deviations are 0,+0.4, -0.7, +0.2, -0.1, and +0.1 respectively, On adding and disregarding their signs, the value is 1.5 and their average value δ is 1.5/6 = 0.25

The probable error is $0.8\ \delta / \sqrt{n-1} = 0.2 / \sqrt{5}$ — 0.1. The final value may, therefore, be written as 8.9 ± 0.1 ohms.

1.3. DEGREE OF ACCURACY IN MEASUREMENT

When several quantities are to be measured in an experiment, it is pertinent to examine the degree of accuracy to which the measurement of the quantities should be pushed. Suppose a physical constant u is to be determined by measuring the three quantities x, y and z whose true values are related to u by the equation,

$$u = x^A y^B z^C \text{ .... (1)}$$

Let the expected small errors in the measurement of the quantities x, y, z be respectively $\delta_x\ \delta_y\ \delta_z$ so that the error in u is δu. It may be shown by simple calculation that the

maximum value of $\frac{\delta u}{u}$ is given by

$$\left(\frac{\delta u}{u}\right)_{max} = a\frac{\delta x}{x} + b\frac{\delta y}{y} + c\frac{\delta z}{z} \text{ .... (2)}$$

In equation (2) a, b, c are numerical values of the powers and are taken as positive.

The quantities $\frac{\delta u}{u}, \frac{\delta x}{x}, \frac{\delta y}{y}, \frac{\delta z}{z}$ are the proportional errors in measurement of the respective quantities. When each is multiplied by 100, the corresponding percentage of error is given. As the errors in x,y and z may not be in the same direction, the errors in u may be less than that given in relation (2). The error in the quantities to be measured is multiplied by the numerical value of the power to which each quantity is raised as shown in the expression for maximum error. It is, therefore, obvious that *the quantity having the highest power should be measured with a higher precision than the rest.*

For example, in determining the rigidity modulus *(n)* of a wire of length l and radius r, we use the formula

$$n = \frac{360\ lgd}{\pi^2 r^4}\left(\frac{m}{\varphi}\right) \text{........ (3)}$$

The power is 4 for r, 2 for π and 1 for all other quantities. The value of π is known. The value of r is to be measured. If r be measured with an error not exceeding 0.01 mm, and if the value obtained for r is 0.50 mm, then the percentage of error is $\frac{1}{50} \times 100 = 2\%$. Its contribution to the maximum error in n will be 4 times this value *i. e.* 8%. This shows that the radius of the wire should be measured with high precision.

1.4 DRAWING OF GRAPHS

The results of experiments often form a series of values of interdependent quantities of which one can be directly controlled by experimental conditions and is called an *independent variable*, and the other which undergoes a consequent change as an effect is called *dependent variable*. The relations of such quantities can be expressed in graph.

(a) **Representation of the variables along the axes.** It is customary that when the variables are to be plotted in a graph, independent variables are plotted as the abscissae horizontally from left to right and the dependent variables as ordinate upwards. The variables plotted along an axis should be written on the side of the axis. For example, in load elongation graph, the elongation always changes with the change of the load. Hence load is the independent variable and the elongation is the dependent variable.

(b) **Marking of origin.** First select the minimum value of the two variables. Take the round numbers smaller than the minimum values as origins for the two variables. The values of the two variables at the origin need not be equal. In certain cases one or both of the co-ordinates of the origin may be required to have zero value of the variables, even though the minimum value of the corresponding variables may be far above zero values.

Example: In determining the pressure co-efficient of a gas, temperature is the independent variable and pressure is the dependent variable.

A sample data is shown below:

Temperature in °C	Pressure in cms. of Hg.
30	75.8
35	76.8
39.5	78.2
42.5	79.1
47.5	80.3
51.5	81.6
60.0	83.5
64.5	84.7
69.0	85.5
72.5	86.7

Here the minimum values of temperature and pressure are 30°C and 75 cms of Hg respectively. As the value of pressure

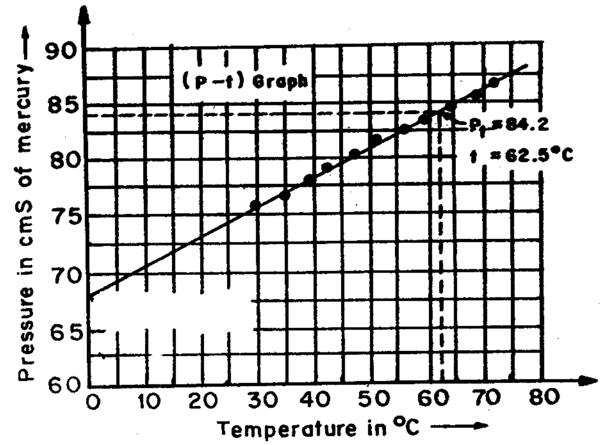


Fig - 1.1

at O°C comes on the formula, the value of the origin for temperature is chosen to be O°C. Therefore, the value of the origin for temperature should be O°C (Fig. 1.1)

(c) **Selection of units along the axes.** First determine the round number greater than the maximum value of the two variables. Then determine the difference between this round number in respect of each variable and its value at the origin. Divide this difference by the number of smallest divisions available along that axis of the graph paper. The quotient thus obtained gives the value (in the unit of the variable quantities) of the smallest division along the axis.

(d) **Marking of data along the axes.** After marking the origin and choosing the unit, put down the values of the quantity corresponding to each large division mark on the squared paper. These values should be integers, tenths or hundredths, but never bad fractions.

(e) **Plotting.** Then plot the experimental data. Mark each point by a small dot and surround it by a small circle or put a cross. Co-ordinates of the point need not be noted unless it is required for quick reference. Much writing makes the graph look clumsy.

(f) **Joining the points to have the graph.** Using a fine pencil, draw the best smooth curve through the average of the points. One or two points far away from the curve may be ignored (Fig. 1.2). They are incorrectly recorded. See that the curve touches the majority of the points and other points are evenly distributed on both sides of the curve. When it is a straight line graph, draw it with the help of a scale taking care to see that it passes through the majority of the points (Fig. 1.1).

(g) **Finding the value from the graph.** If it is required to determine the value of one variable corresponding to the value of the other, proceed as follows: suppose that the value of the ordinate is to be determined corresponding to the

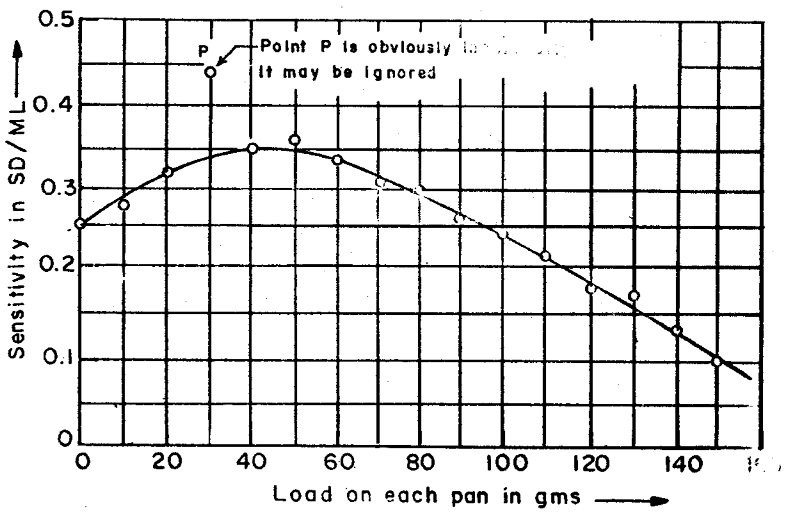


Fig 1.2

giv-en value of the abscissa. From the given point of the abscissa, draw an ordinate to cut the curve at a point. From this point of the curve, draw a horizontal line to cut the y-axis at a point. The value of y-axis at this point gives the value of the ordinate.

Similarly for a given value of the ordinate, the corresponding value of the abscissa can be determined.

(h) **Graphs serve both illustrative and analytical purposes.** A graphical presentation usually conveys much more information than tabulated numerical values though it is not as precise. Graphs help identify regions of interest as well as the presence of systematic errors. They also emphasize readings that do not agree with others or with the theory. Graphs indicate the overall precision of the experiment. A primary function of graphical analysis is to give an *empirical* relation (based on observation rather than theory) between two quantities and to indicate the range of validity of this relation. This has its most practical application in plotting calibration curves for experimental equipment. In a similar way a graphical presentation is the best way of comparing experimental results with predicted theoretical behaviour and the range over which agreement is obtained.

1.5 EXPERIMENTAL GUIDELINES

Planning:

a. Try to anticipate everything that will occur during the course of an experiment.

b. Derive the particular relation for the combination of independent random errors in the final result. Tentatively identify the variables with dominant error contributions.

c. Outline comprehensive survey experiment that will indicate any changes or modifications needed in the equipment or measuring process.

d. Draft a tentative programme for the performance of the experiment with a detailed procedure for critical or complicated measurements. Put special emphasis on the measurement of variables with dominant error contributions.

Preparation:

a. Test and familiarize yourself with each instrument or component of the apparatus separately before assembling it. Calibrate the instruments where necessary.

b. Assemble the equipment, test that it is functioning properly and check all zero settings.

c. Perform a survey experiment running through the complete procedure when possible. Use this rehearsal

(i) *to identify any changes or modifications needed in the original equipment or experimental plan.*

(ii) *to find the regions of interest in the measured variables and suitable instrument scales to investigate these regions.*

(iii) *to distinguish systematic errors and minimize their effects.*

(iv) *to determine the variables with the most significant of the random error contributions. Maximize the sensitivity of these measurements and*

(v) *to identify the variables with insignificant error contributions under optimum experimental conditions. The errors in these variables can be estimated.*

d. Finalize a detailed experimental procedure.

Performance:

a. During the course of an experiment continuously monitor zero settings, environmental conditions, and the data being taken. The procedure should have built in checks to insure that all conditions remain constant during the course of an experiment.

b. To retain control over experimental conditions scientific discipline is necessary. This involves following a systematic sequence of steps, each being a consequence of planned necessity. Avoid the tendency to rush through any sequence: this can be very tempting when the investigation is relatively unimportant.

c. It is essential to control the influence of various independent variables. Always try to isolate each independent variable to see how the result depends on it while everything else is held constant.

d. Whenever possible perform the experiment under equilibrium conditions where the results are consistent when the experiment is worked backwards and forwards.

e. When keeping a *Laboratory Notebook* keep a detailed record of everything that happens as it happens. Try to produce a running account that is accurate, complete and clear.

(i) *Record experimental details and data directly into a permanent record— do not write on scraps of paper.*

(ii) *Record all raw data directly into prepared tables.*

(iii) *Do not erase or overwrite incorrect entries, cross them out with a single line and record the correct entry beside it.*

(iv) *Label all pages, equations, tables, graphs, illustrations, etc.*

(v) *Distinguish important equations, results, comments, etc. from less important details by emphasizing them.*

(vi) *It is advisable to write on only one side of a page during the first run through and to leave space in the text where details, tables, comments, calculations, etc. can be added later at the most relevant points.*

PRESENTATION

a. Always be precise in what you write. A precise statement will leave no doubt as to what you mean. Avoid vague expressions such as *almost, about,* etc.

b. Scientific statements should be concise, so use a few carefully chosen words rather than excessive description. *Say as much as possible in as few words as possible.*

c. Clarity is achieved by using precise, concise statements that are simply worded and presented in the most logical sequence. Cross-referencing, tabulation of results, illustrations, graphs, emphasis, repetition and summarization are all aids to clarity.

d. For the purpose of laboratory work two note-books— one *fair* and another *rough,* should be used. While performing the experiment in the laboratory, all observations, all difficulties experienced, calculation and rough works should be recorded in the rough note-book. Report on experiments should be prepared and written in the fair note-book in the following standard format:

i. *Write the name of the experiment in bold characters at the top.*

ii. *Write the date of the experiment at the top left corner.*

iii. *Theory: Here give the brief outline of the essential physical principles and theoretical concepts necessary for interpreting the experimental results. Only the mathematical relations used in the calculations are necessary: their derivation if given elsewhere, should be referred to but not given in detail. Explain clearly the symbols used in the working formula.*

iv. *Apparatus: Give a list of apparatus required for the experiment.*

u *Description of the apparatus: Give a short description of the apparatus. Give a neat diagram on the blank page to the left. Pictures that are purely illustrative should be simple, schematic, and not necessarily to scale ("not to scale" should be indicated)*

vi. *Procedure: Record here what you did in performing the experiment.*

vii. *Results: Record all the data in the order in which you took them. Whenever necessary, they should be recorded in a tabular form. Graphs should be drawn if required. The graphs should have specific title, reference label, and both name and units on each axis. Unless there is a reason not to, the graph scale should be choosen so that the plotted readings are spread evenly over the range. Calculations should be shown on the blank page to the left. Final result of measurement should be written at the end in proper units.*

viii. *Discussion: A short discussion on difficulties experienced during the experiment, precautions, sources of error, and accuracy of observation should be given.*

1.6 A FEW GENERAL INSTRUCTIONS

a. In order to derive full benefit from the laboratory work, it is essentiall that the student must know his work for a particular day beforehand and must carefully prepare the matter at home.

b. Coming to the laboratory and getting the apparatus for work, each part of which must be studied and understood. Hence preparation at home will make one grasp the idea easily.

c. The observations must be recorded as soon as they are taken without the least delay. The reading may be forgotten in a short time.

d. Every arithmetical figure used in recording an observation must be written very distinctly so that no doubt may arise as to its identity at the time of calculation.

e. The calculations made to arrive at the final result must be shown. This may be done on the left page of the laboratory note-book.

CHAPTER II

GENERAL PROPERTIES OF MATTER SOME LABORATORY INSTRUMENTS

2.1. THE SLIDE CALLIPERS

Slide callipers is used for the measurement of the length of a rod, the external and internal diameters of a cylinder, the thickness of a lens, etc.

A slide callipers consists of a nickel plated steel scale M usually graduated in centimetres and millimetres on one edge and in inches and its subdivision on the other edge (Fig. 2.1).

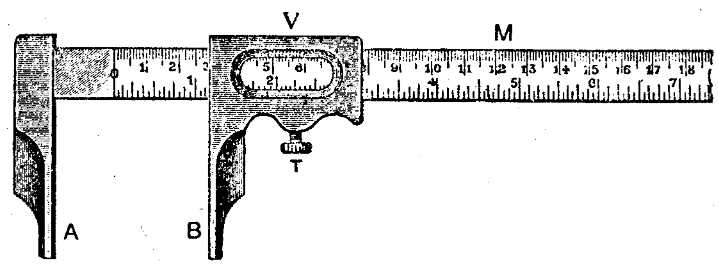


Fig. 2.1

This is the principal scale. A jaw A is fixed at right angles at one end of the scale. The other jaw B can slide over the scale and can be fixed at any position by means of a screw T. This movable jaw carries with it two vernier scales V, one on each side, corresponding to the two main scales. The inner edges of the jaws are so machined that when they touch each other there is no gap between them. Under this condition, the zero of the vernier should coincide with the zero of the main scale. With such a correct instrument, when the jaws are separated, the distance between the zero of the vernier scale and the zero of the main scale is equal to the distance between their edges. The body, of which the length is to be measured, is placed between the two jaws so as to exactly fit in. The readings of the main and vernier scales gives the length of the object.

Instrumental Error: When the vernier zero does not coincide with the main scale zero, there is an *instrumental error* or **zero error.** In such a case, the actual reading of the scale does not give the true length of the body. There may be two types of zero errors:

(a) The zero of the vernier may be in advance of the zero line of the main scale by an amount x mm. This means that in place of zero reading the instrument is giving a reading $+x$ mm. On placing the body between the jaws if the scale reading be y mm, then the actual length of the body is $(y - x)$ mm. In this case the instrumental error is + ve and must always be subtracted.

(b) When vernier zero is behind that of the main scale by an amount x mm, the instrumental error is - ve and must be added to the actual reading to get true length of the body.

Inside and Outside Vernier with Depth Gauge. Some instruments are provided with arrangement to measure the internal diameter and the depth of a cylinder (Fig. 2.2).

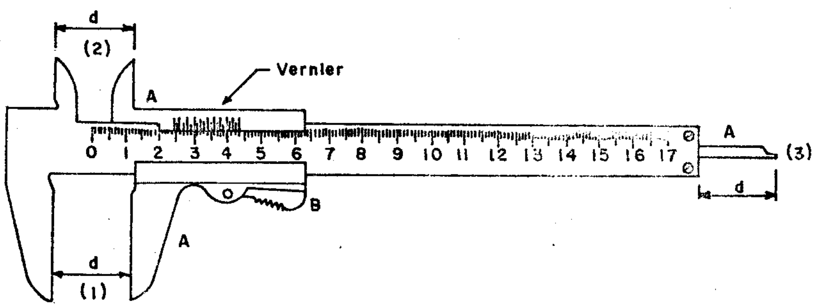


Fig. 2.2. Vernier callipers. The parts marked A form a rigid unit, which is free to move relative to the rest of the instrument when the spring-loaded button B is pressed. The three distances marked *d* are equal and are read off from the vernier scale. (1) gives the diameter of a rod, (2) the diameter of a hole and (3) the depth of a blind hole.

Such an instrument is provided with two lower and two upper jaws. The scales are so graduated that when the vernier zeroes coincide with the main scal zeroes, the edges

of the lower and upper jaws are in contact. Through a straight groove cut along the entire length of the back side of the bar, a uniform steel rod can slide. The other end of the rod is rigidly fixed to the vernier attachment and the length of the rod is such that when vernier reading is zero, the end of the rod coincides with the end of the scale bar.

To measure the external diameter of a cylinder, rod or ring, the lower jaws are used and the procedure is the same as that of the ordinary callipers.

To measure the internal diameter of a cylinder, pipe or ring the upper jaws are inserted inside the cylinders, etc., and then the movable jaw is moved out till the edges touch the inner walls of the body and the usual readings are taken.

To measure the depth of a hollow body, the instrument is put in a vertical position and allowed to rest at the end of the scale on the rim of the body. The movable jaw is slided downward till the end of the rod touches the inside bottom of the body. Then the usual reading is taken which gives the depth of the body.

The instrumental error, if any, must be taken into consideration in all the measurements.

Vernier constant.

Vernier constant is a measure of the difference in length of a scale division and a vernier division in the unit of the scale division.

Let the value of one small division of the main scale = 1 mm and let 10 vernier division be equal to 9 scale division.

10 vernier division = 9 scale division

1 vernier division = $\frac{9}{10}$ scale division.

vernier constant (v.c) = 1 s. d. - 1 v. d.

$= 1 \text{ s.d} - \frac{9}{10} \text{ s.d.} = \frac{1}{10} \text{ s.d.} = \frac{1}{10} \times 1 \text{ mm}$

= 0.1mm = 0.01 cm.

EXPT. 1. TO MEASURE THE LENGTH OF A ROD WITH A VERNIER CALLIPERS.

Theory : If s be the length of the smallest division of the main scale and v that of a vernier division and if n-1 division of the scale be equal *to* n division of the vernier, then

$(n-1)s = nv.$

or $v = \frac{n-1}{n} . s$ .... (1)

Hence $s - v = \frac{n-1}{n} s = \frac{1}{n} . s$ .... (2)

The quantity $(s - v)$ is called the *vernier constant* which is a measure of the difference in length of a scale division and a vernier division in the unit of the scale division. So if L be the reading upto the division of the scale just before the zero mark of the vernier and if x be the number of the vernier division, which coincides with a division on the scale, then the length of the rod which is put between the jaws of the callipers is equal to

$L + x.\frac{1}{n} s.$

While measuring the length of the rod zero error must be considered.

Apparatus : A slide callipers and a rod.

Description of the Slide Callipers : See the description of Fig. 1.

Procedure : (i) Determine the value of the smallest division of the main scale (both in centimetre scale and inch scale) with reference to a measuring scale.

(ii) Slide the vernier scale over the main scale so that the zero line of the vernier scale coincides with a main scale division. Find out the main scale division with which the last vernier division coincides. Count the total number of divisions in both vernier and main scale between these two points of coincidence. Record this. To be sure, these numbers may be rechecked by moving the vernier to some other position. Then calculate the vernier constant.

(iii) Place the two jaws of the callipers in contact. If the vernier zero coincides with the main scale zero there is no instrumental error. If they do not coincide there is an instrumental error. Determine the instrumental error, positive or negative, as described previously.

(iv) Draw out the movalbe jaw and place the rod between the jaws. Make the two jaws touch the ends of the rod, taking care to see that they are not pressed too hard or two

loose. Take the main scale reading just short of the vernier zero line and count vernier division between the vernier zero line and the line which coincides with any of the main scale division. The product of this vernier reading and the vernier constant gives the length of the fractional part. The sum of the main scale reading and the fractional part (taking account of the zero error), gives the length of the rod. Take at least five readings and arrange in a tabular form.

Results :

(tA) Vernier Constant.

(a) **Centimetre Scale.** The value of one small division of the main scale = 1 mm.

$10\ v.\ d = 9\ s.d$ (say)

$1\ v.\ d = \frac{9}{10}\ s.d$

Vernier constant (**$v.c.$**) $= 1 s.d - 1 v.d = 1\ s.d. - \frac{9}{10}\ s.d.$

$= \frac{1}{10}\ s.d. = 0.1$ mm. = 0.01 cm.

(b) **Inch Scale.** Value of one small division of the main scale $= \frac{1}{20}$ inch (say).

$10\ v.d. = 9\ s.d.$

$1\ v.d. = \frac{9}{10}\ s.d.$

v.c. $= 1 s.d. - 1 v.d. = 1 s.d. - \frac{9}{10}\ s.d. = \frac{1}{10}\ s.d. = \frac{1}{10} \times \frac{1}{20}$ inch = 0.005 inch.

(B) To determine the Instrumental Error.

(a) **Positive Error.** When the jaws are in contact, the vernier zero is in advance of the zero line of the main scale and suppose that the fourth vernier division coincides with some line of the main scale. Then the error is 4 x vernier constant = 4x 0.1*mm*= 0.4 *mm*. or 4 x 0.005 inch = 0.02 inch.

This instrumental error must be *subtracted* from the apparent length of the body.

(b) **Negative Error.** When the jaws are in contact, the vernier zero is behind that of the main scale zero. Suppose that the 4th line *i.e.* the 6th line of the vernier counted from the 10th vernier division coincides with some division of the main scale. Then the error is 6 x vernier constant = 6 x0.1 *mm.*= 0.6 *mm.*

This instrumental error must be added to the apparent length of the body.

(C) Length of the Rod.

Scale	No. of obs.	Main scale (a) cm.	Vernier scale (b)	V.C cm.	Excess by vernier b x V.C = d cm.	Total length = (a+d) cm.	Mean length = l cm.	Instru-mental *error* (±e)	Corre-cted length L= (l±e) cm.
Centi metre	1								
	2								
	3								
	4								
	5								
Inch	1								
	2								
	3								
	4								
	5								

Note. *If the radius and cross-section of a rod is to be measured, the diameter of the rod is to be determined at two mutualty perpendicular direction of each of three different positions of the body. Radius r=Diameter/2, Cross-Section=* πr^2 *sq. cm.*

Discussion :

(i) The jaws must not be pressed too hard or too loose.

2.2 THE SCREW GAUGE

The screw gauge is very suitable for the measurement of small length such as the diameter of a wire. It consists of a U- shaped steel frame having two parallel arms at the ends (Fig. 2.3).

One arm carries a solid stud A with a carefully machined terminal. The other arm C acts as a nut in which a screw is

worked by a drum D. The drum has a bevelled end with a circular scale engraved on it. This circular scale contains 50 or 100 divisions. The drum D when rotated, covers or uncovers the scale. For every turn of the drum, it moves through a fixed distance called the *pitch* of the screw. The end face B of the screw is parallel to the face of the stud A. At the end of the drum there is a friction clutch E. When the studs A and B touch each other, the clutch would no longer rotate the drum but would slip over it.

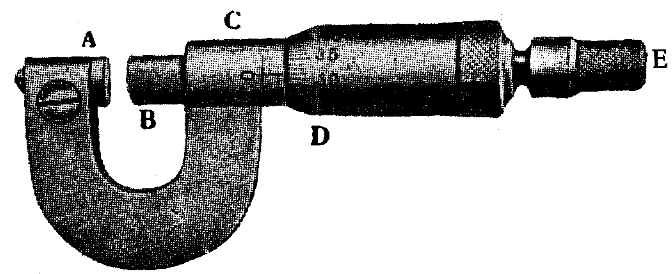


Fig. 2.3

Pitch of the Screw Gauge. When the screw works in the nut the linear distance through which the screw moves is proportional to the amount of rotation given to it. The edge of the bevelled head of the drum is brought on any graduation of the linear scale and the circular scale reading is marked against the reference of the linear scale. Circular scale is rotated until the same circular scale mark comes against the linear scale. The circular scale has been rotated through one complete turn and the amount of linear movement of the collar on the linear scale is the *pitch* of the screw. If p mm be the pitch of the screw and if there are n circular divisions on the micrometer head, then $\frac{p}{n}$ is called the **least count** of screw gauge.

Let the distance along the linear scale travelled by the circular scale when it is turned through one full rotation be 1mm = 0.1 cm (say). This is the pitch of the screw. If the number of divisions in the circular scale = 100 (say) then

$$\text{Least count} = \frac{\text{Pitch}}{\text{Number of divisions in the circular scale}}$$

$$= \frac{0.1}{100} \text{ cm} = 0.001 \text{ cm}.$$

Instrumental Error. It is sometimes found that circular scale zero and the linear scale zero do not coincide when the studs are in contact. The circular scale zero may be in advance or behind the linear scale zero by a certain number of division n of the circular scale. If the least count be c, then the instrumental error is either $+ nc$ or $- nc$ according as the circular scale leads or *l* ags as in vernier scale. When the position of the circular scale zero is in advance of the main scale zero, the error is to be subtracted and in the other case it is to be added to the apparent reading.

Back-lash Error Due to the continued use of the instrument the screw and the nut wear away and the space within the nut gradually increases. In such a case when the screw is turned in one direction, the stud moves as usual, but when it is rotated in the opposite direction the stud does not move for a while. The error that is thus introduced on reversing the direction of turning is called the **back-lash error.** This error can be avoided by turning the screw in the same direction before taking any reading.

EXPT 2. TO MEASURE THE DIAMETER OF A PIECE OF WIRE WITH A SCREW GAUGE AND TO FIND ITS AVERAGE CROSS-SECTION.

Theory : The least count of the screw gauge is the pitch divided by the number of divisions in the circular scale. The diameter of the wire just fitting between the studs is equal to the reading in the linear scale plus the value of the circular scale reading.

Apparatus : A screw gauge and the wire.

Description of the Apparatus : See the description of fig. 2.3.

Procedure : (i) In reference to a metre scale find the value of the smallest division of the linear scale, and read the number of divisions in the circular scale. By turning the screw, bring the bevelled end of the drum carrying the circular scale on any graduation of the linear scale and give

the scrwe a complete turn. The distance through which the edge moves is the pitch of the screw. Calculate the least count by dividing the pitch by the number of divisions in the circular scale.

(ii) Find out the instrumental error by turning the screw head until the studs are in contact and taking the reading of the circular scale against the reference line of the linear scale. If the zero of circular scale coincides with the zero of the linear scale there is no zero error. The number of divisions in advance or behind the zero of the linear scale multiplied by the least count gives the *zero error.* In the former case the error is *positive* and to be *subtracted* from the observed reading and in the latter case the error is *negative* and to be *added* to the observed reading.

(iii) Place the wire breadth wise in the gap between the studs. By slowly turning the friction clutch in one direction make the studs just touch the specimen. Note the reading of the last visible division of the linear scale and that of the circular scale which is opposite the baseline. At each place of the wire take two perpendicular readings. Take readings at several places of the wire.

(iv) Calculate the mean value of the readings, add or subtract the instrumental error.

Results :

(A) Least Count.

Value of the smallest division of the linear scale = 1 *mm*= *0.1 cm* (say)

Pitch of the screw = 1 *mm* = 0.1 cm (say)

No. of divisions in the circular scale = 100 (say)

Least count of the instrument

$$= \frac{\text{Pitch}}{\text{No. of divisions in the circular scale}}$$

$$= \frac{0.1}{100} \, cm = 0.001 \; cm.$$

(B) Instrumental Error.

Table 1

Position of the collar	No. of readings	Main scale	Circular scale	Value of circular scale	+ve or - ve error	Mean reading	Instrumental error
In advance of behind linear zero	1	0			+ve/ - ve		
	2						
	3						
	4						
	5						

(C) DataforDiameter.

Table 2

No. of readings	Linear scale reading cm	Circular scale divisions cm	Least count	Value of circular scale divisions cm	Total readings cm	Mean cm	Instru-mental error cm	Corrected diameter cm
1 (a)								
(b)								
2 (a)								
(b)								
......								
......								

[(a) and (b) are mutually perpendicular readings]

Radius, $r = \dfrac{\text{Diameter}}{2}$

Area of cross-section = πr^2 = ... sq. cm

Discussions : (i) Back-lash error is to be avoided by turning the screw in one direction.

(ii) Care should be taken to see that the studs just touch the wire. Tightening will injure the threads.

(iii) Mutually perpendicular readings should be taken at each position of the wire to avoid error due to the wire not being uniformly round.

2.3 THE SPHEROMETER

A spherometer is used for the measurement of the thickness of a glass plate or the radius of curvature of a spherical surface. It works on the same principle as that of a screw gauge. It consists of a frame-work with three equi-distant pointed steel legs A, B and C (Fig. 2.4). At the center of the frame there is a nut in which a fine screw with pointed end P works and forms an adjustable centre leg. The screw supports a round graduated disc D at its upper end. A milled head M is rigidly fixed with the graduated disc. A small scale S, ususlly graduated in millimeter, is fixed to one of the outer legs A at right angles to the graduated disc. The axis of the screw is perpendicular to the plane defined by the tips of the three outer legs. In an accurate instrument the zero line of the main scale and zero of the circular scale should coincide when all the four legs just touch a plane surface. But due to long use, the edge of the disc is below or in advance of the main scale zero when the four legs stand on the same plane, involving a positive or negative instrumental error, depending upon the direction in which a subsequent measurement is to be made.

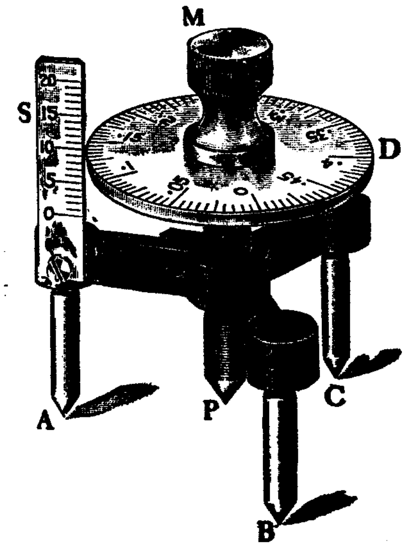


Fig. 2.4

The least count of the spherometer is equal to the pitch of the central leg divided by the total number of divisions in the circular scale. (See Art. 2.2)

EXPT 3. A. TO DETERMINE THE THICKNESS OF A GLASS PLATE WITH A SPHEROMETER.

Theory : The thickness of the plate is equal to the difference in readings of the spherometer when its central leg first touches the plane sheet on which the outer legs rest and then touches the upper surface of the plate.

The least count of the spherometer is equal to the pitch of the central leg divided by the total number of divisions in the circular scale.

Apparatus : A spherometer, a piece of plane glass (base plate) and a thin glass plate (test plate).

Description of the spherometer : See description.

Procedure : (i) Determine the value of the smallest division of the vertical scale. Rotate the screw by its milled head for a complete turn and observe how far the disc advances or recedes with respect to the vertical scale. This distance is the pitch of the instrument. Divide the pitch by the number of divisions in the circular scale. This gives the least count of the instrument.

(ii) Place the spherometer upon a plane glass piece (base plate) and slowly turn the screw so that the tip of the central leg just touches the surface of the glass. When this is the case, a slight movement of the screw in the same direction makes the spherometer legs develop a tendency to slip over the plate.

(iii) Take the reading of the main scale nearest to the edge of the disc. Take also the reading of the circular head against the linear scale. Tabulate the results. Take five such readings and take the mean value.

(iv) Now raise the central screw and put the glass plate of which the thickness is to be measured between the base plate and the central leg.

(v) Turn the screw head again till it just touches the plate. Take the reading of the main and circular scales.

(vi) By moving up the central screw, slightly shift the position of the glass plate and take reading again for this position of the plate. Thus go on taking reading five times. Take the mean value.

(vii) The difference of the two mean values gives the thickness of the glass plate.

(If the spherometer is old and if the plane of the disc slightly oscillates as it rotates, it is proper to count only the total number of circular scale divisions passed through from the initial to the final stage, see alternate method).

Results :

(A) Calculation of Least Count.

The main scale is graduated in millimetres (suppose).

Pitch of the micrometer screw= 0.5 mm = 0.05 cm

No. of divisions in the circular scale = 100

Least count of the instrument = $\frac{0.05}{100}$ cms = 0.0005 cms

(B) Data for Thickness.

Readings on	No. of obs.	Linear scale l cms	Circular scale n	Least count L cms	Excess by circular scale (nxL) cms	Total reading l+nxL cms	Mean cms	Thickness cms
Base plate	1							
	2							
	3							
	4							
	5							
Glass plate	1							
	2							
	3							
	4							
	5							

B. Alternate method of measurement of thickness.

Form continued use, the parts of the spherometer wear out and thrown out of adjustment. For such an old instrument, the following method is convenient.

(i) Find the pitch and least count of the spherometer as usual.

(ii) Now place the spherometer on the base plate and raise the central leg sufficiently.

(iii) Place the test plate under the central leg and with the help of the milled head screw, bring it down until it just touches the test plate. Note the division of the circular scale against the linear scale.

(iv) Carefully take away the test plate without disturbing the relative position of the spherometer and the base plate. Screw down the central leg slowly and count the number of rotations of the circular head, till the central leg touches the base plate.

The total count is to be done by two instalments—by the number of complete revolutions of the disc and the difference of initial and final disc readings.

(v) Repeat the observation at least five times and tabulate the results.

Reaults :

(C) Calculation of Least Count (See 3A)

No.of obs.	No.of complete revolutions	Revolutions equivalent to cm	Disc reading			Least count cm	LC x disc reading	Thickness t	Mean
			Initial	Final	Difference				
1									
2									
3									
4									
5									

Note : *If the disc rotates in the clock-wise direction in the descending order of the division marks on it, and if after* n *complete rotations, 70 be the initial reading and 90 be the final reading, then the difference in disc reading is* (100+70) - 90 = 80.

C. To measure the radius of curvature of a spherical surface with a spherometer.

Theory : When all the four legs of a spherometer are made to touch the spherical surface, the radius of curvature of the spherical surface is given by

$$R=\frac{a^2}{6h}+\frac{h}{2}$$

where a is the mean distance between the outer legs of the spherometer and h the height of the central leg above or below the plane through the tips of the outer legs.

In the above formula, a is, in fact, the length of the side of the equilateral triangle formed by the three legs of the spherometer (Fig. 2.5). Let x denote OB, the radius of the circumscribing circle. Then, if OD be at right angles to BC,

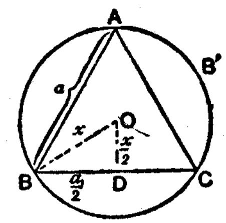


Fig. 2.5a

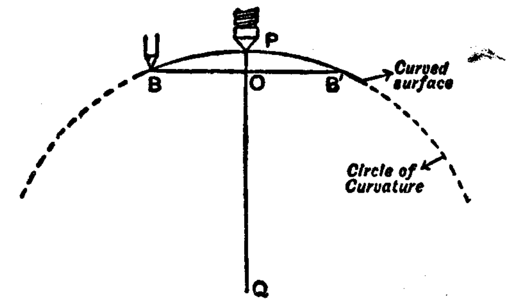


Fig. 2.5b

$BD=\frac{a}{2}$ and $OD=\frac{x}{2}$

The angle OBD is 30°. Therefore, $\frac{a}{2}=x\cos 30°$.

i.e., $\frac{a}{2}=x.\frac{\sqrt{3}}{2}$ or $a^2=3x^2$ .... (i)

To find the radius of curvature R, we consider a section of the sphere by a plane through its centre and through the line BO in Fig. 2.5a. Thus we obtain Fig. 2.5b. in which only a portion of the circle of curvature is shown. If the diameter PQ meets this circle again in S (not shown in Fig. 2.5b), then

QS = QP = R and let us take OB=OB′ = x and OP=h. We know that OS.OP=OB.OB′

Hence $(2R - h)\,h = x^2$ or $2Rh = x^2 + h^2$

or $R=\frac{x^2}{2h}+\frac{h}{2}$

(d) Raise the beam fully when equilibrium is nearly obtained and the pointer oscillates. Lower the beam every time the small weights are added for final adjustments.

(e) Having weighed a body, count the weights while they are on the scale pan and enter them in the note-book. Then remove them one at a time to their places in the box.

(f) While determining the balance point, close the door of the balance case to prevent disturbance due to air draught.

(g) Always close the door of the balance case and the weight box after the experiment is finished.

2.5 TRAVELLING MICROSCOPE (ALSO KNOWN AS VERNIER MICROSCOPE).

Travelling microscope, also known as **Vernier microscope,** is used in making large number of accurate measurements of lengths in the laboratory. There are various **forms** of the instrument, one of which is shown in Fig. 2.7.

It consists of a microscope which is mounted on a vertical pillar so that it can slide up and down along the scale S_1 by a rack and pinion arrangement. The vernier scale V_1 slides with the microscope and serves to determine its position. The vertical scale with the microscope can move about within a groove made on a horizontal base provided with levelling screws and can be fixed at any position by tightening a screw. On the base just at the border of the groove there is a similar scale S_2. The movable base of the microscope is provided with another vernier V_2. The bases of some instruments are provided with spirit level. The position of the microscope is changed by rack and pinion arrangement. For finer adjustment use is made of the scrwes T_1 and T_2. The distance through which the microscope moves vertically or horizontally can be read from the scales S_1 and S_2 with the help of the verniers V_1 and V_2 moving with the microscope. The microscope can be fitted about a horizontal axis, so that its axis can be either vertical or horizontal or can make any angle with them. This allows the microscope being focussed on the object which is being measured. Cross-wires are fitted in the eye-piece which can

slide in and out so that these cross-wires can be focussed. The microscope can be focussed on the object with the focussing screw, providing a rack and pinion motion parallel to the axis of the microscope. In measuring the length of an

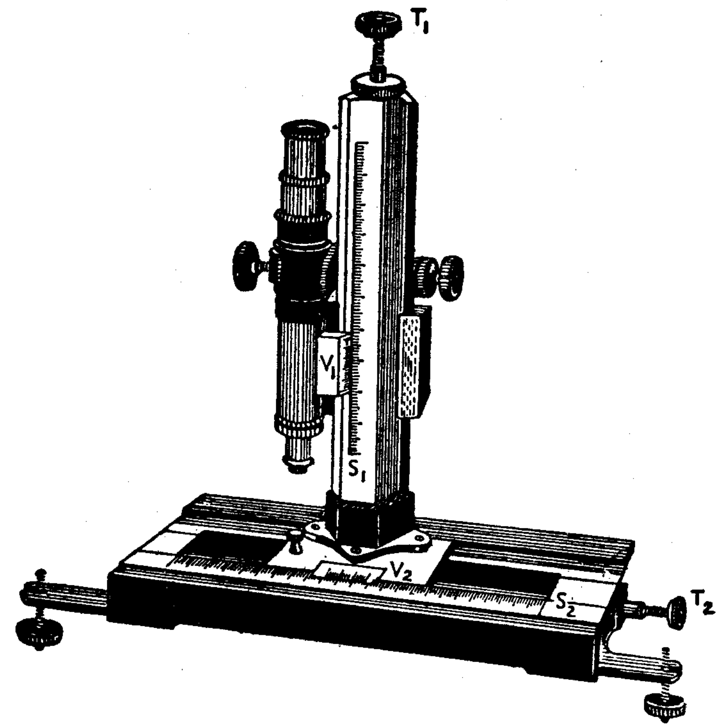


Fig. 2.7

object, the object is placed on the base of the instrument and parallel to the scale S_2. The cross-wires in the eye-piece are focused and the microscope is moved so that the objective is just vertically over one end of the object. By the vertical movement of the microscope, it is focussed on the end of the object and readings on the scale S_2 and vernier V_2 are taken. The microscope is then moved to the other end of the object on which it is focussed and again readings on S_2 and V_2 are taken. The difference of these two readings gives the length of the object.

In measuring the distance between two points, the microscope is focussed first on one of them. It is then shifted till it is focussed on the other, the line of joining the two points being adjusted parallel to the direction of motion of the microscope. The difference between the readings for the microscope positions in the two cases gives the distance required.

The instrument can be used to measure both horizontal and vertical distances.

For measuring small lengths, microscopes are provided with finely graduated scales called micrometer scale placed at the common focus of the eye-piece and the objective.

To measure the value of one division of the micrometer scale, place a finely graduated scale on the base of the microscope. Focus it and count the number N divisions of the micrometer scale covered by n divisions of this scale.

Then one division of the micrometer scale = $\frac{n}{N}$ division of the graduated scale.

To measure the length of a small object, focus the microscope upon the object and note the number (d) of the division of the scale covered by the image. Then the length of the object is d multiplied by the length corresponding to one division of the micrometer scale.

2.6. CATHETOMETER

A cathetometer is an instrument for accurately determining vertical length about a metre or so. It consists of a vertical column AB fixed to a heavy metal stand in such a way that it can be made to rotate about a vertical axis, the rotation being limited by two adjustable stops (Fig. 2.8)

The column and the metal stand are provided with levelling screws at the base. Along the column a telescope T can be moved, the axis of which is horizontal. The column has a scale engraved along one face. The telescope is supported by a carriage C which can slide along the column, a second carriage D sliding along the same column being connected with the carriages which support the telescope by a micrometer screw E. This carriage D can be clamped to

the column and then by turning the screw E the telescope can be moved up or down through a small distance and so its position adjusted. The position of the carriage C can be read off on the scale on the column by means of a vernier V. The telescope is provided with a spirit level L on the top which serves to show when the axis of the telescope is horizontal. The instrument is levelled with the help of the levelling screws at the base and the screw below the telescope in the telescope carriage. The telescope is provided with cross-wires. In measuring the distance between two points, the horizontal wire is usually made to coincide with the images of the points one after another and its position noted from the vernier. The difference between the two posi-tions gives the desired distance.

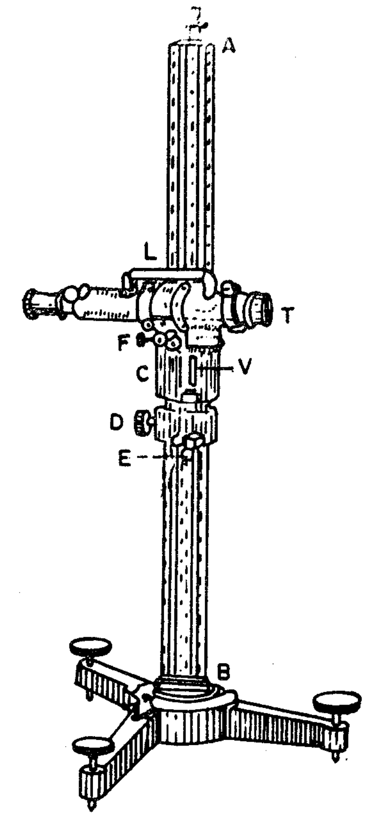


Fig.2.8

Using the Cathetometer.

(i) Before using the cathetometer for measuring distances it is necessary to level the cathetometer so that its column is vertical and the telescope axis is horizontal. To do this, turn the column till the telescope is parallel to the line joining two of the levelling screws of the base and by turning these screws bring the bubble of the telescope level half-way back to the centre. Turn the screw attached to the telescope carriage to bring the bubble fully to the centre. Next turn the vertical column with the telescope carriage through 180°. If

Results :

No. of. obs	load on pans		Readings of the pointer		Mean reading		Resting point $\frac{m_1+m_2}{2}$	Mean Resting	Sensitivity $\frac{Q-P}{10}$ s. d 1mg
	Left	Right	Left	Right	Left (m_1)	Right (m_2)			
			(i) ---	---					
			---	---	---				

	0	0							
			(ii) ---	---					
			---	---	---	---	---	--- = P	

			(iii) ---	---					
			---	---	---	---	---		

1									
			(i) ---	---					
			---	---	---				

	0	10mg							
			(ii) ---	---					
			---	---	---	---	---	--- = Q	

			(iii) ---	---					
			---	---	---	---	---		

2									
			(i) ---	---					
			---	---	---				
			---						
	10 gm	10gm							
			(ii) ---	---					
			---	---	---	---	---	--- = P	

			(iii) ---	---					
			---	---	---	---	---		

3									
			(i) ---	---					
			---	---	---				
			---						
	10 gms	10gm	(ii) ---	---					
		+	---	---	---	---	---	--- = Q	
		10mg	---						
			(iii) ---	---					
			---	---	---	---	---		
			---						
etc	etc	etc	etc	etc	etc	etc	etc	etc	

Oral Questions and their Answers.

1. *Why are the beam and the pans of a balance supported by knife-edges on agate plate?*
   In order to diminish the friction of working parts of support and suspension
2. *When will the beam of the balance be horizontal?*
   When the moment of the weight of the body to be weighed and that of the standard 'weight' about the fulcrum are equal.
3. *What are the requisites of a good balance?*
   Must be truely sensitive, stable and rigid (See a text book)
4. *What is sensitivity of a balance?*
   See theory Expt. 5.
5. *Why are the weights put on the right-hand pan and the body on the left-hand pan?*
   The weights are to be varied and for convenience of putting them, they are placed on the right-hand pan.
6. *Distinguish between mass and weight. How do they vary?*
   Mass (m) of a body is the quantity of matter contained in the body. It is an invariable quantity.
   Weight (mg) is the force with which the body is attracted by the earth towards its centre. As the acceleration due to gravity changes from place to place, the weight varies. It varies from place to place. It decreases when the body is taken (i) at high altitude (ii) in deep mine (iii) from pole to equator. At the centre of the earth it vanishes.
7. *What is measured by a balance—mass or weight?*
   Here mass is measured by comparing it with that of the standard 'weights'. Only the spring balance gives the weight, but the common balance does not.

EXPT. 6. TO DETERMINE THE YOUNG'S MODULUS FOR THE MATERIAL OF A WIRE BY SEARLE'S APPARATUS.

Hooks Law

Theory : Provided the distortion of a body is not too great, it has been found that the amount of distortion is directly proportional to the magnitude of the forces producing the distortion. This fact is known as "Hooke's law". If a wire of natural length l is stretched or compressed a distance x by a force F, experiment reveals that

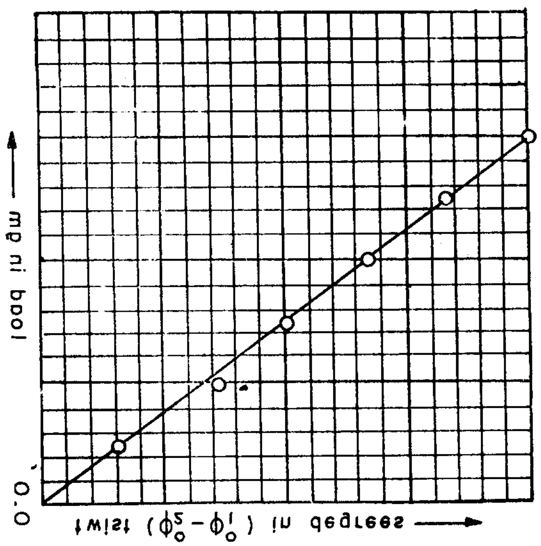


Fig. 2. 17.

Mean value of $\dfrac{m}{(\varphi_2^o - \varphi_1^o)}$ as obtained from the graph = ...

Acceleration due to gravity = ...cm/sec²

$$n = \frac{360(l_2-l_1)gd}{\pi^2 r^4} \times \frac{m}{(\varphi_2^o - \varphi_1^o)} \text{ ......dynes/sq.cm.}$$

Discussions : (i) The length of the wire is to be measured from the point of suspension upto the point at which the pointer is attached.

(ii) The radius of the wire should be measured with maximum possible accuracy.

(iii) The threads supporting the hangers should be parallel to ensure that the arm of the couple is equal to the diameter of the fly-wheel.

Oral Questions and their Answers

1. *What are shearing stress and shearing strain?*
   Shearing stress is the tangential force applied per unit area while shearing strain is the angle of shear expressed in radians
2. *What is rigidity? What is its unit?*
   Rigidity is the ratio of shearing stress to the shearing strain. In C. G. S. system its unit is dynes/sq. cm.
3. *Does the change in the values of lengh and diameter of the wire affect the value of rigdity?*
   No; such changes only change the twist.
4. *What is the effect of change of temperature on rigidity?*
   With the increase of temperature, rigidity decreases.
5. *Distinguish between torsional rigidity τ and simple rigidity (n)*
   The couple required to twist the wire by one radian is the torsional rigidity (τ) while ratio of the shearing stress to shearing strain is the simple rigidity (n). $\tau = \dfrac{n\pi r^4}{2l}$

EXPT. 10. TO DETERMINE THE MODULUS OF RIGIDITY OF A WIRE BY THE METHOD OF OSCILLATIONS (DYNAMIC METHOD)

Theory : If a heavy body be supported by a vertical wire of length l and radius r, so that the axis of the wire passes through its centre of gravity (Fig 2.18) and if the body be turned through an angle and released, it will execute torsional oscillations about a vertical axis. If at any instant the angle of twist be θ, the moment of the torsional couple exerted by the wire will be

$$\frac{n\pi r^4}{2l\theta} = C\theta .....(1)$$

where $C = \dfrac{n\pi r^4}{2l}$ = a constant

and n is the modulus of rigidity of the material of the wire. Therefore, the motion is simple harmonic and of fixed period

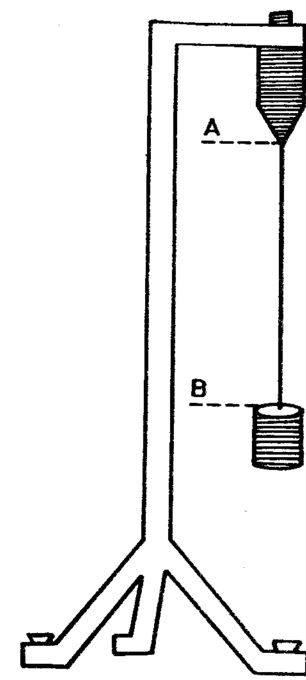


Fig.2.18

$$T = 2\pi\sqrt{\frac{I}{C}} \;\ldots\ldots\; (2)$$

where I is the moment of inertia of the body.

From (1) and (2).

$$T^2 = \frac{4\pi^2 I}{C} = \frac{8\pi I l}{n r^4}$$

$$\text{or } n = \frac{8\pi I l}{T^2 r^4} \text{ dynes/sq.cm}$$

Apparatus : A uniform wire, a disc or cylindrical bar, suitable clamps, stop-watch, screw gauge, metre scale, etc.

Description of the apparatus : The apparatus consists of a solid cylinder C suspended from a rigid support by means of the wire of which the modulus of rigidity is to be determined (Fig 2.18). The upper end of the wire A is fixed at a rigid support. By means of a detachable screw the cylinder is attached to the lower end of the wire B so that the axis of suspension coincides with the axis of the cylinder. In some cases the whole arrangement is enclosed in a glass case to avoid air disturbances.

Procedure : (i) Detach the cylinder from the suspension and weigh it with a balance. Also measure its diameter by means of a pair of slide callipers at five different places. Then calculate the moment of inertia of the cylinder from its mass M and radius a using the relatton $I = \frac{1}{2} Ma^2$.

(ii) Measure the diameter of the wire by means of a screw gauge at five different points along the length of the wire, taking two mutually perpendicular readings at each position.

(iii) Suspend the cylinder with the experimental wire from the rigid support so that it rotates about the axis of the wire.

(iv) Measure the length of the wire from the point of support and the point at which the wire is attached to the cylinder with a rod and metre scale.

(v) Put a vertical chalk mark on the surface of the cylinder and when it is at rest, place a pointer facing the vertical line. In reference to this pointer, oscillations are counted. Alternately a telescope is to be focussed from a distance on the vertical line on the cylinder so that it may remain coincident (without parallax) with the vertical line of the cross-wire of the telescope.

(vi) Give a little twist to the cylinder from its position of rest through a certain angle so that it begins to oscillate about its axis of suspension. With the help of a stop-watch, note the time for 30 complete oscillations. When the vertical line on the cylinder is going towards the right, crossing the tip of the pointer or the vertical line of the cross-wire of the telescope, a stop-watch is started. The cylinder will perform one complete oscillation when the line on it crosses the pointer or the vertical line of the cross-wire again in the same direction.

(vii) Repeat the operations three times and from these observations calculate the mean period of oscillation.

Results :

(A) *Readings for the diameter of the wire.*
Tabulate as in expt. 9.
Mean diameter of the wire = ... cm
Mean radius of the wire. r = ...cm

(B) *Readings for the diameter of the cylinder*
Tabulate the result as in expt. 9
Radius of the cylinder, a = ... cm

(C) *Mass of cylinder, M = ... gm.*
Moment of inertia of the cylinder
$I = \frac{1}{2} M a^2 = \ldots\ldots$ gm cm^2

(D) *Length of the wire, l.*
(i) ...cm (ii) ... cm (iii) ... cm
Mean l =... cm

(E) *Readings for the time period T.*

No.of obs	Time for 30 oscillations	Period of oscillation T	Mean T.
1			
2			
3			

Calculation : Modulus of rigidity

$n = \frac{8\pi Il}{T^2 r^4}$ dynes/sq.cm

Discussions : (i) Since the radius of the wire occurs in fourth power, it should be measured very accurately.

(ii) A large number of oscillations should be counted for determining ordinary T, the period of oscillation.

(iii) The e··peimental wire should pass through the axis of the cylinder.

(iv) The pendulum oscillation of the cylinder, if any, should be stopped.

(v) Since the ratio of displacement to the acceleration is constant, the angular amplitude may have any value within the elastic limits of the experimental wire.

(vi) With the increase of the length of the wire period of oscillation increases and with the increase of the diameter of the cylinder the period decreases.

Oral Questions and their Answers.

1. *How do the length and diameter of the wire affect the period of oscillation of a torsional pendulum?*
   See 'Discussion (vi)'
2. *Does the period of oscillation depend on the amplitude of oscillation of the cylinder?*
   No. The angle of oscillation may have any value within the elastic limit of the suspension wire.
3. *How will the period of oscillation be affected if the bob of the pendulum be made heavy?*
   With greater mass, the moment of inertia increases and hence it will oscillate slowly with greater period.

EXPT. 11. TO DETERMINE THE SPRING CONSTANT AND EFFECTIVE MASS OF A GIVEN SPIRAL SPRING AND HENCE TO CALCULATE THE RIGIDITY MODULUS OF THE MATERIAL OF THE SPRING.

Theory : If a spring be clamped vertically at the end P, and loaded with a mass m_o at the other end A, then the period of vibration of the spring along a vertical line is given by

$$T = 2\pi\sqrt{\frac{m_o+m}{k}} = 2\pi\sqrt{\frac{M}{k}} \quad \ldots\ldots \quad (1)$$

where m' is a constant called the *effective mass* of the spring and k, the spring constant *i.e.*, the ratio between the added force and the corresponding extension of the spring.

How the mass of the spring contributes to the effective mass of the vibrating system can be shown as follows. Consider the knietic energy of a spring and its load undergoing simple harmonic motion. At the instant under consideration let the load m_o be moving with velocity v_o as shown in fig. 2.19.

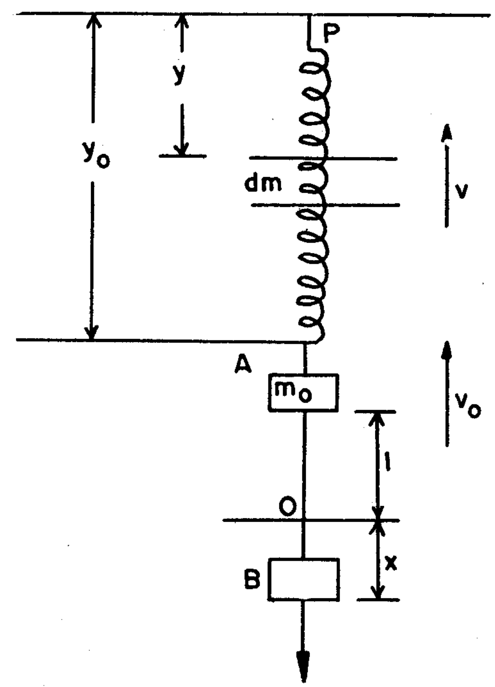


Fig.2.19.

At this same instant an element dm of the mass m of the spring will also be moving up but with a velocity v which is smaller than v_o. It is evident that the ratio between v and v_o is just the ratio between y and y_o. Hence, $\frac{v}{y} = \frac{v_o}{y_o}$ i.e., $v = \frac{v_o}{y_o} y$.

The kinetic energy of the spring alone will be $\int_0^{0} \frac{1}{2} v^2\, dm$.

But dm may be written as $\frac{m}{y_o}$ dy, where m is the mass of the spring.

Thus the integral equals to $\frac{1}{2} (\frac{m}{3}) v_o^2$. The total kinetic energy of the system will then be

$\frac{1}{2} (m_o + \frac{m}{3}) v_o^2$ and the effective mass of the system is, therefore, $m_o + \frac{m}{3}$

Hence $m' = \frac{1}{3} m$ ....(2)

where m' = effective mass of the spring and m = true mass of the spring. The applied force $m_o g$ is proportional to the extension l within the elastic limit. Therefore $mg=kl$.

Hence $l = \frac{g}{k} . m$ ....(3)

If n is the rigidity modulus of the material of the spring, then it can also be proved that

$n = \frac{4NR^3k}{r^4}$ ....(4)

where N = number of turns in the spring, R = radius of the spring and r = radius of the wire of the spring and k=spring constant.

Apparatus : A spiral spring, convenient masses with hanging arrangement, clamp or a hook attached to a rigid framework of heavy metal rods, weighing balance, stop clock and scale. The spiral spring may be a steel spring capable of supporting sufficient loads. A cathetometer may also be used to determine vertical displacements more accurately.

Procedure : (i) Clamp the spring at one end at the edge of the working table or suspend the spring by a hook attached to a rigid framework of heavy metal rods.

(ii) Measure the length L of the spring with a metre scale. Put a scale behind the spring or make any other arrangement to measure the extensions of the spring.

(iii) Add suitable weight to the free end of the spring so that it extends to the position O (Fig. 2.18). On the reference

frame put behind the spring, read the extension l and note the position O.

(iv) Pull the load from position O to a moderately low position B and then let it go. The spring will now execute simple harmonic motion and vibrate up and down about the position O. With a stop clock take the time of 50 vibrations. Count the vibrations by observing the transits in one direction of the upper edge of the load at O across the reference line.Compute the period T in sec per vibration.

(v) Repeat operation (iii) and (iv) for at least 5 sets of loads.

(vi) Draw graphs with added loads m_o in grams (abscissa) against the extensions of the spring in cm (ordinate) and with T^2 as a function of m_o. Draw lines of best fit through the points.

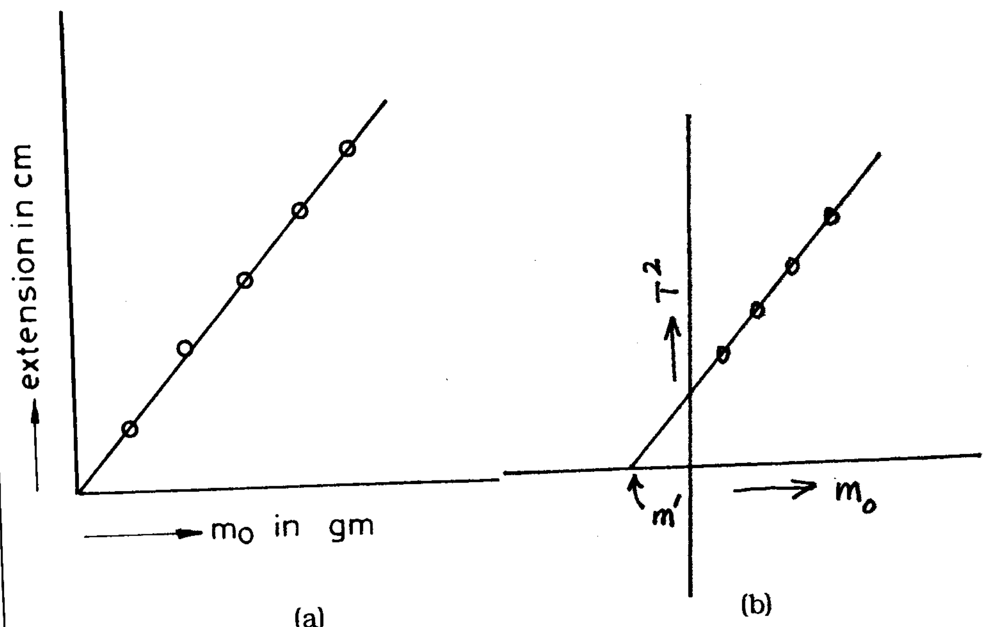


Fig. 2.20

(vii) From the first graph determine the slope of the line by choosing two points on it, one near the origin with co-ordinates x_1 cm and y_1 gm-wt and the other near the upper end of the line with co-ordinates x_2 cm and y_2 gm-wt.

The slope will be $\frac{y_2 - y_1}{x_2 - x_1}$ gm-wt/cm and the spring constant k will be this slope multiplied by g.

The second graph T^2 *vs* m_o does not pass through the origin owing to the mass of the spring which has not been considered in drawing it. The intercept of the resulting line on the mass-axis give m' the effective mass of the spring

(viii) Measure the mass m of the spring with a balance and show that the effective mass m' obtained from the graph is $\frac{1}{3}$ of it i.e., $m' = \frac{m}{3}$

(ix) Count the number of turns in the spring. Determine the radius of the spring. With the help of a slide callipers (Art. 2.1) find out the inside and outside diameters of the spring. Make several observations. Take the mean values. If D is the outside diameter and d is the inside diameter then mean radius of the spring is given by $\frac{D+d}{4}$

Also measure the radius of the wire of the spring very carefully with a screw-gauge. A number of values are to be obtained at different points and the mean value taken.

Then with the help of eqn. (4), calculate the rigidity modulus of the material of the spring.

Results :

(A) Length of the spring L = cm

(B) Determinations of extensions and time periods.

No.of obs.	Loads m_o in gms	Extension in cms.	No.of vibrations	Total time in secs	period T in sec.	T^2
1						
2						
3						

(C) Draw the graph as described in procedure (vi).

(D) Calulation of k, the spring constant and m' the effective mass of the spring as described in procedure (vii).

From Fig. 2.20a, $\frac{y_2 - y_1}{x_2 - x_1}$ = ...gm-wt/cm = M (say).

Spring constant k = Mg = ...dynes/cm

(E) Measurement of the mass of the spring, m =...... ....gms.

(F) Data for calculation of n, the rigidity modulus of the material of the spring.

(a) No. of turns N in the spring = ...

(b) Radius of the spring R:

External diameter of the spring (mean) D =...........cm.

Internal diameter of the spring (mean) d = ...cm.

Radius of the spring, R = $\frac{D+d}{4}$ ....cm.

(c) Radius of the wire of the spring (mean) r =.......cm.

Calculation : $n = \frac{4NR^3k}{r^4}$ =.................... dynes/sq.cm.

From graph 1, . $\frac{y_2 - y_1}{x_2 - x_1}$ =................. gm-wt/cm. =M (say).

Spring constant k= Mg =.............dynes/cm.

From Fig. 2.20b, effective mass of spring, m'= ....gms.

Oral Questions and their Answers.

1. *What is spring constant?*
When a force is applied to the free end of a spiral spring suspended from a fixed support, the spring stretches in a normal maneer and obeys Hooke's law. The ratio of the applied force and the elongation is a constant and is known as the spring constant.

2. *What is the effective mass of the spring?*
On the period of vibrations of a spring with a load, the effect of the mass of the spring distributed over its whole length is the same as though one-third the mass of the spring is added to the load. This one-third the mass of the spring is known as the effective mass of the spring.

EXPT. 12. TO DETERMINE THE MOMENT OF INERTIA OF A FLY-WHEEL ABOUT ITS AXIS OF ROTATION.

Theory : Fig. 2.21a, shows a mass M, attached by means of a string to the axle of a fly-wheel radius r, the moment of inertia of which, about its axis of rotation, is I. The length of the string is such that it becomes detached from the axle when the mass strikes the floor. In falling a distance h, the potential energy of the mass has been converted into kinetic rotational and translation energy. If w be the maximum

5. *What is the physical significance of the moment inertia?*
   Moment of inertia plays the same part in rotating bodies as mass plays when bodies move in straight line.
6. *What is the unit of moment of inertia?*
   In C.G.S . system it is gm. cm ^{2}

EXPT. 13. TO DETERMINE THE VALUE OF g, ACCELERATION DUE TO GRAVITY, BY MEANS OF A COMPOUND PENDULUM

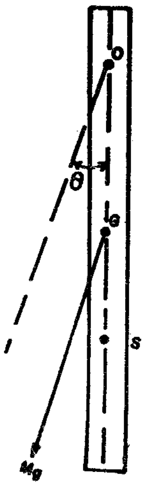


Fig.2.22a

Theory : Compound pendulum is a rigid body of any shape free to turn about a horizontal axis. In Eig. 2.22a, G is the cenire of gravity of the pendulum of mass M, which performs oscillations about a horizontal axis through O. When the pendulum is at an angle θ to the vertical, the equation of motion of the pendulum is Iw = Mglsinθ where w is the angular acceleration produced, l is the distance OG and I is the moment of inertia of the pendulum about the axis of oscillations. For small amplitude of vibrations, sinθ = θ, so that

Iw = Mglθ

Hence the motion is simple harmonic, with period of vibrations,

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

If K is the radius of gyration of the pendulum about an axis through G parallel to the axis of oscillation through O, from the Parallel Axes Theorem,

$I = M(K^2+l^2)$, and so

$$T = 2\pi\sqrt{\frac{k^2+l^2}{gl}} = 2\pi\sqrt{\frac{\frac{k^2+l^2}{l}}{g}} \qquad (1)$$

Since the periodic time of a simple pendulum is given by

$T = 2\pi\sqrt{\frac{L}{g}}$ the period of the rigid body (compound pendulum) is the same as that of a simple pendulum of length

$$L = \frac{k^2+l^2}{l} \qquad (2)$$

This length L is known as the length of the simple equivalent pendulum. The expression for L can be written as a quadratic in (l). Thus from (2)

$$l^2 - lL + k^2 = 0 \qquad (3)$$

This gives two values of l *(*l_1 and l_2*)* for which the body has equal times of vibration. From the theory of quadratic equations,

$$l_1 + l_2 = L \text{ and } l_1 l_2 = k^2$$

As the sum and products of two roots are positive, the two roots are both positiue. This means that there are two positions of the centre of suspension on the same side of C.G. about which the periods (T) would be same. Similarly there will be two more points of suspension on the other side of the C. G., about which the time periods (T) will again be the same. Thus, there are altogether *four* points, *two* on cither side of the C.G., about which the time periods of the pendulum are the same (T). The distance between two such points, assymetrically situated on either side of the C. G., will be the length (L) of the simple equivalent pendulum. If the length OG in Fig. 2.22a is l_1 and we measure the length $GS = \frac{k^2}{l_1}$ along OG produced, then obviously $\frac{k^2}{l_1} = l_2$ Or, OS = OG + GS = $l_1 + l_2$ = L. The period of oscillation about either O or S is the same.

The point S is called the centre of oscillation. The points O and S are interchangeable *i.e.*, when the body oscillates about O or S, the time period is the same. If this period of oscillation is T, then from the exprcssion $T = 2\pi\sqrt{\frac{L}{g}}$ we get

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

By finding L graphically, and determining the value of the period T, the acceleration due to gravity (g) at the place of the experiment can be determined.

Apparatus : A bar pendulum, a small metal wedge, a beam compass, a spirit level, a telescope with cross-wires in the eye-piece, stop-watch, and a wooden prism with metal edge.

Description of the apparatus : The apparatus ordinarily used in the laboratory is a rectangular bar AB of brass about 1 meter long. A series of holes is drilled along the bar at intervals of 2-3 cm (Fig.2.22b). By inserting the metal wedge S in one of the holes and placing the wedge on the support S_1S_2, the bar may be made to oscillate.

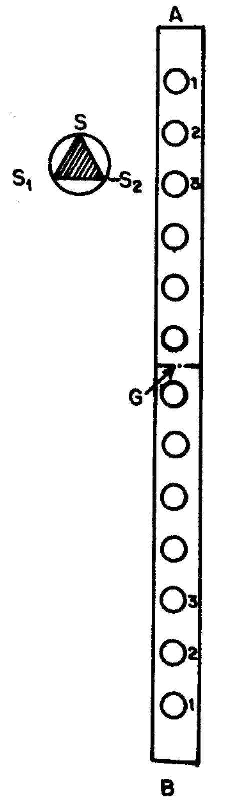


Fig.2.22b.

Procedure : (i) Find out the centre of gravity G of the bar by balancing it on the wooden prism.

(ii) Put a chalk mark on the line AB of the bar. Insert the metal wedge in the first hole in the bar towards A and place the wedge on the support S_1S_2 so that the bar can turn round S.

(iii) Place a telescope at a distance of about a metre from the bar and focus the cross-wires and rotate the collar of the tube till the cross-wires form a distinct cross. Next focus the telescope on the bar and see that the point of inter-section of the cross-wires coincides with the chalk mark along the line AB of the bar.

(iv) Set the bar to oscillate taking care to see that the amplitude of oscillations is not more than 5^0. Note the time for 50 oscillations by counting the oscillations when the line AB passes the inter-section of the cross-wires in the same direction.

(v) Measure the length from the end A of the bar to the top of the first hole *i.e.*, upto the point of suspension of the pendulum.

(vi) In the same way, suspend the bar at holes 2,3,.............and each time note times for 50 oscillations. Also measure distances from the end A for each hole.

(vii) When the middle point of the bar is passed, it will turn round so that the end B is now on the top. But continue measuring distances from the point of suspension to the end A.

(viii) Now calculate the time-period T from the time recorded for 50 oscillations.

(ix) On a nice and large graph paper, plot a curve with length as abscissa and period T as ordinate with the origin at the middle of the paper along the abscissa. (Fig.2.22c).

(x) Through the point on the graph paper corresponding to the centre of gravity of the bar, draw a vertical line. Draw a second line ABCD along the abscissa. AC or BD is the length of the equivalent simple pendulum *i.e.*, $L = l_1 + \frac{k^2}{l_1}$. $AG = l_1$ and $GC = \frac{k^2}{l_1} = l_2$, C being the centre of oscillation.

Similarly $GD = l_1$ and $GB = \frac{k^2}{l_1} = l_2$, B being the centre of oscillation. From this, $g = 4\pi^2 \frac{L}{T^2}$ can be calculated.

(xi) By drawing another line A'B'C'D' calculate another value of g

Alternate method of measuring the length of the pendulum.

Instead of measuring length from the end A to the point of suspension, length can also be measured from the point of suspension to the centre of gravity G of the bar (see Fig. 2.22b). In that case also there will be two sets of readings-one with the end A at the top and again with the end B at the top. Calculate the period T with 50 oscillations at each suspension. Now draw a graph with the centre of gravity of the bar at the origin which is put at the middle of the paper along the abscissa. Put the length measured towards the end A to the left and that measured towards the end B to the right of the origin (see Fig.2.22c). A line ABCD drawn parallel to the abscissa intersects the two curves at A B C and D.

Here also the length AC or BD is the length of the equivalent simple pendulum.

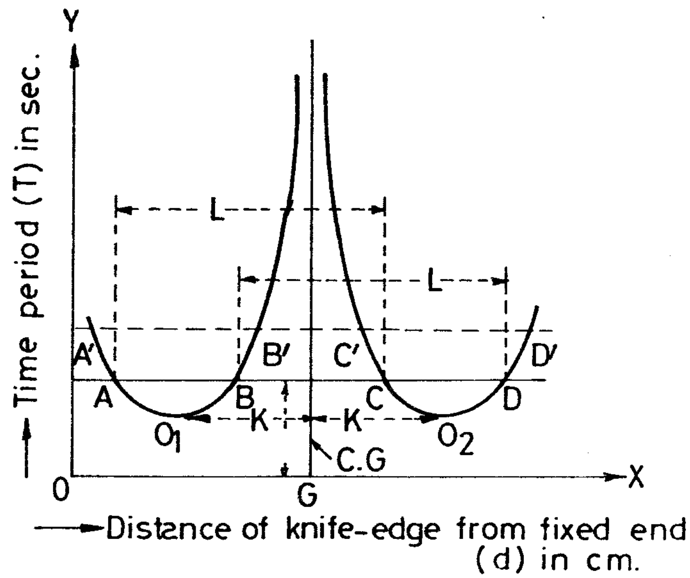


Fig. 2.22c

Results:

(A) Observation for the time period T and the distance of the point of suspension from the end A.

At the top	Hole no.	Distance from A	Time for 50 oscillations	Mean Time	Mean Period T
End A	1	=c m	(i) ....sec (ii) ...sec (iii) ...sec		
	2	= .·. . cm	(i) ....sec (ii) ...sec (iii) ...sec		
	3	= . . . cm	(i) (ii) (iii) etc		
End B	1 2 3	etc.		etc	

(B) Alternate method of measuring length.

Use the above table only changing the third column by "Distance from G",the centre of gravity.

(From graph)

Length AC=.....cm. Length BD =...cm.

Mean length $L = \frac{AC+BD}{2}$ =...cm

Corresponding time-period from the graph.

T =...sec. $g = \frac{4\pi^2 L}{T^2}$ =......cm. per sec^2

Discussions: (i) Distances are to be measured from the end A or the point G, preferably from A.

(ii) In measuring time an accurate stop-watch should be used.

(iii) Oscillations should be counted whenever the line of the bar crosses the intersecting point of the cross- wires, in the same direction.

(iv) Graph paper used should have sharp lines and accurate squares and should be sufficiently large to draw smooth and large curves.

(v) Amplitude of oscillations must not be more than 5°

(vi) Error due to the yielding of support, air resistance, and irregular knife-edge should be avoided.

(vii) Determination of the position of G only helps us to understand that $AG = l_1$ and $GC = \frac{K^2}{l_1} = l_2$ and is not necessary for determining the value of 'g'

(viii) For the lengths corresponding to the points A,B, C and D the period is the same.

(ix) At the lowest points of the curves P_1 and P_2 the centre of suspension and the centre of oscillation coincide.

It is really difficult to locate the points P_1 and P_2 in the graph and so K is calculated from the relation

$$K = \sqrt{GA.GB} = \sqrt{GB.GC}.$$

EXPT .14. TO DETERMINE THE VALUE OF 'g' BY KATER'S REVERSIBLE PENDULUM.

Theory : In a Kater's pendulum if l_1 and l_2 be distances of two points from the centre of gravity of the bar and on opposite direction from it such that the periods of oscillations about these points are exactly equal, then period T is given by

$$T = 2\pi\sqrt{\frac{l_1+l_2}{g}} \quad \text{or } g = 4\pi^2\frac{l_1+l_2}{T^2} \quad \ldots \quad \ldots \quad \ldots(1)$$

But it is extremely difficult to make the periods exactly equal. It can, however, be shown in the following way that the time-periods T_1 and T_2 about these two points need not be exactly equal.

$$T_1 = 2\pi\sqrt{\frac{l_1^2+K^2}{l_1 g.}}\ .\ T_2 = 2\pi\sqrt{\frac{l_2^2+K^2}{l_2 g}}$$

or $T_1^2.l_1 g = (4\pi^2\, l_1^2+K^2)$, $T_2^2.l_2 g = 4\pi^2\,(l_2^2+K^2)$.

Subtracting, $(T_1^2 l_1 - T_2^2\, l_2)g = 4\pi^2(l_1^2 - l_2^2)$

$$\text{or, } \frac{4\pi^2}{g} = \frac{l_1T_1^2 - l_2T_2^2}{l_1^2 - l_2^2} = \frac{1}{2}\left[\frac{T_1^2+T_2^2}{l_1+l_2} + \frac{T_1^2+T_2^2}{l_1+l_2}\right]$$

$$\text{or, } \frac{8\pi^2}{g} = \frac{T_1^2+T_2^2}{l_1+l_2} + \frac{T_1^2-T_2^2}{l_1-l_2}.$$

From the above relation, g can be calculated.

Apparatus : Kater's pendulum, stop-watch, telescope, etc,

Description of the apparatus : The Kater's pendulum consists of a metal rod about one metre in length having a heavy mass W fixed at one end (Fig.2.23). Two steel knife-edges k_1 and k_2 are fixed to this rod with their edges turned towards each other, from which the pendulum can be suspended. Two other small weights w_1 and w_2 can slide along the rod and can be screwed anywhere on it. With the help of these two weights, centre of gravity of the rod can be altered and the periods of oscillation of the pendulum about k_1 and k_2 can be made equal. The smaller weight w_2 has a micrometer arrangement for fine adjustment. The pendulum is made to oscillate about one of the knife-edges from a rigid support.

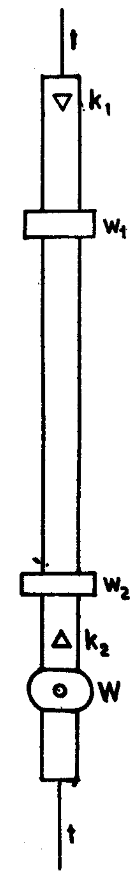


Fig. 2.23

Procedure : (i) Suspend the pendulum from a rigid support about the knife-edge k_1, so that the weight W is in downward position.

(ii) Focus the cross-wires of the telescope and rotate the collar of the tube till the cross-wires form a distinct cross. Next place the telescope at a distance of about one metre from the pendulum and focus it on the lower tail t of the pendulum (or alternately on a chalk line marked along the length of the pendulum) so that the vertical line of the cross-wire or the point of intersection of the cross-wires (when none of them is vertical) coincides with the tail t or the chalk mark.

(iii) Displace the pendulum slightly and release it. The pendulum will begin to oscillate. Note the time for 10 complete oscillations (the amplitude of oscillations should be small) with an accurate stop-watch. Repeat the same for the knife-edge k_2. The two times will generally differ.

(iv) Slide the heavier weight w_1 in one direction and note the time for 10 oscillations about k_1 and k_2. If the difference between hese two times decreases, then the weight w_1 should be slided in the same direction in subsequent adjustments. But If the difference between these two times increases, slide the weight w_1 in the opposite direction.

(v) Go on adjusting the weight w_1 until the times for 10, 15 and 20 oscillations about the knife-edges k_1 and k_2 become nearly equal.

(vi) Then make the final adjustment by sliding w_2 until the time for 50 oscillations about the two knife-edges are very nearly equal.

(vii) The apparatus is now ready for recording periods T_1 and T_2. Suspend the pendulum about the knife-edge k_1 and carefully record the time for 50 oscillations. Repeat the process 5 times. Then suspend the pendulum about the knife-edge k_2 and make 5 observations with 50 oscillations each time. The mean time-period about k_1 is T_1 and that about k_2 is T_2.

(viii) Carefully remove the pendulum from the support without disturbing any of the weights. Place the rod system on the wedge and find out the C.G. of the system. Measure accurately the distance l_1 of k_1 from C.G. and l_2 of k_2 from C.G. Hence the distance between the two knife-edges is l_1+l_2.

Then calculate 'g' from the relation given in eqn. (2) in the theory.

Results :

(A) *Recording of time for 10,15,20, etc, oscillations after successive adjustments.*

No.of obs.	Time about knife-edge k_1	Time about knife-edge k_2
1		
2		
3		
etc.		

(B) *Recording of time for 50 oscillations after successive finer adjustment.*

No of. obs	Time for 50 oscillations about knife-edges	
	k_1	k_2
1		
2		
3		
etc.		

(C) *Recording of the periods T_1 and T_2*

No.of obs.	Time for 50 oscillations about the knife-edge k_1	Mean T_1	Time for 50 oscillations about the knife-edge k_2	Mean T_2
1				
2				
3				
4				
5				

T_1 and T_2 should be nearly equal.

(D) *Distance between the two knife-edges.*

No.of obs	Reading at k_1	Mean (a)	Reading at k_2	Mean (b)	Mean distance (l_1+l_2)=a~b
1	...cm		...cm		
2		...cm		...cm	....cm
3					

(E) Measurement of l_1 and l_2.

No.of obs	Reading at knife-edge k_1	Mean (a)	Reading at C.G.	Mean (b)	Reading at knife-edge	Mean (c)	Mean length l_1=a-b	Mean length l_2=b-c
1	...cm		....cm		...cm			
2		...cm		...cm	k_2	...cm	...cm	...cm
3								

$$\therefore \frac{8\pi^2}{g} = \frac{T_1^2+T_2^2}{l_1+l_2} + \frac{T_1^2-T_2^2}{l_1-l_2}$$

or, g =......cm/sec^2

Discussions : (i) The arc of swing should be small.

(ii) The support should be rigid and should not move when the pendulum oscillates.

(iii) Telescope may not be used in the earlier part of the adjustments.

Oral Questions and their Answers.

1. ***What is a compound pendulum?***
   See theory of Expt. No.13.
2. ***Which is superior—compound pendulum or a simple pendulum?***
   The ideal conditions of a simple pendulum cannot be attained in practice. In a compound pendulum the length of an equivalent simple pendulum can be determined and hence the value of 'g' can be accurately found out. The compound pendulum oscillates as a whole and due to its heavy mass, goes on oscillating for a long time. Hence compound pendulum is superior to simple pendulum.
3. ***What do you mean by centre of supension and centre of oscillation?***
   It is possible to find out two points on the opposite side of the centre of gravity of the pendulum such that the periods of oscillation of the pendulum about these points are equal. One point is called the centre of suspension and the other point is called the centre of oscillation.
4. ***What is the length of the equivalent simple pendulum?***
   The distance between the centre of suspension and the centre of oscillation is called the length of the equivalent simple pendulum.
5. ***What are the defects of the compound pendulum?***

(i) The compound pendulum tends to drag some air with it and this increases the effective mass and hence the moment of inertia of the moving system. (ii) The amplitude of oscillation is finite which needs some correction.

EXPT. 15. TO DETERMINE THE SURFACE TENSION OF WATER BY CAPILLARY TUBE METHOD AND HENCE TO VERIFY JURIN'S LAW.

Theory : The surface tension of a liquid is the force acting perpendicular to each centimetre of the imaginary line in the plane of the surface. If one end of a clean capillary tube of fine bore is dipped into a liquid, the liquid rises up the tube through a height h (Fig.2.24) The surface tension T acts upwards along the tangent to the meniscus. The component of T acting vertically upwards is $T\cos\theta$ and the total force acting upwards is $T\cos\theta.\ 2\pi r$, r being the internal radius of the capillary tube. This is the upward force due to surface tension of the liquid.

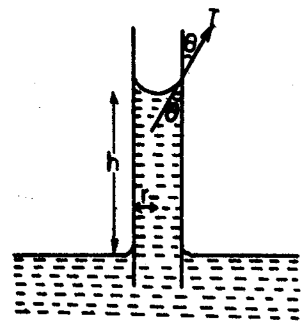


Fig-.2.24

The weight of the liquid column acting downwards is equal to v x ρ x g where ρ is the density of the liquid and g is the acceleration due to gravity.

The volume $V= \pi r^2 h$ + volume of the meniscus for a tube of uniform bore. If the radius r is small, the meniscus = volume of a cylinder of radius r and height h - volume of hemisphere of radius r. This can be written as

$$\text{Volume of meniscus} = \pi r^3 - \frac{2}{3}\pi r^3 = \frac{1}{3}\pi r^3$$

$$\text{Therefore } V= \pi r^2 h + \frac{1}{3}\pi r^3 = \pi r^2 \left(h+ \frac{r}{3}\right)$$

$$\text{Hence weight of the liquid column} = \pi r^2\left(h+\frac{r}{3}\right) \rho.g.$$

Since the column is in equilibrium the upward force due to surface tension must support the weight of the liquid column.

Hence, for equilibrium,

$$T\cos\theta \times 2\pi r = \pi r^2 \left(h+ \frac{1}{3}r\right) \rho.g.$$

For water θ is zero and hence $\cos\theta$ is unity. So the above relation gives

CHAPTER V
LIGHT

5.1 Parallax

In many experiments on light, one usually comes across the term *parallax*. Now what exactly is meant by parallax?

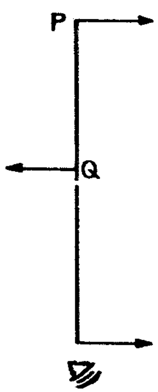


Fig. 5.1

This can be answered by considering two distant objects P and Q which are situated at two different distances from the eye but are in line with it to begin with (Fig. 5.1). Now if the eye is moved towards the right, P will appear to have moved in the *same direction* as the eye while Q will appear to have moved backwards in the *opposite direction* *i.e.*, towards the left. The eye no longer appears to lie in one line with P and Q. This apparent change of position of distant objects, due to the actual change of position of the observer, is known as *parallax*. Thus *parallax means separation*. The amount of the apparent shift is known as *parallactic shift*. The separation becomes less as the distance between P and Q decreases and it simply vanishes when P and Q are coincident in one position.

Cause and elimination of optical parallax : It can be easily seen that the cause of optical parallax is due to the fact that the two objects lying in different vertical planes perpendicular to the line of sight, subtend different angles when the eye is moved obliquely *to and fro* perpendicular to the line of sight. To illustrate this point let us consider the Fig. 5.2. Let E, Q and P represent the position of the eye and the two objects (*one of the objects may, in fact, be the image of the other as it so often happens in optical experiments, or they both may be the images of two different objects*) respectively on the same line. To begin with, if the eye is at the position E on the line EQP then the two rays QE and PE from Q and P respectively follow the same path and hence the two objects Q and P will be found to lie in one straight line.

Now if the eye is moved towards left in the position E_1, then the ray PE_1, from P will remain on the left side of the ray QE_1, from Q. As a result the object P will appear to move towards the left while the object Q appears to move towards right *i.e.*, in the opposite direction. For exactly similar reason, the object P will appear to move towards the right, while Q will appear to move towards left when the eye is moved towards right in the position E_2.

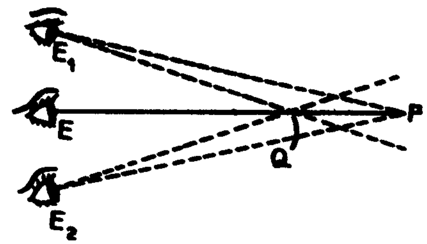


Fig. 5.2

Thus it can be seen that *as the eye moves, the more distant of the two objects viz. P moves with the eye while the nearer object viz. Q moves opposite to the eye.* Therefore, by the movement of P and Q relative to the movement of the eye, one can detect which object (here Q) is nearer to the eye and which object (here P) is far away from the eye.

We have already seen that parallax vanishes when the two objects are coincident. Hence to eliminate parallax between the two objects P and Q, the nearer object (Q) will have to be moved away from the eye *i.e.*, towards the distant object (P) or the distant object (P) will have to moved towards the eye *i.e.*, towards the nearer object (Q), until there is no separation between P and Q whether the eye is moved from E towards E_1 or E_2. This means that the two objects are now coincident with one another and they will be found to move together with the movement of the eye.

The principle of parallax is used in may cases to locate the position of an image by moving a pointer until it appears to coincide with the image despite movements of the observer's eye. The process is illustrated in Fig. 5.3. P represents the real image of the pin Q seen on looking from some distance vertically above the pin Q into a biconvex lens placed above a plane mirror. On moving the head from side

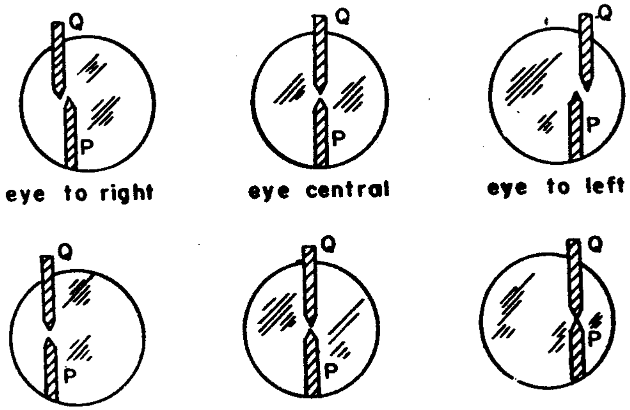


Fig. 5.3

to side, the pins appear to cross the lens surface as indicated in the top diagram of Fig. 5.3. The bottom diagram shows the position of no parallax. When this position is found, the pin Q is in the same place as its image P which has to be located. As explained above, it can be seen that the pin Q (Fig. 5.2) is too near the observer and must be moved back to give the required result.

5.2 The optical bench and its uses.

A very common piece of apparatus used for the measuremen-

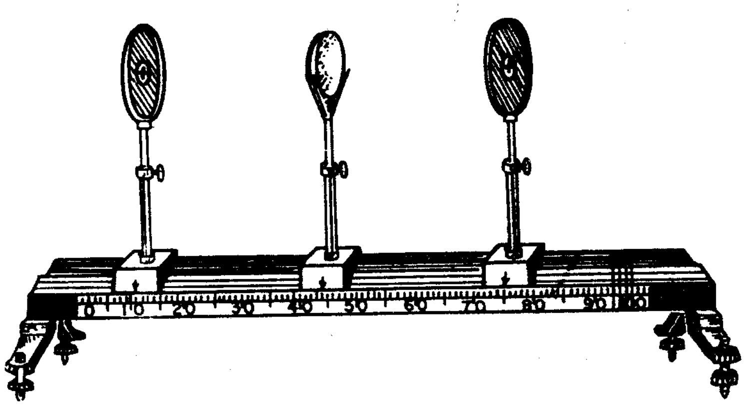


Fig.5.4

ts of the optical constants of mirrors and lenses is the *optical bench*. In its simplest form, it consists of a long, narrow, horizontal bed, on which can slide several vertical stands (Fig. 5.4). These stands which carry the object, screen, lens or mirror, may be fixed at any desired height. They can be fixed at any position on the bench and their positions can be read from the scale fitted along the length of the horizontal bed of the optical bench, with the help of an index mark which is engraved on the base of each stand adjacent to the scale. The stands can also be turned about the vertical axis and in such cases they can even be moved horizontally perpendicular to the length of the optical bench.

The object screen has a hole at the centre which is fitted with a cross-wire. This cross-wire when illuminated by a candle or an electric lamp serves the purpose of the object. The image screen is nothing but a ground glass or a white paper fixed to a frame. Lenses are held in lens holders of various forms, one of which is shown separately in Fig. 5.5.

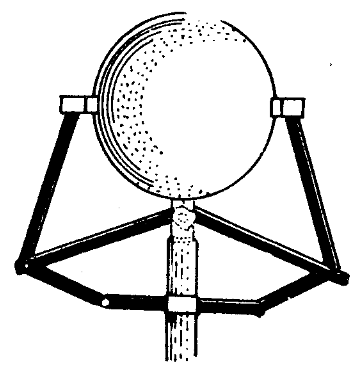


Fig. 5.5

Index correction : When working with an optical bench, it is the actual distance between the different parts, *viz*, the object, lens, mirror or screen which is needed. But the actual distance between any two of them say the object and the lens, may not be equal to the distance indicated by the index marks of the vertical stands carrying them. In order to find the actual distance, a correction known as *index correction* must be carried out in all optical experiments using an optical bench. The procedure for index correction is as follows :

With a metre scale measure accurately the length l of a metal rod with pointed ends, provided for this purpose. Then hold it by a suitable clamp parallel to the length of the optical bench between, say, the object and the lens, so that the ends of the rod just touch the surfaces of the lens at the middle and the object as shown in Fig. 5.6. Let the apparent length of the rod as observed from the bench readings be d. Then the index correction λ for the object distance (between the object and the lens) is given by $(l-d)$. *In order to get the true distance, $\lambda = (l-d)$ is to be algebraically added to the apparent distance.* Similarly the index correction for the image distance (between the lens and the image screen) is to be determined.

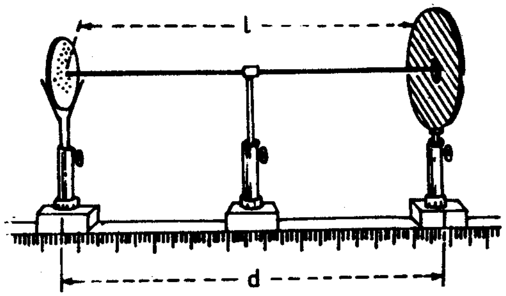


Fig. 5.6

If the object or the screen or the lens is shifted to another position on the bench, the index mark moves through the same distance as the object or the screen or the lens since they are rigidly fixed to the stands carrying them. So the correction for getting the actual distance between them remains the same.

5.3 Lens

Definition : Any transparent refracting medium bounded by two surfaces of which at least one is curved is called a *lens.*

Lenses may be broadly divided into two groups-convex and concave.

A convex lens is bulged at the middle *i.e.*, it is thinner at the edges but thicker at the middle. It has a converging effect on the rays. A converging lens, again, may be of the following three forms :

(i) *Double convex* or *bi-convex* : a lens both of whose refracting surfaces are convex *i.e.*, raised at the middle, is called a *double or bi-convex lens.*

(ii) *Plano-convex* : one of the refracting surfaces of a *plano-convex* lens is plane and the other one is convex.

(iii) Concavo-convex : one of the refracting surfaces of a *concavo-convex lens* is concave and the other one is convex.

A concave lens is thicker at its edges but thinner at its middle. It has a diverging effect on the rays.

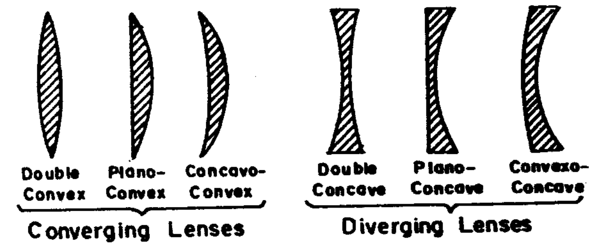


Fig. 5.7

Like convex lens a concave lens may also be of the following three types.

(i) *Double concave or bi-concave :* both of its refracting surfaces are concave.

(ii) *Plano- concave :* one of the refracting surfaces is plane and the other one is concave.

(iii) *Convexo- concave :* one of the refracting surfaces is convex and the other one is concave.

The lenses are illustrated in Fig. 5.7

Certain terms connected with experiments involving lenses :

Principal axis : The surface of the lens on which light is incident is known as the *first surface* of the lens and the surface from which light emerges out is known as the *second surface.* In case of most lenses, these surfaces are curved and are the part of two spheres. The centres of these spheres are known as *centres of curvatures* — the first centre of curvature (C_1) corresponding to the first surface

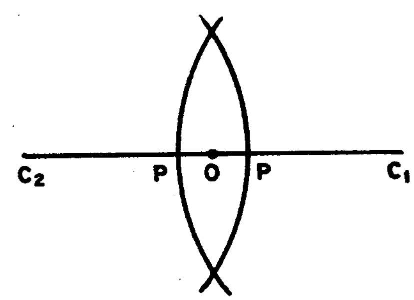
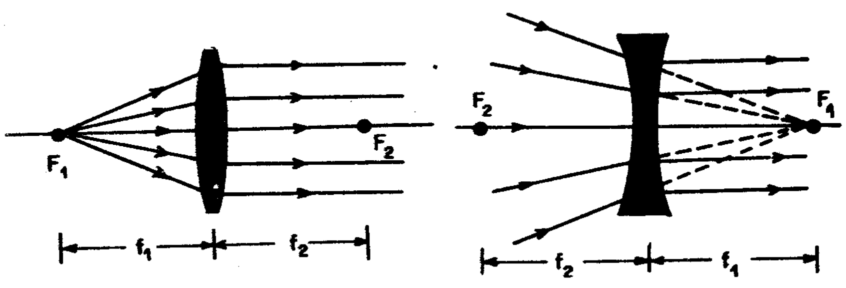


Fig. 5.8

and the second centre of curvature (C_2) corresponding to the second surface (Fig. 5.8). A straight line passing through the centres of curvature of the two surfaces of the lens (C_1OC_2) is called the *principal axis* of the lens. If one of the surface is plane, the axis is a straight line normal to the surface drawn through the centre of curvature of the other surface. The distances OC_1 and OC_2 are known as the radii of curvature r_1 and r_2 of the first and second surface respectively. The points of intersection of the two surfaces of the lens with its principal axis are called the poles (P,P) of the lens.

Principal focus and focal length : A lens has two principal foci. The *First principal focus* (F_1) is a point on the principal

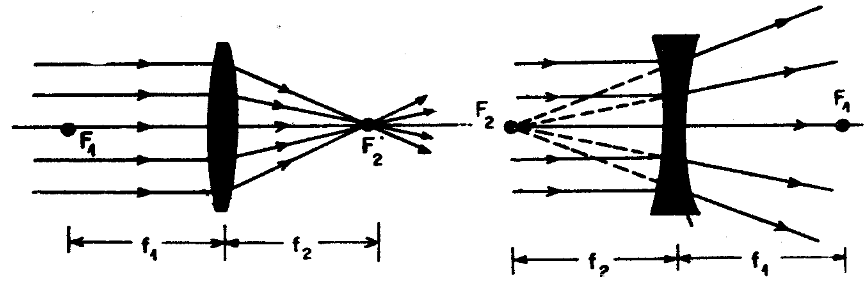


(a) (b)

Fig. 5.9

axis such that a ray diverging from that point or moving towards that point becomes parallel to the principal axis after passing through the lens (Fig. 5.9 a and b). *This is the position of the object, real or virtual, whose image is formed at infinity.* The distance of this point from the centre of the lens, *i.e.*, the *object distance when the image is at infinity*, is known as the *first focal length* (f_1).

The second principal *focus* (F_2) is a point on the principal axis such that the incident ray moving parallel to the principal axis will, after passing through the lens, actually converge to or appear to diverge from this point (Fig. 5.10a and b). *This is a point on the principal axis where*



(a) (b)

Fig. 5.10

an image, real or virtual, would be formed for an object at infinity. The distance of this point from the centre of the lens, *i.e., the image distance when the object is at infinity*, is known as the *second focal length* (f_2) of the lens. When the medium on both sides of the lens *is same (as in the case of a lens placed in air), the two focal lengths are numerically equal but opposite in sign.*

Note : *The second principal focus, either of a convex lens or of a concave lens, is active in forming an image of an actual object. Hence unless specifically mentioned, the terms principal focus and focal length of a lens refer to its second principal focus and second focal length respectively.*

Optical centre : It is a point on the principal axis inside the lens so that all rays passing through this point within the material of the lens will have their emer-

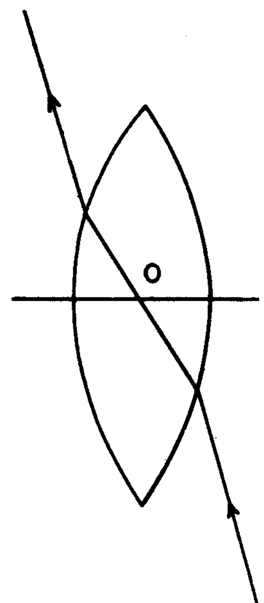


Fig. 5.11

gent rays parallel to the corresponding incident rays (Fig. 5.11). The ray passing through this point is refracted without undergoing an angular deviation; it just suffers a lateral shift. This point is called the *optical centre* of the lens. The lateral shift between the incident and emergent rays, increases with the thickness of the lens. In the extreme case, when the lens is exceedingly thin, the lateral shift may be regarded as zero and the optical centre may then be defined as that point on the principal axis within the lens through which a ray passes undeviated.

Conjugate foci : If two points on the principal axis are situated in such a way that when one serves as the object point, the other becomes the corresponding image point and *vice versa*, then these points are called *conjugate foci.*

Lens formula : The general formula of a lens, convex or concave, connecting object distance (u), image distance (v) and its focal length (f) is given by,

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

The general formula of a lens connecting the radii of curvature of the two surfaces of the lens (r_1 and r_2), refractive index of the material of the lens (μ) and the focal length (f) of the lens is given by,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

Note : *The relation* $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ *holds good usually for a thin lens. The lenses used in the laboratory are generally thick.*

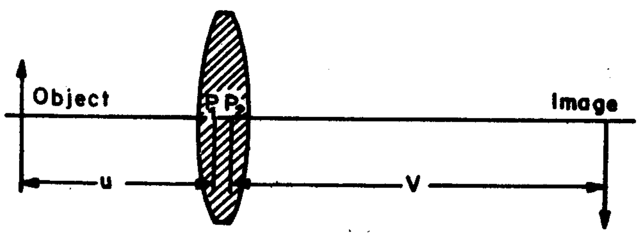


Fig. 5.12

But the above relation will also hold good for thick lenses provided the distances on either side of the lens are

measured from two planes perpendicular to the axis, called the principal planes. In the case of an equi-convex lens of glass, having a refractive index of approximately 1.5, the planes are situated at a distance t/3 inside the lens where t is the thickness of the lens (Fig. 5.12). Thus it is advisable that while calculating the focal length of a thick lens, the student should add one-third of the thickness of the lens (t/3) to the observed values of the object and the image distances measured form the surface of the lens.

Sign convention : In every optical system, the derivation of various formulae (such as $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$) are based on measu-

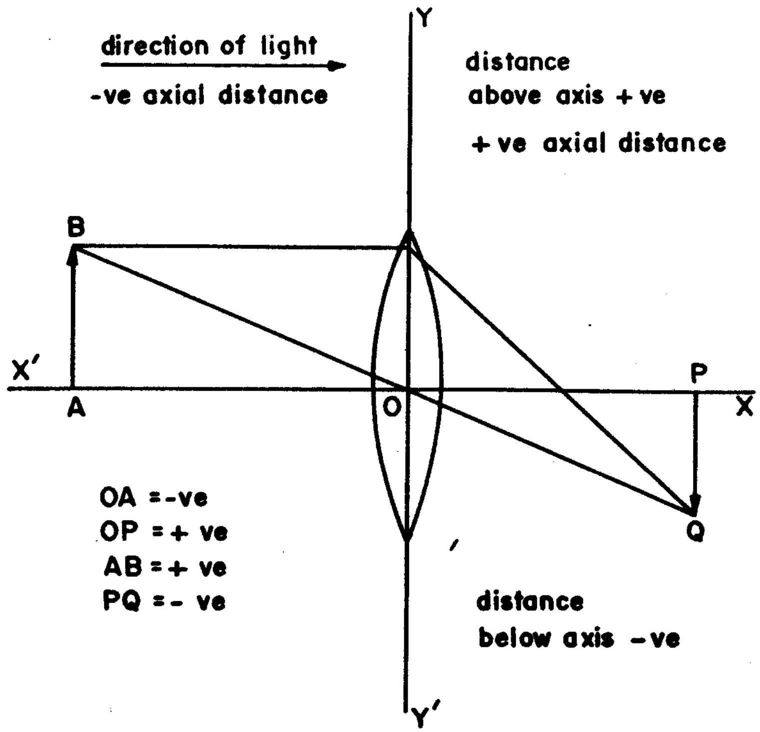


Fig. 5.13

rement of various distances, *e.g.*, object distance, image distance, etc. *These distances are vector quantities and, therefore, must be represented with proper signs.* It is therefore, essential to adopt a convention of signs to ensure consistency in the derivation and use of various formulae. The following set of conventions which agree with the usual convention of *Cartesian set of co-ordinates* used in co-ordinate geometrey as shown in Fig. 5.13 will be followed throughout this book.

(i) All figures are to be drawn with the incident light travelling from left to right.

(ii) The centre of the refracting system is at the origin O and its axis is along Xx'

(iii) All distances should be measured from the centre of the refracting system, i.e., from O. Distances measured to the left of O are considered negative while all distances to the right are considered positive.

(iv) Distances measured upward and normal to the X-axis are taken as positive, while downward normal distances are taken as negative.

In Fig. 5.13 AB represents an object while PQ is the corresponding image. The object distance OA is negative while the image distance OP is positive. The size of the object AB is positive while the size of the image is negative.

As can be seen from Fig. 5.10, according to the sign convention mentioned above, *the focal length, i.e., the second focal length of a convex lens is positive while the focal length of a concave lens is negative*

Magnification : Magnification (m) is defined as the ratio of the size of the image to that of the object.

$$m = \frac{\text{size of the image}}{\text{size of the object}} = \frac{\text{image distance}}{\text{object distance}} = \frac{v}{u}$$

Power of lens : The power of a lens is defined as its ability to converge a beam of light and is measured by the amount of convergence it can produce to a parallel beam of light. Since a convex lens produces *convergence*, its power is taken as *positive*. The power of a concave lens, which produces *divergence (opposite of convergence)*, is, therefore, taken as *negative*. Again a convex lens of small focal length produces a converging effect to a beam of light which is greater than that produced by a convex lens of longer focal length to the same beam of light. Thus a convex lens of small focal length has greater power than a convex

lens of large focal length. *Power can, therefore, be taken as the reciprocal of the focal length.*

The unit in which power is measured is called *dioptre* (D). A convex lens of focal length 1 meter has a power of + 1 dioptre. Mathematically,

$$P = \frac{1}{\text{focal length in metres}} \text{ dioptre.}$$

$$= \frac{100}{\text{focal length in centimetres}} \text{ dioptre.}$$

EXPT. 38 TO DETERMINE THE FOCAL LENGTH AND HENCE THE POWER OF A CONVEX LENS BY DISPLACEMENT METHOD WITH THE HELP OF AN OPTICAL BENCH.

Theory : If the object and the image screen be so placed on an optical bench that the distance D between them is greater than four times the focal length (f) of a given convex lens, then there will be two different positions of the lens for which an equally sharp image will be obtained on the image screen. Let the points O and I and L_1 and L_2 in Fig. 5.14 represent respectively the positions of the object and

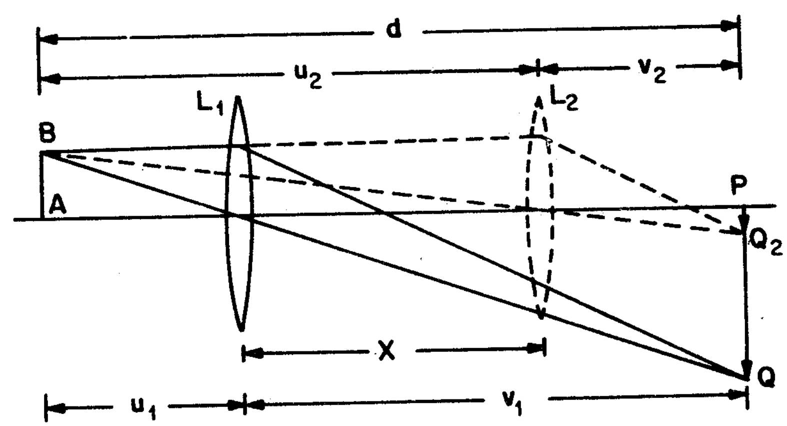


Fig. 5.14

the image screen and the two different positions of the lens for which an equally sharp image is obtained. Let the distance OI = D and $L_1 - L_2 = x$.

From the lens equation, we have

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

or, $\frac{1}{D-u} - \frac{1}{u} = \frac{1}{f}$ (since u + v =D)

Applying sign convention, u is negative.

or, $\frac{1}{D-u} + \frac{1}{u} = \frac{1}{f}$

or, $u^2 - ud + df = O$

Solving the above equation which is quadratic, we have two values of u corresponding to the two positions of the lens. These are

$u_1 = \frac{D}{2} - \sqrt{\frac{D^2 - 4Df}{2}}$ position L_1 of the lens

and $u_2 = \frac{D}{2} + \sqrt{\frac{D^2 - 4Df}{2}}$ position L_2 of the lens

Then $x = L_1 \sim L_2 = u_1 \sim u_2 = \pm \sqrt{D^2 - 4Df}$

or $x^2 = D^2 - 4Df$

or $f = \frac{D^2 - x^2}{4D}$ .... (1)

where D is the distance between the object and the image and must be greater than 4f and x is the distance between two different positions of the lens.

The power P of the lens is as usual given by the relation,

$$P = \frac{100}{f(\text{in cm})} \text{ dioptres}$$

Procedure : (i) Determine the approximate focal length of the given lens by holding it either in the sun or in front of a distant bright lamp and obtaining a sharply focussed image (light spot) on a piece of paper. Then the distance between the lens and the paper gives the approximate focal length.

(ii) Arrange the object (which may be a cross-wire fixed on a circular aperture of a screen, illuminated by a wax candle or milky electric bulb) and the image screen on their respective stands at a distance somewhat greater (by about 5 cm) than four times the focal length. In so doing place the object near one end of the optical bench and keep this position of the object fixed throughout the experiment. Place the lens, mounted on its stand, between the two and adjust the heights of all the three (object, screen and lens) so that the centres of the cross-wire of the object, the image screen and the lens are all in one horizontal straight line. Also make their planes perpendicular to the length of the optical bench.

(iii) Illuminate the cross-wire of the object screen. Now bring the lens close to the object. Then gradually move it away till you obtain a real, inverted and magnified image of the object which is sharply focussed on the screen. Note the position of the lens. Repeat the operation thrice. The mean of this three readings gives the position L_1.

(iv) Now move the lens further away from the object, till you obtan another sharply defined real, inverted but reduced image on the screen. Note the position of the lens. Repeat the operation thrice, the mean of which gives the position L_2 of the lens.

(v) Note down the position of the object and image screen, the difference of which gives the apparent distance D' between the object and the screen. Determine the index correction (λ) (see Art. 5.2) between the object and the screen. Then $D' + \lambda = D$ is the correct distance between the object and the screen. The distance $L_1 \sim L_2$ gives the displacement x of the lens which is free from any index error.

(vi) Repeat the whole operation at least three times, every time increasing the distance D in steps of say 4 to 5 cm. This should be done by moving away the image screen.

(vii) From the noted values of D and x, calculate f for each set of data. Determine the mean value of f and from this calculate the power (P) of the lens.

Results :

(A) Index error (λ) for D.

Table 1

Length of the index rod in cm (l)	Difference of bench scale readings in cm when the two ends of index rod touch the object and the screen (d)	Index correction for D in cm $\lambda = (l - d)$

(B) Readings for D and x.

Table II

No. of obs.	Position of				Displacement of lens $x = L_1 \sim L_2$ (cm)	Apparent distance between object and image $D' = O \sim I$	Corrected distance bewteen object and image $D = D' + \lambda$
	Object (O)	Image (I)	Lens at L_1	Lens at L_2			
			...	...			
1			...	...	...	..	..
2			...	...			
3	...	...					

(C) Table for calculation of f

Table III

No. of obs.	Lens dis placement x rom Tab. II	Corrected dis tance d from Tab. II	Focal length $f = \frac{D^2 - x^2}{4D}$	Mean focal length (f) cm	Power $P = \frac{100}{f}$ dioptes
1					
2					
3					

Note : *The method is advantageous because it involves the determination of only one index error. Also no determination of the thickness of the lens is involved.*

Note: *The focal length can also be determined as follows:*

Plot a graph with D as the abscissa and x^2/D as the ordinate. The resulting graph will be a straight line. Its intercept on the x-axis is numerically equal to 4f.

Eqn-1 can be written as $x^2/D = D - 4f$. Therefore, if a graph is plotted with D as abscissa and x^2/D as ordinate, it will be a straight line. The point where the graph cuts the x - axis, has the co-ordinates (4f, o), since $y = O = x^2/D$. Thus $D - 4f = O$;

or, $D = 4f$.

So, the point where the straight line cuts the x - axis has the value numerically egual to 4f.

Discussions : (i) The formula used in the experiment is true only when $D > 4f$ since the value of x diminishes with that of D and is zero when $D = 4f$ numerically. On the other hand D should not be very large, since the diminished image (when the lens is at L_2) will be so small that it could not be detected. The best way is to keep the values of D between 4f and 5f.

(ii) The value of D should be increased in steps of 4 to 5 cm since a small change in the value of D causes a large change in the value of x.

Oral Questions and their Answers.

1. *What is a lens?*
2. *Define (a) the principal axis., (b) principal focus and (c) optical centre of a lens.*
3. *What are the different kinds of lenses?*
4. *Define first and second focal lengths of a lens. Which one of them is normally taken as the focal length of the lens? Are the two focal lengths equal or different?*
5. *What are conjugate focii?*
6. *What do you mean by power of a lens?*

For answers to the above questions see Art. 5.1 - 5.3.

7. *Does the focal length depend on colour?*

Yes, as can be seen from the relation

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

the focal length f depends on the refractive index μ since the radii of curvature r_1 and r_2 are constant for the same lens. As μ depends on colour, *i.e.*, wavelength of light, f, therefore, also changes with the colour of light.

8. *What is the condition for getting a real image of a real object?*

The lens must be convex. The distance between the object and the image screen should be at least four times the focal length of the lens. The lens should be placed mid-way between the object and the image screen.

9. *How can you test whether a given lens is convex or concave?*

Hold the lens very close to a printed paper and move it along the paper.

(a) If the image of the printed letter is erect and diminished and move in the same direction as the lens, then it is a concave lens.

(b) If the image is erect and magnified and move in the opposite direction then it is a convex lens.

10. *What are the practical uses of a lens?*

They are used in telescopes, microscopes and other optical instruments such as cameras, magnifying glasses, spectacles, etc.

11. *What is the minimum distance between an object and the screen to get images for two positions of the lens?*

D must be greater than 4f.

12. *Why should the separation between the object and screen be more than 4f in this experiment?*

Otherwise images cannot be formed for two positions of the lens.

13. *Is it advisable to make D very large? If not why?*

See discussions.

14. *Why the index correction for x is not necessary?*

For the displacement of the lens must be equal to the displacement of the index mark of the lens stand.

15. *Why one image is magnified while the other is diminished?*

This is so because magnification = $\frac{\text{image distance}}{\text{object distance}}$

Hence as the object distance gets bigger and bigger, the magnification becomes smaller and smaller for the same value of D.

16. *Under what condition will a real magnified or a diminished image be formed?*

When the object is placed at a distance between the focus and 2f from the lens, then the image will be real and magnified. But if the object is placed between 2f and infinity the image will be real and diminished.

17. *By employing your data can you find f graphically?*

Yes, See Note at the end of Table-III

EXPT. 39. TO DETERMINE THE FOCAL LENGTH AND HENCE THE POWER OF A CONCAVE LENS BY USING AN AUXILIARY CONVEX LENS.

Theory : A concave lens cannot produce a real image of a real object; but if a virtual object is placed within its focus, it can produce a real image of the virtual object. This principle is utilised in determining the focal length of a concave lens. At first a real image of a real object is produced with the help of a convex lens. Then a concave lens is interposed between the convex lens and its real image in such a way that the real image falls within the focus of the concave lens. The real image then acts as the virtual object for the concave lens. This method has the advantage that the focal length of

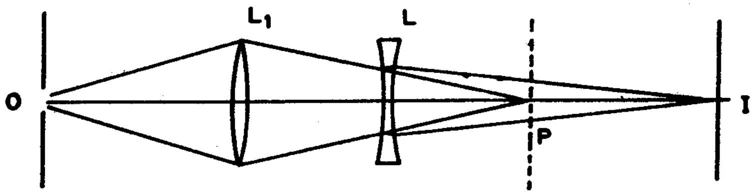


Fig. 5.15

the convex lens need not necessarily be less than that of the concave lens and is therefore suitable for any pair of concave and convex lenses. However, for greater accuracy of measurement, it is desirable that the focal length of the convex lens should be neither too large nor too small as compared to that of the concave lens.

Referring to Fig. 5.15 it can be seen that the convex lens L_1 forms at P a real image of the object O. Now if the concave lens L be so placed that the distance LP is less than its focal length, then the image at P will act as a virtual object for the concave lens and as a result a real image will be formed at the point I. Here the object distance LP = u and the image distance LI = v. According to sign convention both are positive.

Hence f, the focal length may be determined from the relation

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \qquad \text{or } f = \frac{uv}{u-v} \text{........ (1)}$$

since v > u, f will be negative which is quite in accordance with the chosen sign convention (Art.5.3)

The power P of the concave lens may be determined as usual from the relation

$$P = \frac{100}{f(cm)} \text{ dioptres .... (2)}$$

According to sign convention the power of a concave lens is negative (Art. 5.3.)

Apparatus : Optical bench, convex lens, concave lens, screen, index rod, etc.

Procedure : (i) Select a convex lens L_1 which has a focal length of the same order as that of the given concave lens.

(ii) Determine the approximate focal length of the convex lens (see procedure i, expt 38). Mount the object, the convex lens and the image screen in the manner described in procedure (ii) of expt. 38. The object, which is a cross-wire illuminated from behind, should be placed at one end of the optical bench. Place the image screen at a distance of 4f from the object where f is the focal length of the convex lens.

[If the distance is less than 4f no real image of a real object will be produced by a canvex lens. On the other hand if the distance is greater than 4f, then images will be obtained for two positions of the lens (expt. 38). It is important for this experiment that an image is obtained for only one position of the convex lens. This happens when the distance between the object and the screen is 4f.]

Place the convex lens mid-way between the object and the image screen and by slight adjustment of the screen or the lens or both, make sure that a sharply focussed image is obtained on the screen *for only one position of the lens.* The point P, which is the position of the screen will be the virtual object for the concave lens.

(iii) Note the position of the object, the lens and the screen. For the position of the image, take three independent readings and use the mean in your calculation. *The object and the convex lens should be left undisturbed throughout the rest of the experiment.*

(iv) Shift the image screen by about 5 cm from its position at P to a new position at I. Introduce the concave lens between P and L_1. The light from O will now be less convergent and as a result the image will no longer be formed at P. Adjust the position of the concave lens until a sharp image is formed on the screen at its new position I. Adjust the position of the concave lens three times independently and each time note its position from the main scale. Use the mean of these three positions in your calculation.

(v) Shift the position of the screen away from the concave lens for two or three more times by steps of about 5 cm and each time adjust the position of the concave lens until a sharp image is formed on the screen. As before, the position of the concave lens should be adjusted thrice and the mean of the three readings should be used.

(vi) Next determine the index correction (λ) between the concave lens and the screen and hence determine the corrected values for u and v.

(vii) From the corrected values of u and v determine f for each set of observations of u and v. Then find out the mean f which should be used in equation (2) to determine P, the power of the lens.

Results :

(A) Data for index error (λ) between the concave lens and the screen.

Table I

Length of index rod in cm (l)	Diff. of bench-scale readings in cm when the two ends of the index rod touch the concave lens and the screen (d)	Index correction in cm $\lambda = (l - d)$
...	...	...

(B) Table for u and v.

Table II

No. of obs.	Positions of Object (O)	Convex lens (L_1)	Image with convex lens (P)	Concave lens (L)	Image with combination (I)	Apparent object distance $u' = L \sim P$	Apparent image distance $v' = L \sim I$	$u = u' + \lambda$	$v = v' + \lambda$
1				...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...
3				...	...	...	...	...	...
4				...	...	...	...	...	...

(C) Table for 'f

Table III

No. of obs.	Object distance (u)	Image distance (v)	Focal length $f = \frac{uv}{u-v}$	Mean focal length (f) cm	Power $P = \frac{100}{f\,(cm)}$ dioptre
1					
2					
3					
4					
5					

Discussions : (i) The image formed by the concave lens should be focussed on the screen by shifting the positions of the concave lens and not by moving the screen. This is necessary because the focussed condition of the image will not change within an appreciable range of the movement of the screen.

(ii) If LP is equal to the focal length of the concave lens, then the light emerges from the concave lens parallel to the axis and consequently no image is formed.

Oral Questions and their Answers.

1. *Why do you use an auxiliary convex lens?*
   See theory.
2. *What happens if the convex lens forms the real image beyond the focal length of the concave lens?*
   In that case the image due to the concave lens is virtual and therefore cannot be held on the screen.
3. *Can the experiment be performed with a convex lens of any focal length?*
   Yes.
4. *Where should the object of the convex lens be placed?*
   Outside the focal length of the convex lens so that a real image may be formed.

EXPT. 40 TO DETERMINE THE REFRACTIVE INDEX OF A LIQUID BY PIN METHOD USING A PLANE MIRROR AND A CONVEX LENS.

Theory : If a convex lens is placed on a few drops of liquid on a plane mirror, then on squeezing the liquid into the space between the mirror and the lens a plano-concave liquid lens is formed. The curved surface of this liquid lens has the same radius of curvature as the surface of the convex lens with which it is in contact. Thus we have a combination of two lenses - one of glass and the other of liquid, which behaves as a convergent lens. If F be the focal length of the combination then we have the relation

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \dots\dots\dots (1)$$

where f_1 and f_2 are the focal lengths of the convex lens and the liquid lens respectively.

Correcting for the sign of f_2 which is negative,

we get $\frac{1}{F} = \frac{1}{f_1} - \frac{1}{f_2}$

or, $\frac{1}{f_2} = \frac{1}{f_1} - \frac{1}{F} \dots\dots\dots (2)$

Determining F and f_1 experimentally, we can calculate f_2 from relation (2).

The focal length f_2 of the plano-concave liquid lens is also given by the relation $\frac{1}{f_2} = (\mu - 1)\left(\frac{1}{r} - \frac{1}{r'}\right) = (\mu - 1)\left(\frac{1}{r}\right)$ ($r' = \infty$, the lower face of the liquid lens being a plane)

According to sign convention, both f_2 and r are negative. Thus

$$\frac{1}{f_2} = (\mu - 1)\left(\frac{1}{r}\right)$$

or, $\frac{1}{f_2} = \frac{\mu - 1}{r}$ or, $\mu = 1 + \frac{r}{f_2} \dots\dots\dots (3)$

where μ is the refractive index of the liquid.

Finding r, the radius of curvature of the lower surface of the convex lens *i.e.*, the surface in contact with the liquid, and knowing f_2 from relation (2), the refractive index μ of the liquid can be found out by using relation (3).

Apparatus : A convex lens, plane mirror, pin with its tip painted red, spherometer, slide callipers, stand and some experimental liquid.

Description of the apparatus : Spherometer (see Art 2.3)

Procedure : The experimental procedure may be divided into three parts -

(a) determination of the focal length f_1 of the convex lens

(b) determination of the focal length of the combination and

(c) measurement of the radius of curvature of that surface of the convex lens which is in contact with the liquid.

(a) Determination of the focal length of the convex lens: The focal length of a convex lens may be determined by the method described in expt. 38. But an easy and quicker way to determine this is by a method known *as pin method*. The method depends on the fact that if an object, say a pin P, be placed at the principal focus of a convex lens L (Fig. 5.16.), then the rays from it after passing through the lens emerge parallel. Parallel rays will be incident normally on the plane mirror M and will retrace their path after reflection. As a result an image (P') of the object will be formed just by the side of the object. The distance PL between the centre of the lens and the object is the focal length of the lens.

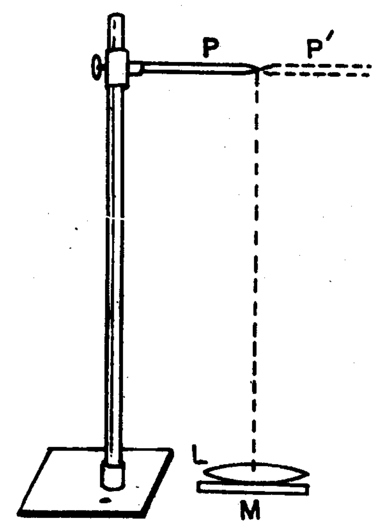


Fig. 5.16

(i) For the measurement of the focal length (f) of the convex lens place a plane mirror M on the table with its reflecting face upwards (Fig. 5.16). Place the lens L over the plane mirror M and clamp a pin, whose tip should be painted red, horizontally on a vertical stand in such a way that the tip of the pin is visible (see discussion i). Now find the position of the pin by moving it up or down so that there is no parallax (see Art 5.1) between P and P' *i.e*, the image of the tip and the tip itself. Measure the distance PL between the tip of the pin and the centre of the lens. In order to measure PL first measure the distance h_1 between the pin tip and the upper surface of the lens near its middle by a metre scale. Then remove the lens and measure its thickness t with a pair of slide callipers. PL is then equal to $h_1 + \frac{t}{3}$.

(ii) Repeat the operation (i) for three or four different settings and take the mean value of PL. *i.e.* f_1

(b) Determination of the focal length of the combination:

After determining the focal length of the convex lens carefully introduce a few drops of the liquid, whose refractive index is to be determined, into the air film between the plane mirror and the lens. The liquid will thenbe squeezed into the space between them by capillary action and a plano-concave lens of the liquid will be formed (Fig. 5.17). The combination of the liquid lens and the convex lens behaves as a convergent lens. Repeat the operations (i) and (ii) described in (a) and obtain the mean value of F.

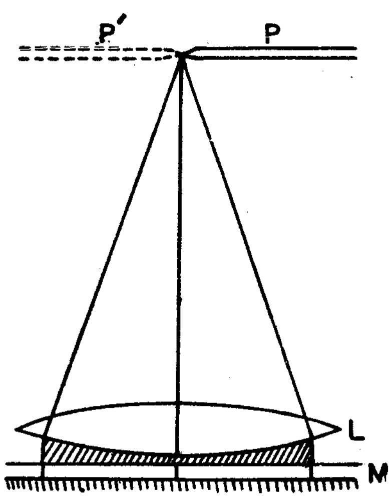


Fig. 5.17

(c) Determination of the radius of curvature:

Remove the lens and wipe it dry. With the help of a spherometer, measure the radius of curvature (r) of the surface of the lens which was in contact with the liquid in the manner described below :

(i) Determine the value of the smallest division of the vertical scale of the spherometer. Rotate the screw by its milled head for a complete turn and observe how far the disc advances or receeds with respect to the vertical scale. This distance is the *pitch* of the spherometer. Divide the pitch by the number of divisions in the circular scale. This gives the *least count* of the instrument.

(ii) Place the spherometer upon a piece of plane glass plate (base plate) and slowly turn the screw so that the tip of the central leg just touches the surface of the glass. When this is the case, a slight movement of the screw in the same direction makes the spherometer legs develop a tendency to slip over the plate.

(iii) Take the reading of the main scale nearest to the edge of the disc. Take also the reading of the circular head against the linear scale. Tabulate the results. Take three such readings at different places of the glass plate and take the mean value.

(iv) Now raise the central screw and place the spherometer on that surface of the convex lens which was in contact with the liquid. Turn the screw slowly till it just touches the surface of the lens. Note the readings of both the linear and circular scales. Repeat the operation at least three times at different places of the surface and take the mean of these readings. Let the difference of this reading and the reading on the base plate be *h*.

(v) Finally place the spherometer upon a piece of paper and slightly press it so that the three legs leave three dots on the paper. Measure the distance between these marks individually with a divider referred to a vernier scale. Take the mean of the three individual readings. Let this reading be *a*.

Then the radius of curvature of the surface of the lens is given by

$$r = \frac{a^2}{6h} + \frac{h}{2}$$

Results :

(A) Calculation of the Least Count.

Main scale is graduated in millimetres (say). Pitch of the micrometer screw, P = ... mm = ... cm

No. of divisions in the circular scale, n = ...

Least count (L.C.) of the instrument = $\frac{P}{n}$ = ... cm

(B) Measurement of h

Reading on	No. of obs.	Linear scale reading	Circular scale division	Least count	Fractional reading	Total	Mean
		cm	n	cm	nxL.C	cm	cm
Base Plate	1 2 3						
Lens surface	1 2 3						

h = Reading on lens - Reading on the base plate = ... cms

(C) Measurement of a .

(i) ...... cm (ii) ...... cm (iii) ...... cm

Mean value of a = ... cm

Hence the radius of curvature of the spherical surface,

$r = \frac{a^2}{6h} + \frac{h}{2}$ = ... cms

(D) Determination of the focal lengths.

Thickness of the lens, t = ... cm

No of obs.	Distance between the pin and the face of the lens without the liquid (h_1)	Focal length of the convex lens $f_1 = h_1 + \frac{t}{3}$	MEAN f_1	Distance between the pin and the top surface of the lens with the liquid (h_2)	Focal length of the combination F $= h_2 + \frac{t}{3}$	MEAN F	Focal length of the liquid lens $f_2 = \frac{F f_1}{F-f_1}$
1 2 3	... ...	... ...	... ...	...	... ...	...	... ...

Calculation : $\mu = 1 + \frac{r}{f_2} = ...$

Discussions : (i) If the pin is placed within the principal focus of the lens a virtual erect image will be observed, which is of no use, since it is the coincidence with the real inverted image which is looked for. The pin has to be moved further away from the lens till the image seen is inverted. Then the point of coincidence is found by strictly avoiding parallax.

(ii) The pin should be moved along the axis of the lens so that refraction may occur through the centre of the lens, thus avoiding spherical and chromatic aberrations.

EXPT. 41 TO DETERMINE THE REFRACTIVE INDEX OF THE MATERIAL OF A CONVEX LENS BY A TELESCOPE AND SPHEROMETER.

Theory : When a telescope is focussed at an object at infinity and the image formed at the cross-wires of the eye-piece of the telescope, then the cross-wires must have been placed at the principal focus of the objective, because the image distance *i.e.*, the distance between the cross- wires and the objective in this case must be equal to the focal length of the objective of the telescope (Fig. 5.18). Now let a convex lens, the refractive index of whose material is to be determined, be placed in front of the telescope objective in such a way that it just touches the objective. Without any adjustment of the telescope, if an object at a certain distance u from the convex lens be focussed so that its image is still formed on the cross-wires, then the object distance u must be

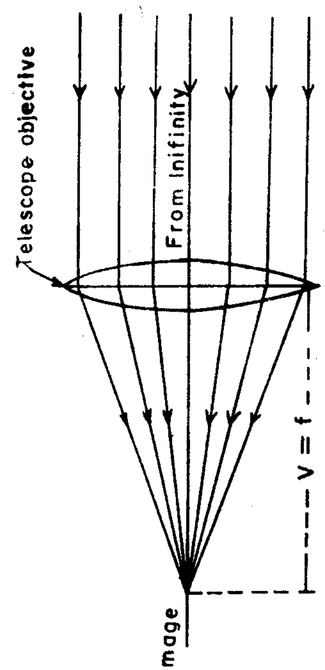


Fig. 5.18

always have a point-to-point phase relationship, *i.e.*, they are coherent. The formation of interference fringes by (i) Fresnel bi-prism, (ii) Lloyd's single mirror, (iii) Fresnel's double mirror, (iv) Rayleigh's interferometer, etc., belong to this category.

(b) Division of amplitude : In this method, the wavefront is also divided into two parts by a combination of both reflection and refraction. Since the resulting wavefronts are derived from the same source, they satisfy the condition of coherence. Examples of this class are the interference effects observed in (i) thin films, (ii) Newton's rings (iii) Michelson interferometer, (iv) Fabry-Perot interferometer, etc.

EXPT. 46. TO DETERMINE THE RADIUS OF CURVATURE OF A LENS BY NEWTON'S RINGS.

Theory : Newton's rings is a noteworthy illustration of the interference of light waves reflected from the *opposite surfaces of a thin film of variable thickness*. When a plano-convex or bi-conves lenx L of large radius of curvature is placed on a glass plate P, a thin air film of progressively increasing thickness in all directions from the point of contact between the lens and the glas plate is very easily formed (Fig. 5. 36). The air film thus possesses a radial symmetry about the point of contact. When it is illuminated normally with monochromatic light, an interference pattern consisting of a series of alternate dark and bright circular rings, concentric with the point of contact is observed (Fig. 5.37). *The fringes are the loci of points of equal optical film thickness* and gradually become narrower as their radii increase until the eye or the magnifying instrument can no longer separate them.

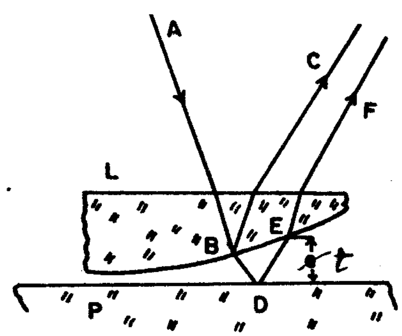


Fig. 5.36

Let us consider a ray of monochromatic light AB from an extended source to be incident at the point B on the upper surface of the film (Fig. 5. 36). One portion of the ray is reflected from point B on the glass air boundary and goes upwards along BC. The other part refracts into the air film along BD. At point D, a part of light is again reflected along DEF. The two reflected waves BC and BDEF are derived from the same source and are *coherent*. They will produce constructive or destructive interference depending on their path difference. Let e be the thickness of the film at the point E. Then the optical path difference between the two rays is given by $2\mu e \cos(\theta+r)$ where θ is the angle which the tangent to the convex surface at the point E makes with the horizontal, r is the angle of refraction at the point B and μ is the refractive index of the film with respect to air.

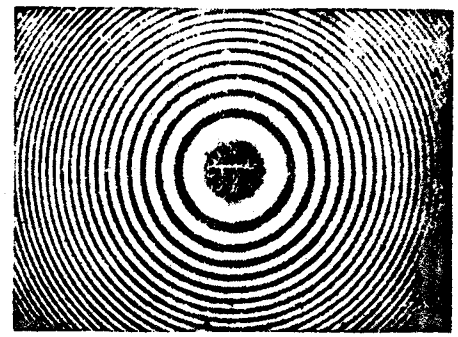


Fig.5.37

From an analytical treatment by Stokes, based on the principle of *optical reversibility*, and Lloyd's single mirror experiment, it was established that *an abrupt phase change of π occurs when light is reflected from a surface backed by a denser medium, while no such phase change occurs when the point is backed by a rarer medium.* In Fig. 5.36 the point B is backed by a rarer medium (air) while the point D is backed by a denser medium (glass). Thus there will be an additional path difference of $\frac{\lambda}{2}$ between the rays BC and BDEF corresponding to this phase difference of π. Then the total optical path difference between the two rays is

$$2\mu e \cos(\theta+r) \pm \frac{\lambda}{2}$$

The two rays will interfere constructively when

$$2\mu e \cos(\theta+r) \pm \frac{\lambda}{2} = n\lambda$$

$$\text{or} \quad 2\mu e \cos(\theta+r) = (2n-1)\frac{\lambda}{2} \ldots \quad \ldots (1)$$

The minus sign has been chosen purposely since n cannot have a value of zero for bright fringes seen in reflected light. The rays will interfere destructively when

$$2\mu e \cos(\theta+r) \pm \frac{\lambda}{2} = (2n \pm 1)\frac{\lambda}{2}$$

$$\text{or } 2\mu e \cos(\theta+r) = n\lambda \ldots \quad \ldots. (2)$$

λ is the wavelength of light in air.

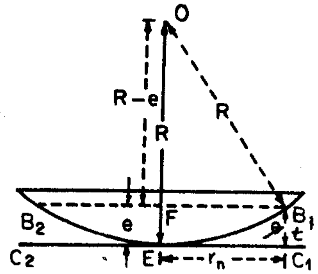


Fig. 5.38

In practice, a thin lens of extremely small curvature is used in order to keep the film enclosed between the lens and the plane glass plate extremely thin. As a consequence, the angle θ becomes negligibly small as compared to r. Furthermore, the experimental arrangement is so designed (Fig. 5.39) that the light is incident almost normally on the film and is viewed from nearly normal directions by reflected light so that cosr = 1. Accordingly eqns. (1) and (2) reduce to

$$2\mu e = (2n-1)\frac{\lambda}{2} \ldots \ldots. \text{ bright}$$

$$\text{and } 2\mu e = n\lambda \ldots \quad \ldots \text{ dark.}$$

Let R be the radius of curvature of the convex surface which rests on the plane glass surface (Fig. 5.38). From the right angled triangle OFB_1, we get the relation

$$R^2 = r_n^2 + (R-e)^2$$

$$\text{or } r_n^2 = 2Re - e^2$$

where r_n is the radius of the circular ring corresponding to the constant film thickness e. As outlined above, the condition of the experiment makes e extremely small. So to a sufficient degree of accuracy, e^2 may be neglected compared to 2Re. Then $e = \frac{r_n^2}{2R}$

Substituting the value of e in the expressions for bright and dark fringes, we have

$$r_n^2 = \frac{n\lambda R}{2\mu} \ldots \quad \ldots \text{ bright}$$

$$\text{and } r_n^2 = (2n-1)\frac{\lambda R}{\mu} \quad \ldots \quad \ldots \text{ dark.}$$

The corresponding expressions for the squares of the diameters are

$$D_n^2 = 2\,(2n-1)\frac{\lambda R}{\mu} \quad \ldots \quad \ldots \text{ bright}$$

$$\text{and } D_n^2 = \frac{4n\lambda R}{\mu} \quad \ldots \quad \ldots \text{ dark.}$$

In the laboratory, the diameters of the Newton's rings can be measured with a travelling microscope. Usually a little away from the centre, a bright (or dark) ring is chosen which is clearly visible and its diameter measured. Let it be the n^{th} order ring. For an air film $\mu=1$. Then we have

$$D_n^2 = 2\,(2n-1)\lambda R \quad \ldots \quad \ldots (3) \ldots \quad \ldots \text{ bright}$$

$$\text{and } D_n^2 = 4n\,\lambda R \ldots \quad \ldots (4) \ldots \quad \ldots. \text{ dark}$$

The wavelength of the monochromatic light employed to illuminate the film can be computed from either of the above equations, provided R is known.

However, in actual practice, another ring, p rings from this ring onwards is selected. The diameter of this $(n+p)^{th}$ ring is also measured. Then we have

$$D_{n+p}^2 = 2(2n+2p-1)\;\lambda R \quad \ldots \quad \ldots \text{ bright}$$

$$\text{and } D_{n+p}^2 = 4(n+p)\;\lambda R \quad \ldots \quad \ldots \text{ dark}$$

Subtracting D_n^2 from D_{n+p}^2, we have

$$D_{n+p}^2 - D_n^2 = 4p\,\lambda R \ldots \quad (5)$$

for either bright or dark ring.

$$\text{or } R = \frac{D_{n+p}^2 - D_n^2}{4p\lambda} \ldots \quad \ldots (6)$$

Note : *In Newton's rings experiment eqn. (5) is invariably employed to compute λ or R. The advantage of eqn. (5) over eqns, (3) and (4) lies in the fact that eqns. (3) and (4) have been derived on the supposition that the surfaces of the lens and the plate are perfect, i.e., the thickness of the air film at the point of contact is zero (e=o). This gives rise, in a reflected system, a fringe system of alternate bright and dark rings concentric with a central dark spot. In actual practice, either due to some imperfections in the surfaces in contact or due to encroachment of some dust particles between the lens and the plate, they may not be in perfect contact i.e., the thickness of the film may not be zero at the central point. The order, x, of the central ring is therefore indeterminate, i.e., it is not possible to say with certainty if the central dark ring corresponds to zero, 1st, 2nd, etc., order. The central spot may even be white. As a consequence, the order of every other bright or dark ring advances by this indeterminate nubmer x. For any one of them, the square of the diameter is not given by eqn. (3) or (4). But this indeterminacy does not occur in eqn. (5) when the difference of the squares of the diameters of the n^{th} and $(n+p)^{th}$ dark or bright rings are considered, counting the rings p, between them visually.*

Apparatus : Two convex lenses one of whose radius of curvature is to be determined, glass plate, sodium lamp, travelling microscope,etc.

Description of the apparatus:

The experimental arrangement of the apparatus is shown in Fig. 5.39. Light from an extended monochromatic source S (sodium lamp),placed at the principal focus of the convex lens C, falls on the lens and are rendered parallel. This parallel beam of light then falls on the glass plate G, inclined at an anlge of 45°, and are reflected downwards normally on to the lens L, the radius of curvature of whose lower surface is R. The lens L (see discussion v) is placed on the glass plate P which is optically worked *i.e.*, silvered at the back. A

travelling microscope M, directed vertically downwards, magnifies the system of rings. The lens C, can be fitted in the circular aperture of a screen which can be used to prevent light from the source to reach the observer's eye.

Travelling Microscope : See Art.2.5

Sodium lamp or bunsen flame soaked with NaCl sloution: See Art. 5.4.

Procedure : (i) Arrange your apparatus as shown in Fig.5.41. Level the microscope so that the scale along which it slides is horizontal and the axis of the microscope is vertical. Focus the eye-piece on the cross-wires. Determine the vernier constant of the micrometer screw of the microscope.

(ii) Carefully clean the surfaces of the lens L and the glass plate P by means of cotton moistened with benzene or alcohol. Place the glass plate P as shown in the figure. Make an ink dot-mark on the glass plate and focus the microscope on this dot. Now place the lens L on it in such a way that the centre of the lens, which is exactly above the dot, is vertically below the microscope objective.

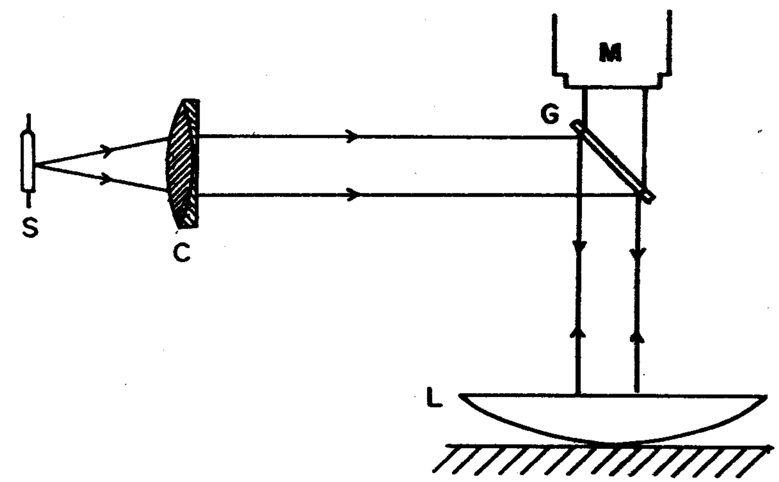


Fig. 5.39

(iii) Place the glass plate G in its position, as shown in the figure, in such a way that light from the source S, after passing through the lens C, is incident on it at an angle of approximately 45°. If you now look into the microscope, you will probably see a system of alternate dark and bright rings. Adjust the glass plate G by rotating it about a horizontal axis until a large number of evenly illuminated bright and dark rings appear on both sides of the central dark spot. Adjust the position of the lens C with respect to the flame so that a maximum number of rings are visible through the microscope. This will happen when the flame will be at the focal plane of the lens C.

(iv) After completing these preliminary adjustments, focus the microscope to view the rings as distinctly as possible and set one of the cross-wires perpendicular to the direction along which the microscope slides. Move out the microscope to the remotest distinct bright ring on the left side of the central dark spot. The cross-wire should pass through the middle of the ring and should be tangential to it. Note the reading of the microscope. Move the microscope back again. Turn the screw always in the same direction to avoid any error due to back-lash. Set the cross-wire carefully on the centre of each successive bright ring and observe the microscope reading. Go on moving the microscope in the same direction. Soon it will cross the central dark spot and will start moving to the right side of it. As before set the corss-wire on the consecutive bright rings and take readings. Proceed in this way until you have reached the same remotest bright ring as in the case of left side of the dark spot. Considering a particular ring, the difference between the left side and right side readings, gives the diameter of the ring. In this way, the diameters of the various rings are determined (see discussion)

(v) Tabulate the readings as shown below. *While tabulating the reading you should be careful about the*

number of the ring so that the left side and right side readings correspond to the same ring.

(vi) The whole experiment may be repeated moving the microscope backwards in the opposite direction over the same set of rings.

(vii) Draw a graph with the square of the diameter as ordinate and number of the ring as abscissa. The graph should be a straight line (Fig.5.40)

(viii) From the graph determine the difference between the squares of the diameters of any two rings which are separate by say about 10 rings *i.e.*, p is equal to 10. Now calculate R with the help of eqn. (6)

Results :

Vernier const. of the micrometer screw : (Record details as in previous expts.)

Table for ring diameter

ring number	Readings of the microscope								Diameter of the ring [D=L~R]	D^2
	Left side				Right side					
	Main scale reading (S) cm	Vernier reading (V) = Ver.divn. X V.C. cm	Total reading = S+V cm	Mean (L)	Main scale reading (S) cm	Vernier reading (V) = Ver. divn. X V.C. cm	Total reading = S+V cm	Mean (R)		
---	--- --- ---	--- --- ---	--- --- ---	---	--- --- ---	--- --- ---	--- --- ---	---	---	---
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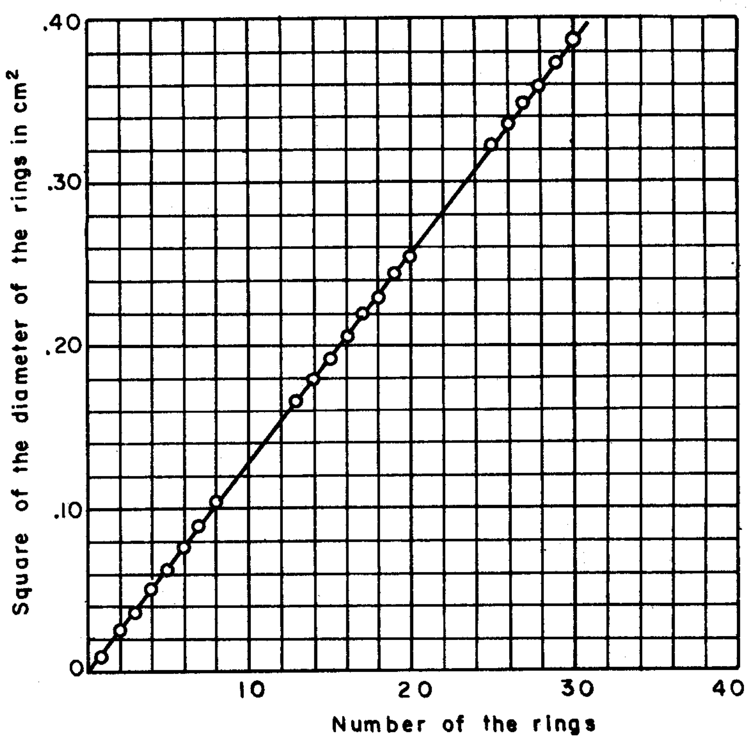

Graph (Fig.5.40)

Calculation :

Mean wavelength of sodium light (λ)=5893 A.U.= 5893×10^{-8} cm

From the graph $D^2_{n+p} - D^2_n = \ldots \quad \ldots\ cm^2$.

$D^2_{n+p} - D^2_n = 4p\lambda R$

$$R = \frac{D^2_{n+p} - D^2_n}{4p\lambda}$$

The radius of curvature of the lower surface of the given lens = ... cm.

Discussions : (i) The intensity of the ring system decreases as one goes from the inner to the outer rings, thus setting a limit for the selection of the outermost ring whose diameter is to be measured.

(ii) Newton's rings can also be observed in transmitted light but in that case the rings will be less clearly defined and less suited for measurement.

(iii) It may be noticed that the inner rings are somewhat broader than the outer ones. Hence while measuring the diameter of the inner rings some error may be introduced. The cross-wire should be set mid-way between the outer and inner edges of a ring. A more correct procedure is to determine the inner and outer diameters of a particular ring by setting the cross-wire tangentially at the inner and outer edges on both sides of the ring. From this the mean diameter can be found.

(iv) The first few rings near the centre may be deformed due to various reasons. The measurement of diameters of these rings may be avoided.

(v) For the purpose of the experiment a convex lens whose radius of curvature is of the order of 100 cm is suitable. Otherwise the diameters of the rings will be too small and it will be difficult to measure them.

(vi) Due account should be taken of the fact that in the present experiment, the rings which are formed in the air film in the space between the lens and the glass plate are not seen directly but after refraction through the lens. This inevitably introduces an error. However, if the lens used is thin then this error is not great.

EXPT. 47. TO DETERMINE THE WAVELENGTH OF MONOCHROMATIC LIGHT BY NEWTON'S RINGS.

Theory : We have seen in the theory of the previous experiment that the difference in the squares of the diameters of the n^{th} and $(n+p)^{th}$ rings is given by

$$D^2_{n+p} - D^2_n = \frac{4p\lambda R}{\mu}$$

For an air-film $\mu=1$

Then $D^2_{n+p}-D^2_n = 4p\lambda R$

or $\lambda = \dfrac{D^2_{n+p}- D^2_n}{4pR}$ ... ... (1)

Thus if R, the radius of curvature of the surface of the lens in contact with the plane glass plate is known, then λ can be determined from the above equation.

Apparatus, Description of apparatus, Experimental set-up: Same as expt.46.

Procedure : (i) Determine the difference between the squares of the diameters of any two rings (D^2_{n+p}- D^2_n) which are separated by say about 10 rings (p=10) in the manner described in the previous experiment.

(ii) Measure the radius of curvature of the surface of the lens which was in contact with the glass plate in the manner described in expt.40.

Results :

A. *Table for ring diameter :*
Same as in expt.46
Graph of ring number *vs.* (diameter)^2
Similar as Fig.5.40

B. *Table for radius of curvature of the lens:*
Arrange your data in the manner shown in expt.40, and calculate R.

Calculation :

From the graph, D^2_{n+p} -D^2_n=... cm^2
Radius of curvature of the lens, R=...cm

$\lambda = \dfrac{D^2_{n+p}-D^2_n}{4pR}$ = ... cm= .. A.U.

Discussions : Same as in expt. 46.

Art. 5.6 : Essential discussions for diffraction experiments.

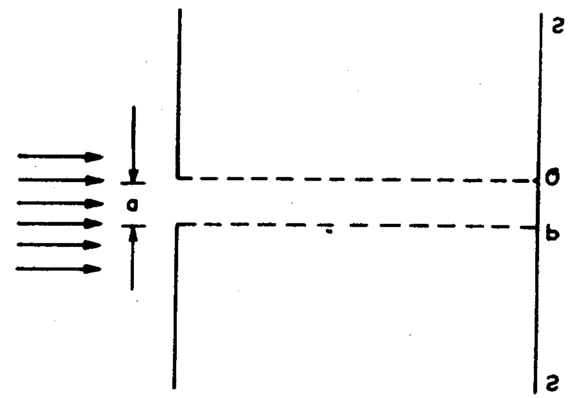

Fig. 5.41

Let us start by refering to Fig. 5.41 where a beam of light is incident on a long narrow slit of width *a* and is allowed to fall on a screen SS' placed at a certain distance from the slit. According to geometrical optics, only the portion PQ of the screen which is of the same dimension as the slit and directly opposite to it will be illuminated. The rest of the screen will remain absolutely dark and is known as the *geometrical shadow*. However, on careful observation it will be found that if the width of the slit is not very large compared to the wavelengh of light used, some light will encroach into the region of geometrical shadow. As the width of the slit is made smaller and smaller, this encroachment of light into the geometrical shadow becomes larger and larger. *This encroachment or bending of light into the region of geometrical shadow is known as diffraction of light.* The phenomenon of diffraction is a part of our common experience. The luminous border that surrounds the profile of a mountain just before the sun rises behind it, coloured circular fringes when strong source of light is viewed through a fine cloth, etc., are the practical day to day examples of diffraction.

Classes of diffraction : Based on the relative positions of the source, obstacle and screen, the diffraction phenomenon is classified into following two groups, known for historical reasons as (i) *Fresnel class of diffraction and (ii) Fraunhofer class of diffraction.*

1. Fresnel class : The source of light or the screen or both are at finite distances from the diffracting aperture or slit. Its explanation as well as practical demonstration is relatively difficult.

2. Fraunhofer class : Both the source and the screen are at infinite distances from the aperture. This is very conveniently achieved by placing the source on the focal plane of a convex lens and placing the screen on the focal plane of another convex lens. The first lens makes the light beam parallel and the second lens makes the screen receive a parallel beam of light, thus effectively moving both the source and the screen to infinity. Thus it is not difficult to observe the Fraunhofer diffraction pattern in the laboratory. An ordinary laboratory spectrometer is all that one needs for observing this pattern; the collimator renders the incident light parallel and the telescope receives parallel beams of light on its focal plane. The diffracting aperture is placed on the prism table.

Diffraction and interference:

Let a beam of parallel monochromatic light be incident normally on a slit on an opaque plate. A slit is a rectangular aperture of length large compared to its breadth. The beam, transmitted through the slit, spreads out perpendicularly to the length of the slit. When this beam is brought to focus on a screen by a lens, a diffraction pattern of the Fraunhofer class is obtained. The pattern consists of a central band, much wider than the slit width, situated directly opposite to the slit and bordered by dark and bright bands of decreasing intensity.

The origin of the pattern can be understood on the basis of Huygens' interference of secondary wavelets. According to Huygens' principle, these wavelets can be thought of as sent out by every point of the wavefront at the instant it occupies the plane of the slit. Each secondary wavelet can be regarded as a spherical wave spreading out in the forward direction. The parts of each wavelet travelling normally to the slit, are brought to focus by the lens at a point on the screen directly opposite to the centre of the slit. The parts of the wavefront travelling at a particular angle with the normal are brought

to focus at another particular point on the screen and are regarded to be diffracted at that particular angle. Thus it follows, exactly along the same argument, that diffracted rays start from every point in every direction. If there are more than one slits, diffraction takes place at individual slits and the diffracted beam from different slits interfere to give an interference pattern. Thus the intensity at any point will depend upon the intensity due to diffraction at the single slit and interference due to two or more slits used, *i.e., the resultant diffraction pattern due to two or more slits is the combination of diffraction and interference effects.*

Diffraction grating : The principal maxima in case of single slit is broad and diffused. If the diffraction patterns due to single, double, ... five .... slits are examined, a gradual change in the diffraction pattern will be observed. The most striking modification consists in the gradual narrowing of the interference maxima as the number of slits is gradually increased. With two slits these maxima are diffuse, the intensity varying essentially as the square of the cosine. With more slits, the sharpness of these principal maxima increases rapidly, essentially becoming narrow lines with 20 slits. Apart from this, by far the most important change which is noticed is the appearance of weak *secondary maxima* between the principal maxima. The number of these secondary maxima increases with the increase in the number of slits, but the intensity of these secondary maxima decreases with the increase in the number of slits. With three slits, the number of secondary maxima is one; its intensity being 11.1 per cent of the principal maxima. With four slits this number becomes two and with five slits there are three weak secondary maxima. With more number of slits, the intensity of the secondary maxima becomes negligibly small so that these are not visible in the diffraction pattern.

A large number of closely spaced parallel slits separated by equal opaque spacings form a *diffraction grating*. If there are N slits the effect at any point may be considered to be due to N vibrations. A cross-section through a grating is shown in Fig 5.42. It consists of a series of slits, of width b

separated by opaque strips of width a. Let a parallel beam of monochromatic light from an illuminated slit be incident normally on this grating. Let this beam of light be diffracted through an angle θ. From the figure it is clear that light reaching the objective lens of the telescope from the various

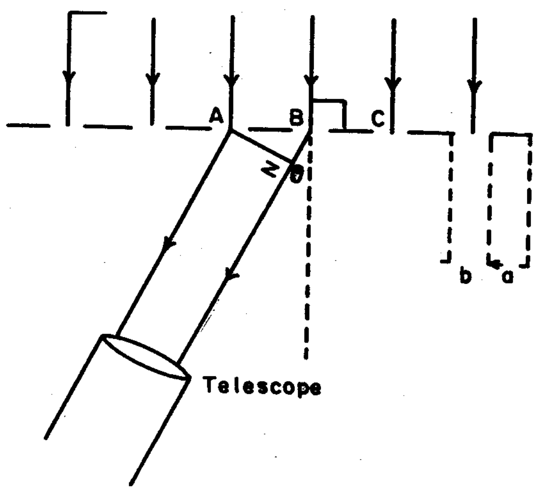

Fig. 5.42

slits of the grating has travelled a distance which is different for different slits. Let the path difference for two rays at A and B which originate from two adjacent slits be BN. But BN=AB sin θ= $(a+b)$ sin θ since AB=$a+b$. Clearly, the path difference for two rays originating from slits which are not adjacent will be a whole number (integral) multiple of $(a+b)$ sin θ .For example, the path difference between wavelets starting from A and C will be 2 $(a+b)$ sin θ and so on.
Taking the phase of vibration from A as zero, the phase from slit to slit increases by $\left(\frac{2\pi}{\lambda}\right)(a+b)\sin\theta$, *i.e.*, this is the common phase difference for N vibrations originating from N slits. The average phase change between two corresponding points on slits A, B is $[o+\left(\frac{2\pi}{\lambda}\right)(a+b)\sin\theta]/2$

$=\left(\frac{\pi}{\lambda}\right)(a+b)\sin\theta$. This is true for any of the two corresponding points on the consecutive slits. If $\frac{A_0\sin\alpha}{\alpha}$ is the amplitude of the secondary wavelets originating from any one of the slits (see a text book on optics), then the resultant for N slits is given by

$$R = \frac{A\sin(nd)}{\sin d}$$

where $A = \frac{A_0\sin\alpha}{\alpha}$, $n = N$ and $d = \frac{\pi}{\lambda}(a+b)\sin\theta$.

$$\therefore R = A_0\frac{\sin\alpha}{\alpha}\,\frac{\sin[N\frac{\pi}{\lambda}(a+b)\sin\theta]}{\sin[(\frac{\pi}{\lambda})(a+b)\sin\theta]}$$

$$\text{Intensity} \quad I = R^2 = A_0^2\frac{\sin^2\alpha}{\alpha^2}\,\frac{\sin^2 N\phi}{\sin^2\varphi}$$

where $\varphi = \frac{\pi}{\lambda}(a+b)\sin\theta$.

The expresssion for intensity contains both diffraction and interference effects.

(i) The term $A_0^2\frac{\sin^2\alpha}{\alpha^2}$ gives the distribution of intensity due to diffraction at a single slit.

(ii) $\frac{\sin^2 N\varphi}{\sin^2\varphi}$ corresponds to interfernce pattern of N slits.

Thus the final diffraction pattern is the resulant of two. The first factor $A_0^2\frac{\sin^2\alpha}{\alpha^2}$ may be taken to be constant for a slit of definite dimensions. The intensity in the final pattern will depend on $\frac{\sin^2 N\varphi}{\sin^2\varphi}$; but for a definite value of N, the intensity depends on phase, *i.e.*, $\varphi = \frac{\pi}{\lambda}(a+b)\sin\theta$.

For principal maxima, the condition is sinθ=0, or θ = ±nπ, where n = 0,1, 2,3,..........

$$\therefore \quad \frac{\pi}{\lambda}(a+b)\sin\theta = n\pi$$

or $(a+b)\sin\theta = n\lambda$ (principal maxima).................(1)

where θ is the angle of diffraction.

Eqn. (1) is fundamental in the theory of grating.

If there are N slits per cm, then

$$\frac{1}{N} = (a+b)$$

$$\text{or} \quad \lambda = \frac{\sin\theta}{nN}$$

where n is the order of the spectrum. $(a+b)$ is called the *grating element* and the reciprocal of the grating element $\frac{1}{(a+b)}$' is known as the *grating constant.*

Hence, if light of wavelength λ is incident on the grating, we expect to find light diffracted through angles $\theta_0 = 0$ [no diffraction]; $\theta_1 = \sin^{-1}\left(\frac{1}{a+b}\right)$ [the first order of diffraction, *i.e*, n=1] $\theta_2 = \sin^{-1}\left(\frac{2\lambda}{a+b}\right)$ [second order of diffraction, *i.e.*, n = 2],

and so on . In practice, the intensity of the light diffracted at any angle decreases rapidly as θ increases. Thus, it is probable that only first and second order diffraction will be seen.

Dispersive power of grating : Differentiating eqn. (1), we have

$$\frac{d\theta}{d\lambda} = \frac{n}{(a+b)\cos\theta} \quad ....(2)$$

Eqn. (2) gives the angular dispersive power of the grating, *i.e.*, its capacity to disperse different wavelengths. Evidently dispersive power depends

(i) directly on the order of the spectrum n.

(ii) inversely on the grating element $(a+b)$ and hence directly on the number of rulings per cm.

(iii) inversely on $\cos\theta$, *i.e.*, directly on θ and hence wavelength λ.

A *diffraction grating* is made by ruling equidistant parallel straight lines on a glass plate. The lines are ruled by a diamond point moved by an automatic dividing engine

containing a very fine micrometer screw which moves sideways between each stroke. The pitch of the screw must be constant so that the lines are as equally spaced as possible, which is an important requirement of a good quality grating. As such a grating is very costly. What is usually used in its place in the laboratory is a *photographic replica* of the same, possibly prepared by contact printing on a fine grained photographic plate. When using a replica, never try to clean or touch its surfaces at any time. Whenever it is to be handled, it must be held by the edges between the thumb and the middle finger.

The diffraction gratings are of two types : *transmission type and the reflection type.* The lines, mentioned above, act as opaque spaces and the space between any two consecutive lines is transparent to light. Such surface act as transmission gratings. If on the other hand lines are ruled on a silvered plane or concave surface, then light is reflected from the positions of the mirror in between any two lines. Such surfaces act as reflection gratings.

EXPT. 48. TO DETERMINE THE WAVELENGTHS OF VARIOUS SPECTRAL LINES BY A SPECTROMETER USING A PLANE DIFFRACTION GRATING.

Theory : If a parallel pencil of monochromatic light of wavelength λ, coming out of the collimator of a spectrometer falls normally on a plane diffraction grating placed vertically on the prism table, a series of diffracted image of the collimator slit will be seen on both sides of the direct image. Reckoning from the direction of the incident light (direct image), if θ be the deviation of the light which forms the n^{th} image and $(a+b)$ be the grating element, then $(a+b)\sin\theta = n\lambda$.

Since $a+b = \frac{1}{N}$, where N is the grating constant *i.e.*, the number of lines or rulings per cm of the grating surface, $\sin\theta = nN\lambda$. Thus $N = \frac{\sin\theta}{n\lambda}$ ...(i) and $\lambda = \frac{\sin\theta}{Nn}$....(2)

By employing sodium light of known wavelength the value of N can be determined first. Then from this knowledge of N, the wavelength λ of any unknown light can be found out with the help of equation (2).

Apparatus : Spectrometer, spirit level, a prism, plane diffraction grating, discharge tubes, etc.

Description of the apparatus : See spectrometer (Art. 5.4) and diffraction grating (Art.5.6),

Description of the apparatus : Spectrometer (See Art. 5.4).

Discharge tube : Gas discharge tubes, also known as *Geissler tubes*, are widely used in the laboratory for spectroscopic purposes. It is generally given in two shapes. The first one is a straight glass tube, the central part BC of the tube being a capillary having a length of about seven or eight centimetres and a diameter of about one millimetre. Two aluminium or platinum electrodes are sealed into this tube at the two ends A and D (Fig. 5.45 a). The tube is filled with the gas, whose spectrum is to be studied, at a pressure of 1 or 2 mm of mercury. More than 2000 volts potential is applied between the electrodes with the help of an induction coil high tension D.C. source (power pack).

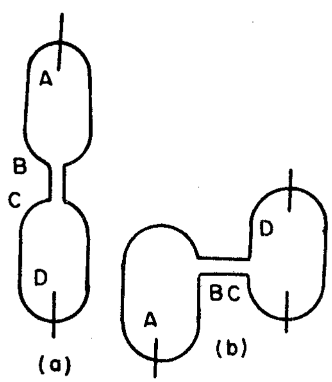

Fig. 5.43

The light comes from the positive column of the discharge and is the most intense in the capillary where the current density is the highest. The second type, as shown in Fig. 5.43 b, also works on the same principle and is of H- shape. The length of capillary tube in this design is only about 4 centimetres. Thus, it makes a source of greater intensity than the first one. The intensity is still further increased if the capillary is viewed *end on*. These tubs were used for many years for the study of the spectra of substances which could be obtained in the form of vapour or gas. They require

a high potential, still the operating current is only of the order of few milliamperes which cannot heat the electrodes sufficiently and therefore they are knwon as cold cathode tubes.

Procedure : The preliminary adjustments for this experiment are twofold (a) those of the spectrometer and (b) those of the grating.

(a) Make all the adjustments of the spectrometer including focussing for parallel rays in the usual manner as described in Art. 5.4.

The following adjustments should be made in connection with the mounting of the grating.

(1) *To make the plane of the grating vertical and set it for normal incidence :* (i) Focus the telescope towards the direct light coming through the collimator. Note the position of the telescope (direct reading). Then turn the telescope through exactly 90°and fix it there.

(ii) Place the grating, mounted in its holder, on the prism table. The grating should be so placed that the lines of the grating are perpendicular to the table and the plane of the grating, defined by the ruled surface, passes through the centre of the table so that the ruled surface, extends equally on both sides of the centre. At the same time, the grating should be perpendicular to the line joining any two of the levelling screws say E and F in Fig. 5.22.

(iii) Rotate the prism table till you get, on the cross-wires of the telescope, an image of the slit formed by reflection at the grating surface. The image may not be at the centre of the cross-wires. If so, turn one of the screws till the centre of the image reaches the intersection of the cross-wires. In this position the plane of the grating has been adjusted to be vertical. The angle at which light is now incident on the grating is obviously 45°. Read the position of the prism table, using both the verniers.

(iv) Now look carefully at the grating on the table and ascertain whether the surface of the grating which first receives the light is the one which also contains the lines. (Allow the light to be reflected alternately from both the surfaces of the grating and observe the image of the slit through the telescope, whose axis must be kept perpendicular to that of the collimator. It will be found that the image formed by one surface of the grating is brighter than that formed by the other surface. The surface which produces the less sharp image is the one which contains the lines). If so, turn the prism table either through 135°or 45° in the appropriate direction so that at the end of this rotation the ruled surface will face the telescope, while light from the collimator will be incident normally on the grating.

If it is the unruled surface of the grating which first receives the light, then the prism table should be rotated through an angle of 45°or 135° in the proper direction to bring the grating into the position specified above. Fix the prism table in its new position.

(2) *To make the grating vertical* : In operation (1) you have made the plane of the grating vertical but the lines may not be so. The grating would require a rotation in its own plane to bring this about.

(i) Rotate the telescope to receive the diffracted image on either side of the direct image. If the lines of the grating are not vertical, the diffracted image on one side of the direct image will appear displaced upwards while that on the other side will appear displaced downwards. But actually the spectra are formed in a plane perpendicular to the lines of the grating.

(ii) Now set the telescope to receive the diffracted image in the highest possible order on one side and turn the third screw of the prism table (G in Fig.5.22) till the centre of the image is brought on the junction of the cross-wires. This screw rotates the grating in its own plane as a result of which the lines become vertical. On turning the telescope it will be observed that the centres of all the diffracted images (on both sides of the direct image) lie on the junction of the cross-wires.

This completes the adjustments required for mounting of the grating. Now proceed to take readings as follows:

(i) With sodium discharge tube placed in fornt of the collimator slit, set the telescope on, say, the first order of the diffracted image on one side of the direct image. Focus the telescope and take the reading using both the verniers.

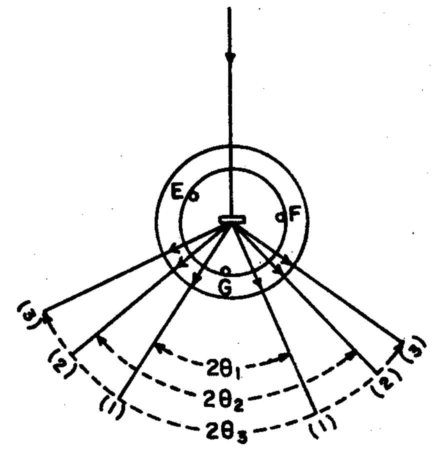

Fig. 5.4

Then focus the telescope on the diffracted image of the same order on the other side of the direct image. Again take the reading. The difference between these two readings is twice the angle of diffraction for this order of image. (Fig. 5.4). (Alternately you can take the readings of the diffracted image and the direct image. The difference is the angle of diffraction. But the previous method is to be perferred since it minimises error in observation).

(ii) Similarly measure the angle of diffractions for the second order, third order and so on. During these measurements the width of the slit should be as narrow as possible. The readings for each diffracted image should be taken at least three times for three independent settings of the telescope. The cross-wires should always be focussed on the same edge of the image of the slit.

(iii) With the help of equation (1), compute N from the known values of the wavelength for sodium-D lines and the angles of diffraction obtained for two or three of the highest orders of the spectra.

Note : *In case the Na-D (yellow) lines are not resolved then the cross-wire should be focussed on the middle of the image. In that case calculate N by assuming λ to be 5893 A.U. But if the lines D_1 (5890 A.U.) and D_2 (5896 A.U.) are resolved readings should be taken for each of these lines and N should be computed separately from each set of readings.*

(iv) Replace the sodium discharge tube by another discharge tube, say of helium, which should be mounted practically in contact with the slit. Instead of one or two lines as in the case of sodium, you will now see a large number of spectral lines of different colours. Adjust the position of the discharge tube till the spectrum look brightest. Identify the different lines of the spectrum (see discussion) and for each line determine the angle of diffraction for as many order as possible in the manner described in operations (i) and (ii). Then from the knowledge of the grating constant N and the order of diffraction n, calculate the wavelength of each of these lines. Compare them with the values obtained from the table.

(v) Replace this discharge tube with another, say of neon. Calculate the wavelength of the prominent lines of the spectrum in the manner described above and compare them with the values given in the table.

Results :

Vernier Constants : Determine the vernier constants in the manner shown in expt.44

Direct reading of the telescope = ... ° ...... ' ...... "

Telescope rotated through 90° and set at = ... ° ..... ' ...... "

Reading of the prism table when the incidence is at 45° = ... ° ...... ' ......"

Prism table is rotated through 135° (or 45°) and set at = ... ° ...... ' ......"

Table for the determination of the grating constant

Wave length (λ) A.U	Order number (n)	Reading for the angle of diffraction θ: Left side: Main scale reading (S)	Left side: Vernier reading (V)	Left side: Total = S + V	Left side: Mean reading (A)	Right side: Main scale reading (S)	Right side: Vernier reading (V)	Right side: Total = S + V	Right side: Mean reading (B)	2θ = A∼B	θ	Grating constant $N = \frac{\sin\theta}{n\lambda}$	Mean grating constant
5890	1	...	...	...	...	...	...	...	...	...	...	...	
	2	...	...	...	...	...	...	...	...	...	...	...	
	etc.	...	...	...	...	...	...	...	...	...	...	...	
5896	1	...	...	...	...	...	...	...	...	...	...	...	
	2	...	...	...	...	...	...	...	...	...	...	...	
	etc.	...	...	...	...	...	...	...	...	...	...	...	

Table for the determination of wavelengths
Helium Tube

Helium Tube

Number of order	Description of the line	Readings for the angle of diffraction θ: Left side: Main scale reading (S)	Left side: Vernier reading (V)	Left side: Total = S + V	Left side: Mean reading (A)	Right side: Main scale reading (S)	Right side: Vernier reading (V)	Right side: Total = S + V	Right side: Mean reading (B)	2θ = A∼B	θ	Wavelength $\lambda = \frac{\sin\theta}{Nn}$	Standard wavelength from Table (A.U.)	Deviation from standard wavelength
Ist. order (n = 1)	Violet	...	...	...	...	...	...	...	...	...	...	...	4471	...
	Bluish green	...	...	...	...	...	...	...	...	...	...	...	4713	...
	Light grenn	...	...	...	...	...	...	...	...	...	...	...	4922	...
	Green	...	...	...	...	...	...	...	...	...	...	...	5016	...
	Yellow	...	...	...	...	...	...	...	...	...	...	...	5876	...
	Red	...	...	...	...	...	...	...	...	...	...	...	6678	...
2nd. order (n = 2)	Violet													
	Bluish green													
	Etc.													

Note : *Make similar tables for other discharge tubes. Tables above refer to one of the two verniers used. Similar tables may be made for the other vernier.*

Oral Questions and their Answers.

1. *What is a diffraction grating?*
   See Art. 5.6
2. *How is a grating constructed? What is a replica grating?*
   See Art. 5.6
3. *What is grating element?*
   See Art. 5.6
4. *What are corresponding points?*
   When two points in the consecutive slit are separated by a distance (a+b), the grating element, then these two points are known as corresponding points.
5. *What happens if the number of rulings per cm (N) is either increased or decreased?*

If N is increased, the order number will be few but they will be separated by a large angle. If N is decreased, the order number will be large, but separated by a small angle.

6. *Why is it necessary that the ruled surface be directed towards the telescope?*
If the ruled surface is directed towards the collimator, then the incident rays will first fall on this surface and will be diffracted. But then these diffracted rays will have to pass through a finite thickness of the glass plate and as such will be refracted again. Hence the angle (θ) measured, is not due to diffraction alone, but will be due to combined effect of diffraction and refraction.

7. *How does a grating form a spectrum?*
See a text book.

8. *How does this spectrum formed by a grating differ from that formed by a prism?*
Provided the angle of diffraction θ is not very large, then the angle of diffraction in the grating spectrum is proportional to λ but in case of prismatic spectrum, the violet end is more drawn out than the red end. Hence the spectrum formed by a grating may be regarded purer then that formed by the prism.

9. *What do you mean by ghost lines?*
If the rulings on a grating are not exactly equidistant or accurately parallel, then some additional lines appear near the real spectral lines. These additional lines are called ghost lines.

10. *What do you mean by resolving power of a grating?*
See a text book.

11. *What is meant by dispersive power of a grating?*
See art. 5.6

Art. 5.7 Polarization of light

Light is emitted in the form of wave trains by individual atoms when in an excited state. The wave trains are transverse in nature, *i.e.*, the vibrations are at right angles to the direction of propagation of the wave. A beam of natural light consists of millions of such wave trains emitted by a very large number of randomly oriented atoms and

molecules in the light source and, therefore, natural light is a random mixture of vibrations in all possible transverse directions.

Looking at such a bean end on, there should be just as many waves vibrating in one plane as there are vibrating in any other as shown in Fig. 5.47 This is referred to as perfect symmetry. As light waves are transverse in nature, each vibrations of Fig. 5.45 can be resolved into two component vibrations along two planes at right angles to each other and also perpendicular to the direction of propagation of light. Although these two components may not be equal to each other, the similarly resolved components from all waves will average out to be equal. Thus a beam of ordinary unpolarized light may be regarded as being made up of two kinds of vibrations only. Half these vibrations vibrate in a vertical plane , say along the plane of the paper, and are referred to as *parallel* vibrations indicated by arrow as in Fig. 5.48 (ii). The other half vibrates perpendicular to the plane of the paper and are referred to as *perpendicular* vibrations indicated by dot as in Fig. 5.48 (iii). Fig. 5.43 (i) will then represent a beam of ordinary unpolarized light.

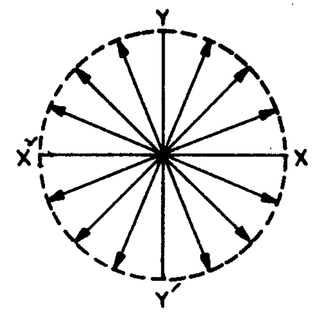

Fig. 5.45

If by some means the vibrations constituting the beam of ordinary unpolarized light are confined to one plane, the light is said to be plane polarized. *Polarization is, therefore, the process by which light vibrations are*

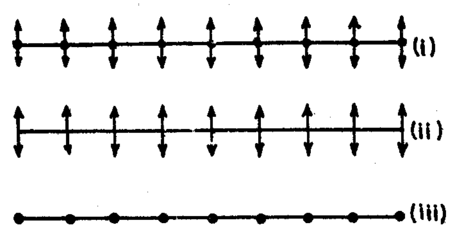

Fig. 5.46

	1	2	3	4	5	6	7
(a)							
(b)							

(a) and (b) are mutually perpendicular readings at the same place.

Mean diameter of the wire, d = ... cm.

(c) Readings for the balance point.

Known resistance R in ohms	Positions of		Balance point (for *l*)			100-*l*	X ohms	Mean X
	Unknown resistance x	Known resistance R	Direct	Reverse	Mean			
	Left Right	Right Left			*l* = ... *l*. = ...	100-*l* 100-*l*		
	Left Right	Right Left						

Note : *When X is in the left gap calculate its value from (1) and when X is in the right gap calculate its value from (2). Specific resistance of the material of the* given wire is given by $\rho = \frac{X\pi r^2}{L} = \frac{X\pi d^2}{4L}$ = ... ohm-cm at the room temp ... °C.

Discussions : (i) See that the null point is not far away from the middle.

(ii) It is essential to see that none of the plugs in the resistance box R is loose.

(iii) Take care to determine the diameter (d) of the wire very accurately.

(iv) On reversing the current if the null point changes appreciably, the thermo-electric effect is too large. In such a case close the galvanometer circuit keeping the battery circuit open. The deflection of the galvanometer should be taken as the zero when looking for a null point.

(v) E.m.f. of the cell should be checked before starting the experiment.

Oral Questions and their Answers.

1. *What is meant by specific resistance and what is its unit?*
Resistance of unit cube of the material. *i.e.*, a material having unit length and unit cross-section. Its unit is ohm-cm.
2. *On what factors does the specific resistance depend?*
It depends on the material and its temperature. It is higher at higher temperature. It does not change with length or diameter of the wire.
3. *Why is it necessary (i) to interchange the resistances and (ii) to reverse the current?*
(i) The pointer which indicates the null point may not be situated exactly above the fine edge of the jockey which makes contact with the bridge wire. This is known as tapping error. This is eliminated by interchanging the resistances. (ii) Reversing the current eliminates the effect of thermo-current in the circuit.
4. *While using a plug key as shunt of the galvanometer, will you use it alone or with a resistance?*
The plug key should be used as a shunt with a resistance otherwise the galvanometer may not show any deflection when the plug is put in the key because in that case all the current passes through the shunt and no current passes through the galvanometer. When a resistance is used with the key, the galvanometer shows a deflection with the shunt and without the shunt.

EXPT. 56. TO DETERMINE THE VALUE OF AN UNKNOWN RESISTANCE AND TO VERIFY THE LAWS OF SERIES AND PARALLEL RESISTANCES BY MEANS OF A POST OFFICE BOX.

A. Determination of the value of an unknown resistance :

Theory : If P and Q are the known resistances in the ratio arms and R that in the third arm (see Figs. 7.29 and 7. 30), the unknown resistance S in the fourth arm is obtained, when there is no deflection of the galvanometer, from the relation

$\frac{P}{Q} = \frac{R}{S}$ or $S = \frac{RQ}{P}$

Apparatus : P. O. Box, unknown resistance, zero-centre galvanometer, cell, commutator, connecting wires, etc.

Description of the apparatus : See Art. 7.9

Procedure : (i) Connect the terminals of the galvanometer between D and K_2 of the P.O. box (Fig 7.29), K_2 being internally connected to the point B. Connect the poles of the cell E through a rheostat Rh to the point K_1 and C, K_1 being internally connected to A. Connect the terminals of unknown resistance S to the points C and D.

(ii) Take out resistances 10 and 10 from the ratio arms BA and BC. *See that all other plugs in the box are tight.* This means *zero resistance* in the third arm. Put the maximum resistance in the rheostat. Press the battery key K_1 and then press the galvanometer key K_2. Observe the direction of the deflection in the galvanometer. Next take out the infinity plug from the third arm and press the keys as done before. If opposite deflection is obtained then the connection is correct. If not check the connections again.

(iii) Then go on gradually reducing the resistance in the third arm until a resistance, say R_1, is found for which there is no deflection in the galvanometer when the circuit is closed. Then the unknown resistance S is given by

$S = \frac{10}{10} R_1 = R_1$ (say 5 ohms).

(iv) If instead of null point, there is a deflection in one direction with R_1 and an opposite deflection with $(R_1 + 1)$ in the third arm, the unknown resistance is partly integral and partly fractional *i.e., it lies between 5 and 6 ohms.*

(v) Now take out the resistance of 100 ohms in the arms P (BA) keeping 10 ohms in the arm Q (BC) so that the ratio is now $\frac{Q}{P} = \frac{10}{100} = \frac{1}{10}$. Hence the null point should occur when the resistance in the third arm is of some value between $10R_1$ and $10(R_1 + 1)$ i.e., between 50 and 60 (if $R_1 = 5$). Observe the opposite deflection and as before *narrow down the range* to obtain the null point at $R_2 = 53$ (say).

Then $S = \frac{53}{10} = 5.3$ ohms. In that case, *the resistance is found correct to one decimal place.*

(vi) If the null point cannot be obtained at this stage also *i.e.*, if opposite deflections are observed for R_2 and $R_2 + 1$ (*viz.* for 53 and 54) in the third arm, *it lies between 5.3 and 5.4 ohms.* Repeat the observations with 1000 ohms in P arm and 10 ohms in Q arm. The resistance in the third arm should be between 530 and 540 for which opposite deflections will be obtained. Narrow down the range to obtain a null point at $R_3 = 535$ (say).

Then $S = \frac{R}{100} = 5.35$ ohms (say). *The resistance is now correct to two decimal place.*

(vii) If even at this stage there are opposite deflections for a change of resistance of 1 ohm in the third arm, the unknown resistance can be determined to the third decimal place by proportional parts. But it is futile to expect that much accuracy from the P.O. box. However, if it is desired to go further, proceed as follows: Count the number of divisions for which the galvanometer is deflected when R_3 is put in the third arm. Suppose it is d_1 divisions to the left. If now for $(R_3 + 1)$ in the third arm, the deflection is d_2 to the right, then for a change of 1 ohm in the third arm, the pointer moves through $d_1 + d_2$ divisions. Hence to bring the pointer to zero of the scale (*i.e.*, for no deflection) a resistance $R_3 + \frac{d_1}{d_1 + d_2}$ is to be inserted in the third arm. Hence the value of the unknown resistance S is given by $S = \frac{1}{100} (R_3 + \frac{d_1}{d_1 + d_2}$

(viii) While taking the final reading with the ratio 1000: 10, reverse the current and take mean value of S.

Results : See table on next page

Resistance in ohms Arm Q	Arm P	Third arm R	Direction of Deflection.	Inference : Third arm resistance is
10	10	0	Left	Too small
			right	Too large
		100	"	"
		50	"	"
		20	"	"
		10	"	Large
		7	"	"
		6	"	"
		5	Left	Small The unknown resistance lies between 5 and 6 ohms
10	100	60	right	Large
		50	left	Small
		55	right	Large
		54	"	"
		53	left	Small The unknown resistance lies between 5.3 and 5.4 ohms
10	1000	539	right	Large
		531	left	Small
		533	"	"
		534	"	"
	a	535	7 div. to the left	$S = \frac{1}{100}(535 + \frac{7}{17})$
		536	14 div. to the right	$= 5.354$
	b	536	8 div. to the left	$S = \frac{1}{100}(535 + \frac{6}{14})$
		535	6 div. to the right	$= 5.354$ ohms.

Mean S = 5.354 ohms.

Note : *Numerical values are not actual readings, they are for illustration. (a) and (b) are direct and reverse readings.*

Precautions to be taken in performing experiments with a P.O. Box.

(i) In experiments with P.O. Box, a cell of any kind may be employed. The galvanometer will remain unaffected for zero potential difference at its ends and there will be no change in the null point. However, the e.m.f. of the battery used in the experiment must not be very high, other wise the standard resistance coils will be damaged by the production of much heat in them. If a storage cell is used, it should always be connected in series with a rheostat of at least 100 ohms to prevent the flow of stronger current through the box. A cell which gives an e.m.f. of about 2 volts should be preferred for the purpose.

(ii) The battery circuit should be completed before the galvanometer circuit to avoid the effect of self-induction.

(iii) The battery key should be closed for that minimum time which is required to find a null point. The battery circuit should be kept open for about two minutes before taking up the next determination of the null point.

(iv) When a very sensitive galvanometer is used, a high resistance in series with or a low resistance in parallel to the galvanometer should be applied during determination of approximate null point. For getting the exact null point the series resistance should be reduced to zero or the shunt resistance made infinite.

(v) Every plug of the P.O. Box should be given a turn within its socket to remove the oxide film between the surfaces of contact. This film, if any, introduces an extra resistance.

(vi) The bridge becomes most sensitive when the resistances in the four arms of the bridge are equal. When employing a P.O. Box to measure a resistance not exceeding 200 ohms, the ratio 10 : 1000 makes the bridge insensitive. Hence it is unnecessary to use this ratio.

Again in measuring resistance lying between 100 to 1000 ohms, it is advisable to use the ratio 100: 100 and 100: 1000 for greater accuracy.

(vii) Sometimes it is found that the limiting ranges with equal ratio do not agree with higher ratio. This may be due to (a) looseness of plugs which should be tightened or (b) resistance of some coils having different values from those noted against them. To remedy this, use different sets of coils making up the required total.

(viii) The position of the null point does not change when the positions of the galvanometer and the battery are interchanged. This means that the position of the null point is independent of the resistances of the galvanometer and the battery.

(ix) The sensitiveness of the bridge is affected by the resistances of the galvanometer and battery; the lower their resistances, the greater is the sensitiveness of the bridge. To increase the sensitiveness, the galvanometer or the battery whichever has the greater resistance should be placed between the junction of the two arms having greater resistance and the junction of two arms having smaller resistance.

(x) Neither very high nor very low resistance can be measured for reasons discussed in the description of P.O. Box (Art.7.9)

B. To Verify the Laws of Series and Parallel Resistances :

Theory : Resistances are said to be connected in series when they are connected with the end of one joined to the beginning of the next and so on as shown in Fig. 7.34 (a).

The equivalent resistance to a number of resistances connected in series is equal to the sum of the individual resistances, *i.e.*,

$$R = r_1 + r_2 + r_3 + \dots \dots \dots \dots \dots \quad (1)$$

When resistances are arranged with their respective ends connected to common terminals, they are said to be connected in parallel as shown in Fig. 7.34 (b)

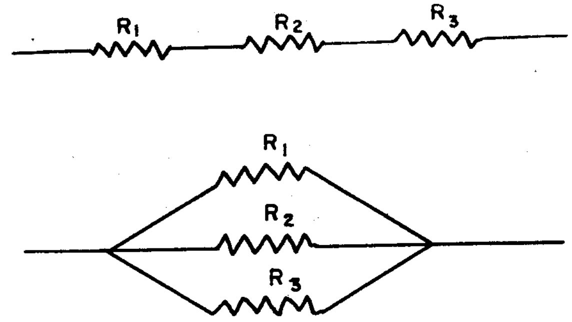

Fig. 7.34

The reciprocal of equivalent resistance to a number of resistances connected in parallel is equal to the sum of the reciprocals of the individual resistances, *i.e.*,

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \dots \dots \dots \dots \dots \quad (2)$$

Measuring r_1, r_2, r_3 etc. separately and the equivalent resistance R by connecting them in series and in parallel, the relation (1) and (2) may be verified.

Procedure : (i) Measure the resistances, r_1, r_2, r_3 etc. separately by means of a P.O. Box as in expt. 59A.

(ii) Join the resistances r_1, r_2, r_3 etc. in series as in Fig. 7.34 (a) and determine the equivalent resistance of the series combination by means of the P.O. Box. Show that relation (1) holds good.

(iii) Connect the resistances in parallel as in Fig. 7.34 (b) and determine the equivalent resistance of the parallel combination as before. Show that relation (2) holds good.

Results : Record data for r_1, r_2, r_3 etc. and for the combination in the same tabular form as in expt. 56A. From the observed and calculated values of the equivalent resistances thus obtained, show that they are equal within the limits of experimental error. This verifies relation (1) and (2).

Oral Questions and their Answers.

1. *What is a P.O. Box and why is it so called?*
   It is a compact form of Wheatstone's bridge in which three arms are given. It was originally intended for measuring the resistance of telegraphic wires in the British Post Office; hence the name.
2. *What is the principle on which it works?*
   Principle of Wheatstone's bridge.
3. *Is it suitable for measuring very high or low resistance?*
   How is it that sometimes the limits found with equal ratio do not agree with those found with a higher ratio?
   See precautions vii and x.
4. *If the resistance coils of the box be calibrated at 20; will they give the same value at other temperatures?*
   No, the resistance of metals increases with temperature.

7. 10 Uses of Suspended Coil Type Galvanometer

In using a suspended coil galvanometer (for descirption and adjustment see Art. 7.3) the following precautions should be taken.

(i) The source of current (*i.e.*, the battery) should never be directly connected with the galvanometer because the flow of heavy current may burn the coil and suspension wire.

(ii) A high resistance should be connected in series with the galvanometer and a shunt box should be joined in parallel to it. By gradually increasing the resistance in the shunt box, the desired deflection may be obtained.

(iii) The galvanometer goes on oscillating for a long time if the coil is wound on a non-conducting frame. *To bring the coil to rest quickly a tapping key should be joined in parallel to the galvanometer.* At the desired moment of stopping the oscillation the key should be suddenly closed and the oscillation will stop.

(iv) For the determination of null point and for the measurement of large current, a low resistance galvanometer should be used. For the measurement of small current and a large potential difference, a high resistance galvanometer should be used. For measuring charge; a ballistic galvanometer should be used.

EXPT. 57. TO DETERMINE THE FIGURE OF MERIT OF A GALVANOMETER.

Theory : The figure of merit or current sensitivity of a galvanometer is defined as the current in amperes (or in micro-amperes) required to porduce a deflection of the light spot by one millimetre on a scale placed normal to the beam of light at a distance of one metre from the galvanometer mirror. In the arrangement as shown in Fig. 7.35, the current C drawn from the battery is given by

$$C = \frac{E}{R + \frac{SG}{S+G}}$$

where R,S and G are the series, shunt and galvanometer resistances respectively and E is the e.m.f.of the cell.

But the current C_g flowing through the galvanometer is given by

$$C_g = C.\ \frac{S}{S+G} = \frac{ES}{R(S+G)+SG} \text{ .... (1)}$$

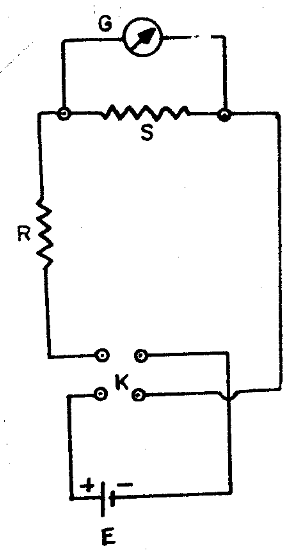

Fig. 7.35

If this current (C_g) produces a deflection of the light spot by d mm on a scale placed at a distance of D cm from the galvanometer mirror, then the deflection N mm which will be produced if the scale be placed at a distance of 100 cm from the mirror is

$$N = \frac{100d}{D}$$

Hence the figure of merit F of galvanometer, by definition, is given by

$$F = \frac{C_g}{N} = \frac{D}{100d} \times \frac{ES}{R(S+G)+SG} \text{ ... (2)}$$

As SG is very small compared to R (S + G), it may be neglected.

Apparatus : Suspended coil galvanometer (G). accumulator (E), high resistance box (R) with 10,000 ohms or more, a low resistance box (S) for shunt, commutator (K).

The shunt protects the galvanometer from damage by allowing the large proportion of the main current to flow through it, thereby reducing the current through the galvanometer.

5. *What will be the change in the galvanometer deflection for a change in the shunt resistance?*
   The galvanometer deflection will increase with the increase of shunt resistance and will decrease with decrease of shunt resistance.
6. *What should be the galvanometer deflection in this experiment and why?*
   The current is proportional to the deflection when the latter is small. This happens when the deflection is round about 10 cm.
7. *What will be the resistance of a shunted galvanometer?*
   Even less than the resistance of the shunt applied.

EXPT. 58. TO DETERMINE THE RESISTANCE OF A GALVANOMETER BY HALF-DEFLECTION METHOD.

Theory : In the arrangement shown in Fig. 7.36 if the shunt resistance S is very small compared to the galvanometer resistance G, then the potential difference (V) between the ends of the shunt resistance S remains nearly constant for all values of R_1.

Thus when R_1= O, then the galvanometer current C_g is given by $\frac{V}{G} = kd$ ... ... (1)

where d is the deflection of the spot of light on the scale and **k** is the galvanometer constant. If now a resistance R_1 is introduced in the galvanometer circuit such that the deflection reduces to $\frac{d}{2}$,

then $C'_g = \frac{V}{G+R_1} = k\frac{d}{2}$ ... ... (2)

where C'_g is the new galvanometer current in the changed circumstances.

Dividing (1) by (2), we get

$$\frac{G+R_1}{G} = 2, \text{ or } G+R_1 = 2G$$

or $G = R_1$... ... ... (3)

Hence by simply measuring R_1, G can be found out.

Apparatus : Suspended coil galvanometer, shunt box S, resistance R and R_1, commutator K, cell E, connecting wires.

Description of the apparatus :

i. Galvanometer : Art. 7.3

ii. Commutator : Art. 7.1

Procedure : (i) Make connection as shown in Fig. 7.36. Bring one sharp edge of the spot of light at the zero mark of the scale.

(ii) Insert a resistance (R) of the order of 1000 ohms in the battery circuit. Make R_1 = 0 by putting all the plugs in the box. Begining with the smallest value (S = 0.1 ohm) of the shunt resistance S, go on increasing S until you obtain a deflection of about 10 cm on the scale. Note this deflection.

(iii) Keeping the resistance R constant, adjust the value of the resistance R_1 until the deflection is reduced to half of the former. Record this value of R_1 which is the value of the galvanometer resistance G.

(iv) Stop the current in the circuit and examine if the same sharp edge of the spot of light is still at zero of the scale. If not, adjust the scale to bring it to zero. Make the value of R_1 zero and keep R the same. Now reverse the current with the commutator K. Repeat the whole operation to get another value of G

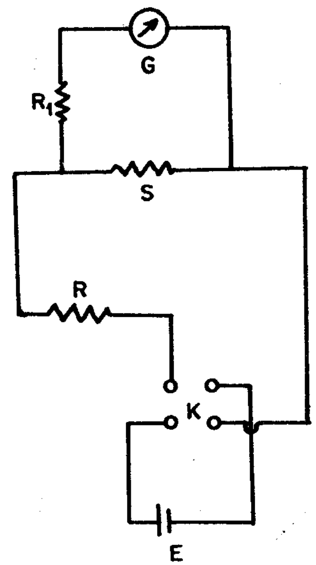

Fig. 7.36

(v) Keeping the value of the rsistance R the same, change the value of the shunt reesistance S to obtain a different deflection of round about 10 cm and similarly determine the value of G.

(vi) Repeat the operation three times with different value of R in the battery circuit and two values of S for each R.

Results : In the following table R is the resistance in the battery circuit and R_1 is the resistance in the galvanometer circuit and G is the galvanometer resistance to be determined. *Numerical values are only examples.*

No. of ohs	Currents	Resistance R in ohms	Shunt resistance S in ohms	Resistance R_1 in ohms	Deflec-tions	$G = R_1$ ohms	Mean G in ohms
	Direct	1000 "	0.1 "	o 80	10.6 5.3	80	
1	Reverse	' '	' '	0 81	10.4 5.2	81	
	Direct "	' '	0.14	0 80	10.2 5.1	80	
2	Reverse	' '	' '	0 79	10.4 5.2	79	
	Direct	750 "	0.16 "	0 "	' '	"	
3	Reverse	' '	' '	0 "	' '	:	
etc.							

Discussions : (i) The series resistance R should never be made equal to zero when the circuit is closed otherwise the galvanometer will be damaged.

(ii) For a steady deflection a storage battery should be used.

(iii) The position of the scale should be normal to the beam of light when no current flows through the galvanometer.

Oral Questions and their Answers.

1. *What is meant by the term galvanometer resistance?*

   The resistance of a galvanometer is the resistance of the coil of wire wound over a rectangular frame kept suspended between the pole pieces.

2. *Why do you maintain the deviation near about 10 cm?*

   If the galvanometer is not provided with concave cylindrical pole pieces the current is not proportional to the deflection and hence the deflection of the spot of light is kept small, say near about 10 cm. Even when the galvanometer is provided with concave pole pieces the current is proportional to $\tan\theta$, where θ is the angle of rotaion of the coil in radian and is small.

3. *Is the method applicable for galvanometer of any resistance?*

   The method is applicable for galvanometer of high resistance only. In case of a low resistance galvanometer, the shunt resistance becomes comparable and the method fails.

4. *How do you find the resistance of a galvanometer, when the resistance is very low?*

   In the case of galvanometer of low resistance, it is best to clamp the coil and to find its resistance by a metre bridge or P.O. Box

5. *Will you prefer a low or high resistance of a shunt?*

   Theory shows that the method gives a correct value of the galvanometer resistance when the shunt is very low. So a very low resistance of the shunt is preferred.

EXPT. 59. TO DETERMINE A HIGH RESISTANCE BY THE METHOD OF DEFLECTION.

Theory : In the arrangement of Fig.7.37, if the unknown resistance X (of the order of not less than 10^4 ohms) is included in the battery circuit by closing the gap OB_1 and if S_1 be the value of the shunt resistance S and d_1 cm be the deflection of the spot of light on the scale, then the current C_g flowing through the galvanometer is given by

$$C_g = \frac{ES_1}{X(S_1 + G) + S_1 G} = kd_1 \quad (1)$$

where k is the constant of proportionality.

If now the known resistance R is introduced in the battery circuit by closing the gap OB_2 and if S_2 be the shunt resistance and d_2 be the deflection (nearly equal to d_1) of the spot of light on the scale, then the galvanometer current C_g is given by

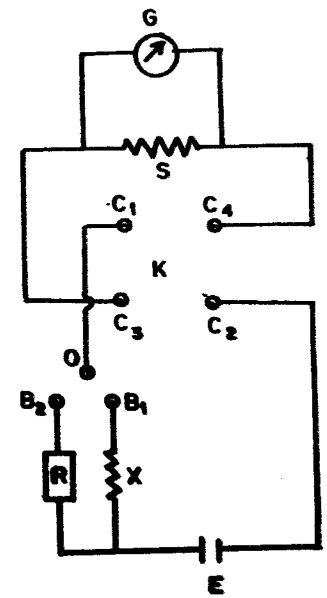

Fig. 7.37

Discussions : (i) If the galvanometer be not sufficiently sensitive then while taking the final reading for the null points, the resistance R' in the galvanometer circuit should be made zero.

(ii) While taking reading for the cell E_1, the key K_2 should be kept open to avoid unnecessary heating of the current circuit containing R_2.

(iii) Current should be allowed to flow in the potentiometer only when readings for null points are taken

(iv) The potentiometer circuit should be kept open for sufficient time before next operation is taken up, to allow the heat generated in the wire in the former operation to dissipate.

Oral Questions and their Answers.

1. *In this experiment, do you measure the current or potential difference?*
   In fact the p.d. across the known resistance is measured and then we get the current by dividing the p.d. by the known resistance.
2. *What are the practical units of current and potential difference?*
   The unit of current is ampere and that of the p.d. is volt. By Ohm's law they are related as
   $i = \frac{E}{R}$ (*i.e.*, Ampere = $\frac{\text{Volt}}{\text{Ohm}}$).
3. *Can you measure resistance by potentiometer?*
   Yes, by determining the p.d.(e) across the unknown resistance (R) we can find the value of the resistance by applying Ohm's law which gives $i = \frac{e}{R}$. The current i flowing through the unknown resistance can be determined by introducing a copper voltameter in the circuit.
4. *Why do you try to take the null point in the last wire?*
   This makes the balance length large and the percentage error in the result small.

EXPT. 66. TO DETERMINE THE INTERNAL RESISTANCE OF A CELL BY A POTENTIOMETER.

Theory : A cell or any other source which supplies a potential difference to the circuit to which it is connected has within it some resistance called *internal resistance.* When there is no current in the cell *i.e.*, at open circuit, the potential difference E between its terminal is maximum and is called its *electro-motive force (e.m.f).* When the cell is discharging *i.e.*, at closed circuit, its terminal potential difference is reduced to e because of the internal drop of potential across its internal resistance b.

In Fig. 7. 48 the balance point for the cell E_1 whose internal resistance b is to be determined, is found out as usual, at a distance l_1 from the end A of the potentiometer with key K_2 open. Then a resistance R is introduced in the resistance box RB and the key K_2 is closed. The potential difference between the terminals of the cell E_1 falls as a current i begins to flow through the circuit. A balance point is now found at a distance l_2 from the end A of the potentiometer. As E and e are the potential difference at the

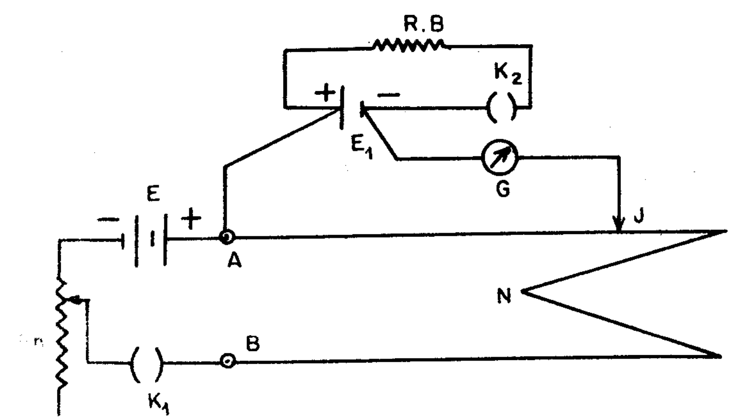

Fig. 7.48

open and closed circuits and b is the internal resistance of the cell, we have $b = \frac{E - e}{i}$ where i is the current flowing through the circuit when the key K_2 is closed. Again $i = \frac{e}{R}$

$$\therefore b = \frac{E-e}{e} R = (\frac{E}{e} - 1) R \ldots \quad \ldots \ldots \ldots \quad \ldots \ldots \ldots \ldots \ldots (1)$$

But as E and e are proportional to l_1 and l_2, we have $\frac{E}{e} = \frac{l_1}{l_2}$

$$\therefore \text{from (1)}, \; b = (\frac{l_1}{l_2} - 1) R = \frac{l_1 - l_2}{l_2} R \ldots \quad \ldots \quad \ldots (2)$$

Apparatus : Potentiometer, battery E, cell E_1, resistance box R, rheostat Rh, two keys K_1 and K_2, zero-centre galvanometer G, connecting wires.

Procedure : (i) Connect the positive terminal of the battery E to the binding screw A of the potentiometer and the negative terminal of the battery through Rh and the key K_1 to the binding screw B of the potentiometer (Fig. 7.48). Join the positive terminal of the cell E_1 whose internal resistance is to be determined, to the binding screw A of the potentiometer and its negative terminal through the galvanometer G to the jockey J. Also connect the resistance box R.B through the key K_2 to the two terminals of the cell E_1. It is better to put a shunt across the galvanometer.

(ii) Adjust a small resistance in the rheostat Rh and close the key K_1.Keep the key K_2 open and press the jockey first near the end A and then near the end B of the potentiometer wire. If the galvanometer deflection are in the same direction, then either the resistance in Rh is too great or e.m.f. of E is too small. Decrease the resistance in Rh until the opposite deflections are obtained at the above two contact points. If necessary, increase the number of cells in the battery E. Adjustment of Rh should be such as to get a null point on the fifth or sixth wire.

(iii) Remove the shunt of the galvanometer (if any) and find out the balance point accurately. Open the key K_1 and calculate the distance l_1 of the balance point from the end A of the potentiometer wire (see discussion i, expt. 66). Determine l_1 three times and calculate the mean value of l_1.

(iv) Close the key K_2 without changing Rh and take out a resistance 10 ohms from the R.B and determine the balance point and calculate the distance l_2 of the balance point from A. Then remove 20,30,40,50 ohms from R and determine the value of l_2 in each case.

(v) Calculate the value of b from the relation (2) for each value of R and then calculate the mean value of b.

Results :

No of obs	Circuit	Resistance in R ohms.	Value of l_1 cm	Mean l_1 cm	l_2 cm	Internal resistance b of the cell	Mean b ohms
	open	infinity	-- -- --	--			
1	closed	10			--	--	
2	closed	20			--	--	
3	closed	30			--	--	
4	closed	40			--	--	
5	closed	50			--	--	

Discussions : (i) The internal resistance of a cell depends on the strength of the current. It decreases as the current increases. It is, therefore, better to change the external resistance over a range of 40 ohms and then to calculate the mean value of b.

(ii) After every reading, the key K_1 should be opened to allow the wire to cool.

(iii) Care should be taken to see that K_2 is open when determining l_1.

(iv) The internal resistance of a cell can be determined with voltmeter and ammeter also but this method is more accurate.

Oral Questions and their Answers.

1. *What do you understand by the internal resistance of a cell?*
   When the external circuit is complete, within the cell a current flows from the plate at a lower potential to the plate at higher potential and the medium between the plates offers a

resistance to the flow of the current. This resistance is known as the internal resistance of the cell. It is the resistance in ohms obtained by dividing the difference in volts between the generated e.m.f. and the potential difference between the terminals of the cell by the current in amperes. See theory.

2. *On what factor does internal resistance of cell depend?*
   It depends on
   (a) the conductivity of the medium between the plates.
   (b) the distance between the plates
   (c) the area of those portions of the plates that are immersed in the electrolytes.
3. *Name cells of high and low internal resistance?*
   The internal resistance of Daniel cell is high while that of a lead accumulator is low. In case of a lead accumulator the distance between the plates is small and the area of the immersed portions of the plates is great.
4. *Show a relation between the e.m.f. E and internal resistance r of a cell when a resistance R is put in the external circuit round which a current i flows.*
   $E=ir+iR$ where ir is the internal voltage drop which is the product of the current and the internal resistance and
   iR is the external voltage drop.
5. *Is the internal resistance of a cell constant?*
   No. See discussion (i).
6. *Do you know of any other method of determinig the internal resistance of a cell?*
   See discussion (iv).

EXPT. 67. TO CALIBRATE AN AMMETER BY POTENTIAL DROP METHOD WITH THE HELP OF A POTENTIOMETER.

Theory : In the Fig. 7.49 the driving battery E sends a steady current C in the potentiometer circuit creating a drop of potential ρ volts per unit length of the potentiometer wire AB. In the auxiliary circuit containing the ammeter Am, let e be the drop of potential betwen the potential leads T_1 and T_2 of the low resistance R_2. If corresponding to the potential leads T_1 and T_2, balancing lengths l_1 and l_2 are obtained in the potentiometer wire AB, then

$e = \rho(l_2-l_1)$ ... ...(1)

If R_p and R be the resistance of the potentiometer wire and that in the box R_1 and E be the e.m.f. of the driving battery then $C = \frac{E}{R+R_p}$ amp. So the voltage drop across the total length L of the potentiometer wire is $V = CR = ER_p/R+R_p$ volts.

In that case, $\rho = \frac{V}{L} = ER_p/(R+R_p)\,L$ volts / cm. (2)

Hence from (1) and (2)

$e = ER_p(l_2-l_1)/(R+R_p)\,L$ volts. (3)

So the unknown current i flowing in the auxiliary circuit is given by

$$i = \frac{e}{R_2} = \frac{ER_p(l_2-l_1)}{(R+R_p)L.R_2} \quad \text{......(4)}$$

Now if the ammeter Am in the auxiliary circuit reads i' amperes, then a correction $(i-i')$ is to be added algebraically to the reading i' of the ammeter. If for different values of i', the corresponding corrections $(i-i')$ are found out, then a graph may be drawn with i' as abscissa (X-axis) and the correction $(i-i')$ as ordinate (Y-axis). This gives the *calibration curve* of the ammeter.

Apparatus : Potentiometer, storage cells, ammeter Am, low resistance R_2, zero-centre galvanometer, high resistance R', resistance box R_1, plug key K, K_1 and K_2, two-way key K_3, rheostat Rh.

Connections of the apparatus : In the unknown current circuit, a battery E_1 is connected to an ammeter Am and through a rheostat Rh and a key K_2 to the two current leads of a low resistance R_2 so that they form a complete circuit. The current that flows in this circuit is read off from the ammeter and also determined by measuring the potential drop across the low resistance R_2 and then the two are compared.

In the potentiometer circuit the positive of a battery E (usually alkali cells) is joined to the binding screw A of the potentiometer wire while the negative terminal of the battery is connected to the binding screw B of the

EXPT. 73. TO DETERMINE THE TEMPERATURE CO-EFFICIENT OF THE RESISTANCE OF THE MATERIAL OF A WIRE.

Theory : The temperature co-efficient of the resistance of the material of a wire may be defined as the change in resistance per unit resistance per degree rise in temperature.

If R_2 and R_1 are the resistances of a coil at temperatures t_2°C and t_1°C respectively, then

$$R_2 = R_1(1+\alpha t)$$

where α is the mean temperature co-efficient between the temperature t_2 and t_1 and $t = t_2 - t_1$

$$\therefore \alpha = \frac{R_2-R_1}{R_1 t} \text{ per°C} \ldots \ldots \qquad (1)$$

Measuring R_1, R_2, t_1 and t_2, α may be determined.

Apparatus : Resistance wire, metre bridge, cell, rheostat, commutator, galvanometer, hypsometer, etc.

Procedure: (i) Take a coil of wire wound non inductively on a

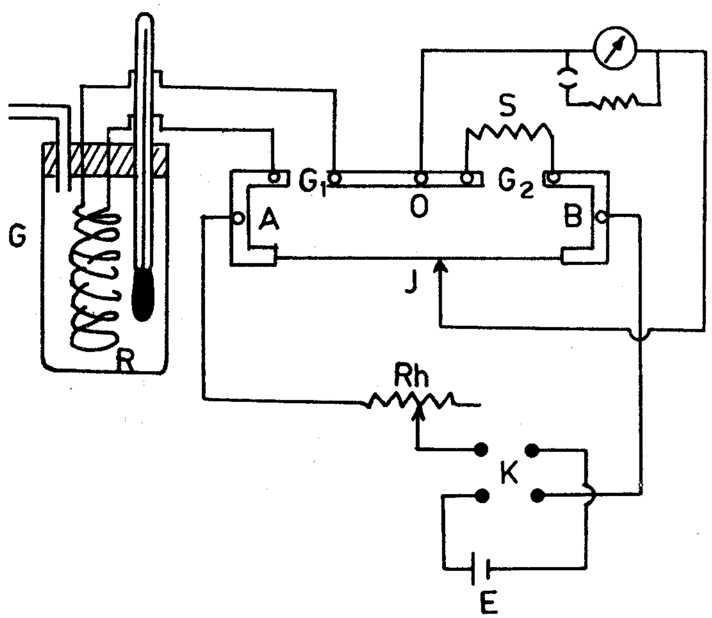

Fig. 7. 55

mica frame and immerse it in a glass tube G containing oil. Close the glass tube with a cork and through a hole in it, insert a thermometer. Insert the tube with its contents inside a hypsometer through an opening in the cork at its top.

(ii) Make connection as shown in Fig. 7.55. Join the coil R of which the temperature co-efficient is to be determined to the gap G_1 of the metre bridge through two connecting wires. Join a resistance box S in the gap G_2. Connect the battery E (usually a Leclanche's cell) to binding screw A and B of the metre bridge through the commutator K and a variable resistance Rh. Join the two terminals of a galvanometer to the binding screw at O and the jockey J. Connect a resistance box and a plug key in parallel to the galvanometer.

(iii) After making connection as described in operation (ii) take out suitable resistance from the box S and find the balance point, both for direct and for reverse currents. The resistance in S should be so chosen that the null point lies at the central region of the metre bridge wire. Record the room-temperature t_1°C from the thermometer. Repeat the operations three times with three different values of the box resistance. Interchange the position of the resistance coil and resistance box in the gaps G_2 and G_1 and for the same set of values of the resistance box repeat the operations as before.

(iv) Boil some water in the hypsometer and go on noting the temperature of the resistance coil. When the thermometer reading shows a steady maximum value t_2°C, find out the null point. Interchange the positions of the resistance coil and resistance box and determine the null point again. In each case take three readings for three different values of the resistance in the box S. As before, the balance point should lie in the central region of the bridge wire.

(v) Calculate the resistance at the two temperatures and find the mean values. Then calculate α from relation (1).

Results :

(A) *Readings for* R_1 *and* R_2 *at temperature* t_1=...°C t_2 =...°C

Temp.	No of obs.	Resistance in Left gap ohm	Resistance in Right gap ohm	Null points with Direct current cm	Null points with Reverse current cm	Mean null point cm	Unknown resistance ohm	Mean resistance ohm
t_1°C	1	R_1	S_1(known)					
	2							
	3							
	4	S1	R_1					
	5							...
	6							$=R_1$
t'_2C =...	1	S_2(known)	R_2					
	2							
	3	R_2						
	4		S_2					...
	5							$=R_2$
	6							

$$\alpha = \frac{R_2 - R_1}{R_1 t} = \dots \dots \text{ per°C}$$

where $t = t_2 - t_1$

Discussions : (i) Care should be taken that the hypsometer and the burner do not heat any other electrical accessories of the experiment.

(ii) While making preliminary adjustment the shunt for the galvanometer should be used. Final adjustments for the null points should be made without the shunt.

(iii) Thermometer reading should remain steady for at least five minutes before readings for balance point are taken. The correct expression is $R_t=R_o(1+\alpha t+\beta t^2)$ where R_t and R_o are resistances at t°C and O°C respectively. For small ranges of temperature (say not exceeding 100°C), β is negligibly small so that the resistance is practically the linear function of the temperature and eqn. (1) is approximately correct.

(iv) For most pure metals , resistance increases with temperature but for certain alloys such as manganin and constantan, there is no change in resistance with the changes of temperature within a certain range. For carbon, resistance decreases with temperature and hence α is negative. α is also negative for most insulators and electrolytes.

Oral Questions and their Answers

1. *What is temperature co-efficient of resistance and what is its unit?*
   It is the increase in resistance per unit resistance per degree rise in temperature. Its unit is ohm per °C.
2. *Why does the resistance of metals change with temperature?*
   Conduction in metals is due to the directive movement of the free electrons under a potential difference. When the temperature rises, the random motion of the electrons increases and their directive motion decreases which decreases the current strength *i.e.*, increases the resistance.
3. *Do you know of any substance whose resistance decreases with temperature?*
   See discussion (iv).
4. *Is the temperature co-efficient for metal is the same for all temperatures?*
   No. Its value is different at different temperatures and hence a mean temperature co-efficient is taken within a range.
5. *What is the most important application of the variation of resistance with temperature?*
   Variation of resistance of platinum with temperature is utilised in measuring the temperature within a long range.
6. *What is the best arrangement for measuring the resistance of a wire at different temperatures?*
   Callender and Griffiths bridge is the best arrangement to measure the resistance of a given wire at various temperatures.
7. *Why should the wire be wound non-inductively?*
   To avoid the effect of induced current.
8. *Why do you use alloys such as manganin and constantan for the construction of standard resistances?*
   For these alloys, there is no change in resistance with the change of temperature within a certain range.

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