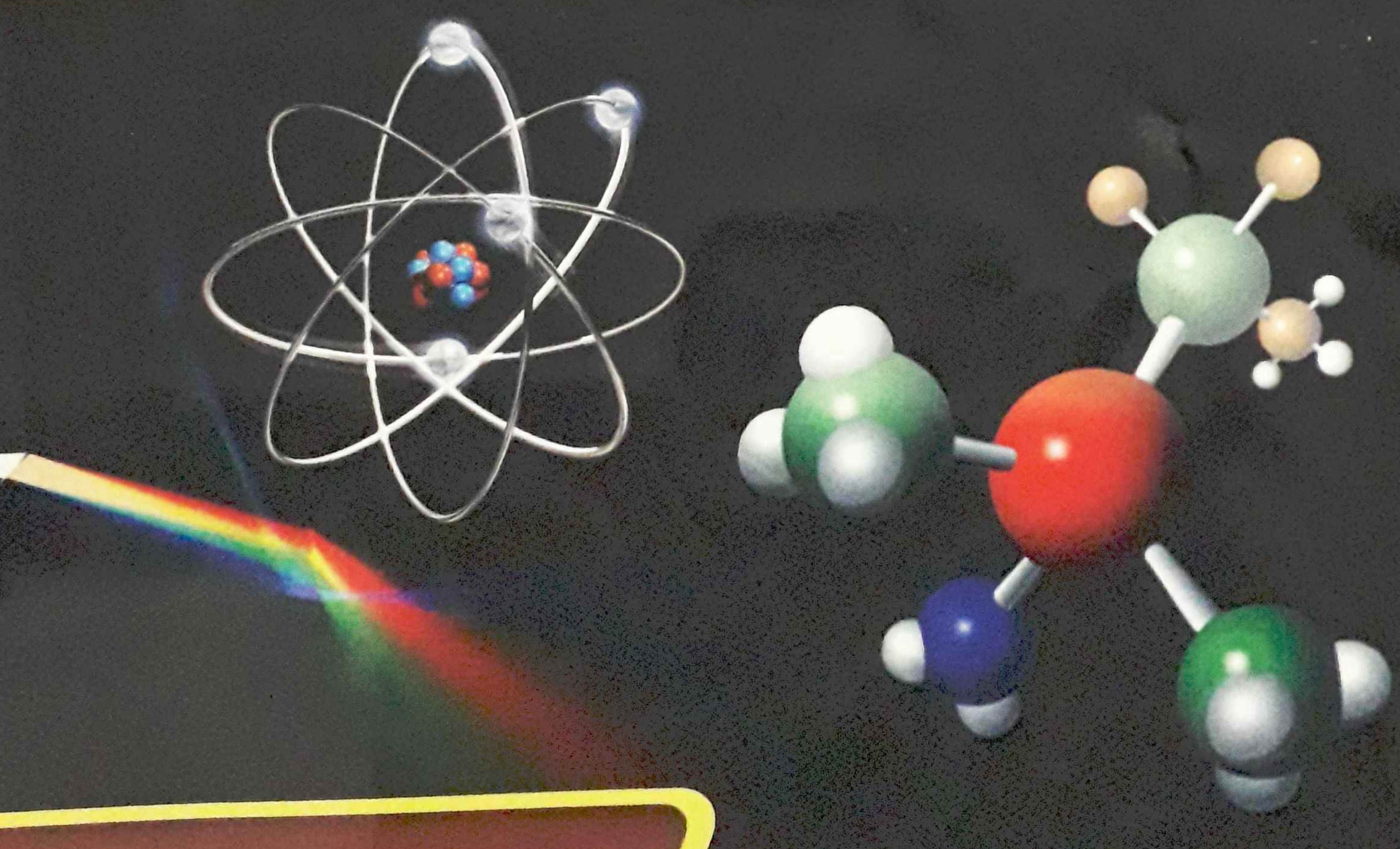
Certificate Level

Physics Practical Guide



U.P. Shrestha

Certificate Level
Physics Practical Guide

Manesh Devkota

Recommended as a Practical Text for classes XI & XII
by Higher Secondary Board

Certificate Level

Physics Practical Guide

[Also for PCL T.U.]

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Preface to First Edition

This book is my first attempt to meet the requirements of students preparing for the Intermediate Examinations of Tribhuvan University. In spite of a number of books available in the market, not a single covers the syllabus of this University completely. So, the need of a suitable Practical text book has been long felt. This is a response to this need. Unnecessary details in theory & procedure have been avoided. If the book be found really useful to those for whom it is intended, I shall think my labour rewarded and will try my best to bring forward some more books in the subject.

In the end, I cannot but thank Sri Ratna Prasad Shrestha of Ratna Pustak Bhandar, who has undertaken to publish this book.

U.P. Shrestha

Manju Nivas, Tripureswar
Kathmandu
Bhadra, 2024

Preface to the 16th Revised Edition

This Practical Text has been written to cover the latest syllabus of the PCL students of T.U., classes XI and XII of the Higher Secondary Education Board of H.M.G., Nepal and most of the experiments for I.Sc. students of Kathmandu University. The book has been thoroughly revised.

As there is a growing tendency of the external examiners to ask viva questions related to the experiments done by a student in the examination, a number of some typical questions have been given at the end of each major chapter short answers to which have been given in the appendix at the end. This, I hope will inspire the students to think further about the experiments. This is the special feature of this edition.

Besides some typical numerical problems are also given. So it is my special request to the teachers in charge of the laboratories to encourage the students to practise these exercises after every experiment so that they may acquire skill and thorough understanding of the experiments performed. I hope the present edition will serve the purpose of the students preparing for the examination of T.U., K.U. and Higher Secondary Board.

In spite of the best care, it is just possible that some errors, printing mistakes might have crept in. I will be thankful if the same be brought to the notice of the author or the publisher. Suggestions for further improvement will be thankfully and gracefully acknowledged and incorporated in the next edition.

I heartily thank Mr. Govinda P. Shrestha of M/S Ratna Pustak Bhandar for taking painstaking efforts for kindly publishing the book and for providing all necessary facilities toward its preparation. Further I am grateful to all my colleagues who have given me helpful suggestions all the time, Mr. Rohit Shrestha for Computer Designing and Mr. K.D. Manandhar of Color Wave Offset Printing for bringing out this book in the present form.

U.P. Shrestha

Bansbari, Kathmandu

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Chapter 1
Introduction

1. Introduction

Physics is the science of accurate measurement.

"When you can measure what you are speaking about and express it in numbers, you know something about it, and when you can not measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. It may be the beginning of a knowledge, but you have scarcely in your thought advanced to the stage of Science."

– Lord Kelvin

Measurement is such an important part of Practical Physics that it may lead a student to hurriedly take certain measurements possible before he understands the reason for doing so without even studying the apparatus he used. But he must realise that every experimental exercise has for its object the elucidation of the physical principles involved. He should bear in mind the theoretical aspect of the experiment and at every step of data collection, he must try to understand what he is doing and why he is doing so. Preferably he should spend some time in setting up the apparatus and studying carefully its construction and working of its component parts so that he may acquire a thorough knowledge of the instrument and some dexterity in its manipulation.

Instruction for writing a Practical Note Book.

The following particulars must be carefully noted while writing a Physics Practical Note Book.

1. Form of the Account

The account should be presented on the following lines

(i) Date of the experiment
(ii) Object of the experiment
(iii) Brief theory
(iv) Procedure
(v) Observations
(vi) Results
(vii) Discussion

2. Recording of Observations

Observation must be noted down directly on the loose leaf Physical sheets and never on the back of an envelope or some other scrap of paper. This is not only a waste of time but may lead to serious error. Some selective copying out, like a table of data summarising the main results, may be desired occasionally. But when results are copied, it is important that all the original measurements be retained.

3. General Comments on the Account

The account should be brief. Sufficient information must be given so that you yourself, looking at the account in six months or a year's time later, will be able to remember and follow what was done. Besides this, any one else, familiar with the experiment should be able to follow your working. This standard can be achieved with bare minimum of description provided you.

(a) give clear diagrams, properly labelled defining all notations.

(b) record your results in a tabular form heading each column with the name or symbol of the quantity followed by the units.

(c) label the axes of graphs, giving the scale with units.

(d) make adequate separation between sets of measurements giving each set a clear and, if necessary, a detailed title.

Mention any precautions you take. A critical survey of the sources of inaccuracy in the experiment is valuable and should be included in the discussion. All working out of results should be shown but calculations should be clearly separated from measurements. Theoretical formula should only be quoted and not worked out.

In all electrical experiments, circuit diagrams are essential to a clear description.

4. Arithmetic

It is often the object of any experiment to obtain a number, and the correct working out of that number is just as important as the taking of the measurements. The result of careful measurements is often ruined by careless working out. Any one is liable to make an arithmetical mistake, but there is a remedy, namely, to check the calculation. Checking is part of the calculation.

5. Measurements are often made of the variation of one quantity y with another quantity x and the pairs of the values plotted on a graph. Whenever possible, the quantities plotted are chosen so that the graph is a

$$\text{St. line } y = mx$$

or

$$y = mx + C.$$

In practice, all the points may not lie exactly on a straight line.

The final result of the experiment is usually obtained from the value of the slope m or–less often – the intercept C. So we need to know the best values of these quantities and the error in each.

N.B. while drawing graphs, it should be remembered that the independent variable should be plotted along the x–axis, and the dependent variable along the y–axis. Besides scales should be properly chosen so as to use as much space of the graph paper as possible. The axis should be labelled and the units given. The points plotted should be marked with crosses or with a dot and a circle using a sharp, hard pencil.

6. The observed value should be checked with the standard value and the percentage error calculated as

$$\%\ \text{error} = \frac{\text{Difference between observed and standard value}}{\text{standard value}} \times 100$$

The results must be given to a sensible order of accuracy stating its proper units.

Theory of Graphs

The graph is a very simple and quicker method of checking the observations and hence the results of an experiment. Hence whenever possible it is always advisable to draw a graph between two variables, involved in an experiment. While drawing graphs connected with experiments in Certificate Level Physics, students are likely to come across the following types.

1. St. Line Graphs

(a) Any physical equation of the form

$$y = mx \qquad \text{...(a)}$$

represents a st. line passing through the origin. For example, from the pendulum equation $t = 2\pi\sqrt{\frac{l}{g}}$ where t is the period, l is the effective length of the pendulum and g the acceleration due to gravity.

we get $$t^2 = \frac{4\pi^2}{g}l \qquad \text{...(i)}$$

which is similar in form to y = mx,

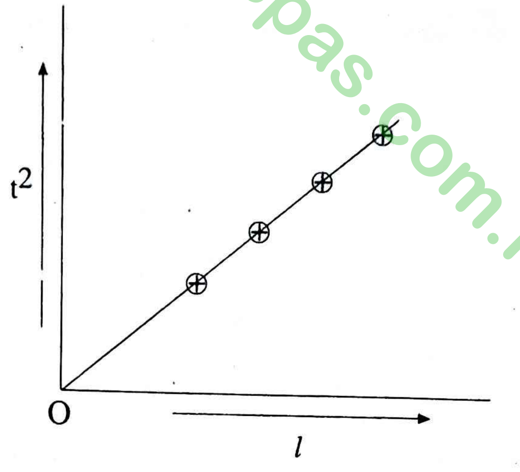

Fig. 1.1

∴ If t^2 is plotted along the y axis and l along the x axis, a st. line passing through the origin is obtained.

(b) Any equation of the form

$$y = mx + C \qquad \text{...(b)}$$

C being a constant, represents a st. line not passing through the origin. For example, for a convex lens,

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

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

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

∴ $$m = \frac{v}{f} \qquad \text{...(b)}$$

which is of the form y = mx + c

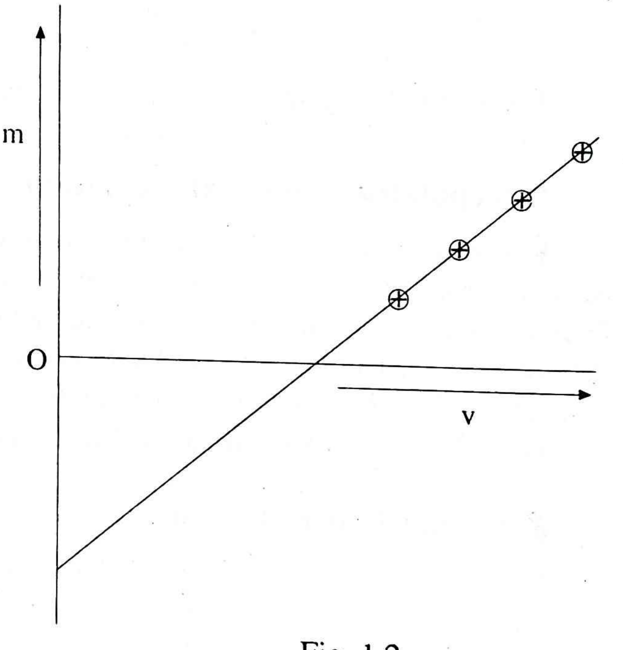

Fig. 1.2

2. Parabolic Curve

Any equation of the form

$$y^2 = 4ax \qquad \text{...(2)}$$

where 4a is a constant. In a simple form

$$y^2 = kx$$

represents a parabola. For example, from the pendulum equation,

$$t^2 = \frac{4\pi^2}{g}l = kl \qquad \text{...(2)}$$

A parabolic curve is obtained when t is plotted against l

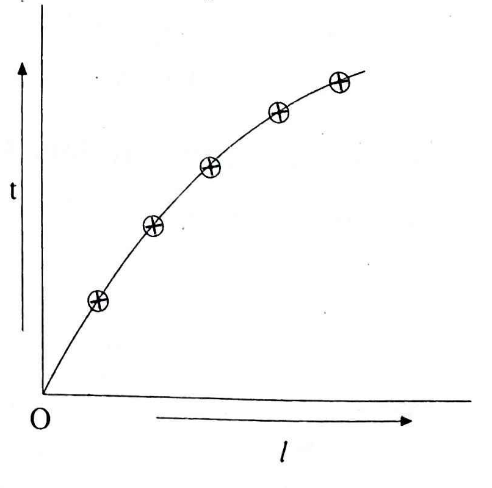

Fig. 1.3

3. Hyperbolic Curve

Any equation of the form xy = k ... (3) (k is a constant) represents a hyperbola. For example, from the Boyle's law equation

$$PV = K \quad \ldots(3)$$

or

$$P = K\frac{1}{V}$$

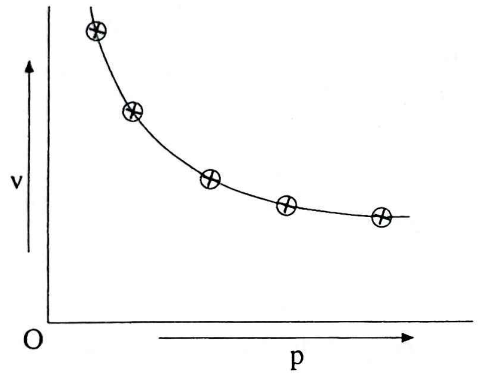

Fig. 1.4

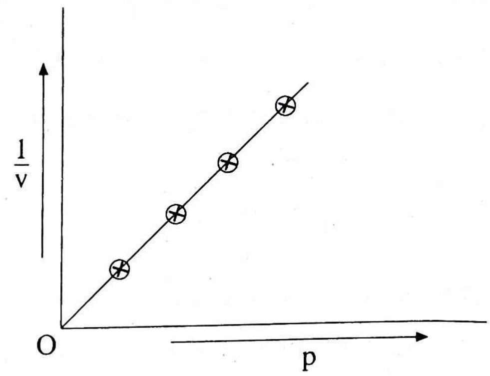

Fig. 1.5

The graph of $\frac{1}{v}$ against P represents a st. line passing through the origin.

Interpolation and Extrapolation

Knowing the value of one quantity on the x–axis, the corresponding value on the y–coordinate can be easily determined from the graph. The given value of x is marked on the abscissa. A vertical line is drawn from the point to cut the graph. From the point of intersection a horizontal broken line is drawn to cut the ordinate. This value of the ordinate gives the required value. If the point of intersection lies on the graph, the value of y is said to be determined by the process of interpolation. If it lies on the extension of the graph, the value of y is said to be determined by the process of extrapolation.

Error and Order of Accuracy

An experiment cannot be regarded as complete unless a result is obtained along with an estimate of its error. The importance of such an estimate is that it indicates how much reliance is to be placed in the result. In particular, we cannot decide if the difference between two results is very significant unless we have an estimate of the error in each case.

The practical work in Physics is subjected to various errors.

Systematic and Random Error

(i) Random error – It may be due to incorrect judgment of the observer. It is equally likely to be positive or negative.

Random error may be detected by repeating the measurements. Furthermore by taking more and more readings, we obtain from the arithmetic mean a value approaching closer and closer to the true value.

(ii) Systematic error – is one which is constant through a set of readings. It may be due to faulty or incorrectly adjusted instruments. Systematic error often arises because the experimental arrangement is different from that assumed in the theory, and the correction factor which takes account of this difference is ignored. An even more common source of systematic error is inaccurate apparatus.

For this reason systematic errors are potentially more dangerous than random errors. Large random errors if present in an experiment will manifest themselves in a large value of the final estimated error. Thus everyone is aware of the inaccuracy of the result and no great harm is done. However the concealed presence of a systematic error may lead to an apparently reliable result, given with a small estimated error which is in fact seriously wrong. There is no general rule for finding and eliminating systematic errors. It is a matter of thinking about an experiment and drawing on past experience. In general one should always suspect an apparatus and if necessary calibrate is against a standard of known accuracy.

If errors and uncertainties are present in an experiment, they should be taken into account while calculating the final result. For example,

(i) The length of a rod measured is as 6.25 cm by a vernier callipers calibrated in mm and cm. and whose venires constant is 0.01 cm. The length should be actually recorded as 6.25 ± 0.01 cm since the readings can be estimated to the nearest $\frac{1}{10}$ of a mm i.e. 0.01 cm to denote the possible range 6.24 to 6.26 cm.

(ii) Next if a solid weighs 25.65 gm, it should be recorded as 25.65 ± 0.001 gm.

Percentage Error

In a calorimetric experiment, if the initial temperature is recorded as 20.5 ± 0.1 °C, the % error is $\frac{0.1}{20.5} \times 100$ i.e. 5%. If they are added, the result is 60.7 ± 0.3 having a % error about 0.5%. If subtracted, the result is 193 ± 3 which is an error of about 1.5%.

The diameter of a wire as measured by a screw gauge is found to be say 0.68 ± 0.01 mm. The % error is about 1.5%.

In calculating the area $\left(\frac{\pi d^2}{4}\right) d^2$ is involved. Thus the error in

$$d^2 = (0.68 \pm 0.01)^2 - (0.68)^2 = \pm 2 \times 0.68 \times 0.01 \text{ approx.}$$

$$\therefore \quad \% \text{ error in } d^2 = \frac{2 \times 0.68 \times 0.01}{(0.68)^2} \times 100 = 3\% \text{ approx.}$$

which is twice the % error in d.

Percentage errors in Products and Quetients.

In measuring the young's modulus of elasticity of a wire, we use the formula:

$$y = \frac{\omega g l}{\pi r^2 x} \qquad \ldots(1)$$

Suppose the error in ω, g, l, r and x are denoted by dω, dg, dL, dr and dx, the % error in Y can be found out by taking the logarithm of both sides, and then differentiating,

$$\therefore \text{ from (1)} \quad \text{Log } Y = \log W + \log g + \log L - \log \pi - 2\log r - \log x \qquad \ldots(2)$$

Hence,

$$\frac{dy}{y} = \frac{dw}{w} + \frac{dL}{L} - \frac{2dr}{r} - \frac{dx}{x} \qquad \ldots(3)$$

$$\therefore \quad \% \text{ error} = \left(\frac{dy}{y}\right) \times 100 = \left(\frac{dw}{w} + \frac{dL}{L} - \frac{2dr}{r} - \frac{dx}{x}\right) \times 100$$

also see appendix.

Chapter 2
Units of Measurements

All Physical quantities are measured in terms of some units known as fundamental units. These are the units of length, mass and time. Besides these, there are other units used for measurement of area, volume, force etc. They are called derived units. They can be expressed in terms of fundamental units.

In practice there are two systems of units

(i) C.G.S. (Centimeter, Gramme, Second System) units.

(ii) M.K.S. (Meter, Kilogram, Second System) units which is now the Internationally accepted system, also called system International, S.I. System used for Scientific measurements and the other is

(iii) F.P.S. (Foot, Pound, Second System) units. This is the British system specially used in Engineering scale. Now S.I. system has been widely followed in Engineering scale also.

(i) Length

(a) C.G.S.: The centimeter is the unit of length

(b) S.I. : The meter is the unit of length

Submultiples

10 millimeters (mm) = 1 centimeter (cm)

10 cm = 1 decimeter (dm)

10 dm = 1 meter (m)

1000 m = 1 kilometer (km)

Conversion

1 in = 2.54 cm

12 in. (or 1 *ft*.) = 30.48 cm.

1 m = 39.37 in.

1 km = 0.624 mile

1 mile = 1.61 km

(ii) Mass

The unit of mass in one gm in C.G.S. system and 1 kg. in S.I. system

10 milligram (mgm) = 1 centigram (gm)

10 cgm = 1 decigram (dgm)

10 dgm or 1000 mgm = 1 gram (gm)

1000 gm = 1 kilogram (kg.)

Conversion

1 Pound (*l*b) = 453.6 gm

1 ounce (oz) = 28.350 gm

1 kg = 2.2 *l*b.

(iii) Time

The unit of time is one second in both the systems.

Measurement of Length

For rough measurement, ordinary scale, divider and scale, simple capallipers are used whereas for accurate measurements, Slide or vernier callipers, Screw gauge, Spherometer, Travelling, microscope are used.

Measurement of Area

The area of certain figure can be determined by

(i) applying formula

(ii) using graphical method (For irregular figures)

(iii) weighing method

Units of area in C.G.S. system	→	one sq. cm. (1 cm^2)
S.I. system	→	one sq. m. (1 m^2)
F.P.S. system	→	one sq. ft. (1 ft^2)

Some standard formulae for area to remember:

(i) a square = $(\text{side})^2$

(ii) a rectangle = length × breadth

(iii) a parallelogram = base × altitude

(iv) a triangle = $\frac{1}{2}$ base × altitude

(v) a circle = $\pi\,(\text{radius})^2$

(vi) an ellipse = πab = π (Semi major axis × Semi minor axis)

(vii) Surface area of a sphere = $4\pi r^2$, where r is the radius of the sphere

(viii) Surface area of a cylinder = $2\pi rL$, where r is the radius of the cylinder L is the length of the cylinder.

2.1 Meter Scale

It is a strip of wood (usually boxwood), 1m long and graduated in cm. and mm. It is used for measuring length roughly. To measure the distance between any two points, it is placed edgewise along the points such that one point lies against a cm. mark and the reading of the mark against the second point is taken. The difference between the two readings gives the distance between the two points.

The scale should always be placed edgewise, and not flat, as otherwise due to the thickness of the scale it is likely the reading taken be a bit short or long depending on whether the eye is towards the left or right of the point. The error due to this is called error of parallax.

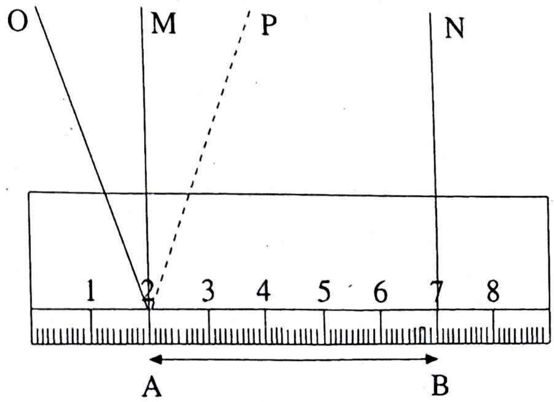

Fig. 2.1

Let us measure the length MN (fig. 2.1) which is actually 5 cm when the meter scale is placed flat, it will be seen that the vertically positioned points M and N may not be close to the division lines. Hence the accuracy of the division depends on the position of the eye with respect to the points. If the eye is a little on the left as at O, the reading will be a bit shorter than the correct reading at M, whereas if the eye is on the right as at P, the reading will be a bit longer than the reading at M. For a correct reading, therefore, the eye should always be placed vertically above point.

If the second point coincides exactly with the full division or a subdivision, the length can be easily determined, but if it falls between any two mm. divisions, the fraction of a mm can be determined approximately by eye estimation, but will not be accurate.

For accurate determination, we use a device, called the Vernier.

2.2 The Vernier

The Vernier is a small scale which slides along the main scale. Its function is to enable a more accurate reading to be made. The vernier scale is so graduated that n divisions of it are equal to (n – 1) or (n + 1) divisions of the main scale. Hence a vernier division is a little shorter or longer than a main division.

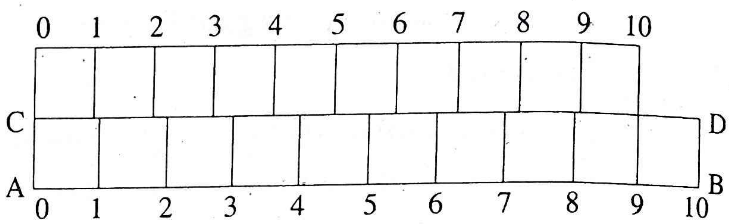

Fig. 2.2

Let S be the value of the smallest division of the main scale and V that of a vernier division. Suppose n divisions of the vernier coincide with (n – 1) divisions of the main scale, then,

$$nV = (n - 1)S$$

or

$$V = \left(\frac{n-1}{n}\right) S = \left(1 - \frac{1}{n}\right) S = S - \frac{S}{n}$$

$\therefore$

$$S - V = \frac{S}{n}$$

The quantity S – V (the difference between a main scale and a vernier scale division is constant for a given device and is called the vernier constant (V.C.). It is also known as the least count of the vernier. Thus

$$\text{Vernier constant (V.C.)} = \frac{\text{Value of 1 main scale division}}{\text{No. of division of the vernier}} = \frac{S}{n}$$

Measurement of Length by Using Vernier

In order to measure the length PQ (say the length of a small cylinder), one end P of the cylinder is first placed opposite to the zero of the main scale. The two divisions between which the end Q lies are noted. The vernier is slided such that its zero just touches Q.

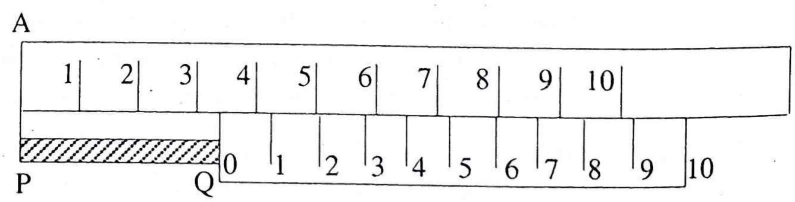

Fig. 2.3

It will be seen that some vernier division say 5 exactly coincides with a main scale division and suppose Q lies between the 3rd and the 4th main scale division. On comparing the 5 vernier division 0 and 5 with the scale division is 5 times the vernier constant. Since the 5th vernier division coincides with the 8th division mark on the main scale, the fraction between 3 and Q is 5a where a is the vernier constant.

$\therefore$ the length of the cylinder = (3 + 5a) cm.

2.3 Vernier Callipers

It consists of a pair of callipers (fig. 2.4) having a main scale and a vernier scale. Here the scale divisions are graduated on a steel strip AB which forms the main scale. The vernier V slides on its sides. A steel jaw C projects at right angles to the strip and is fixed at one of the ends A. Another similar jaw D is fixed to the sliding vernier frame and moves to and fro along the scale. Two other jaws P and Q are projected upwards and these are used for measuring the internal diameter of a hollow cylinder. The object to be measured is held between C and D. A clamp screw 'S' is provided to fix the vernier to the scale as and when required. The apparatus is so constructed that when the two jaws are in contact the zero of the vernier coincides with the zero of the main scale and the distance through which the two jaws open out gives the length of the object.

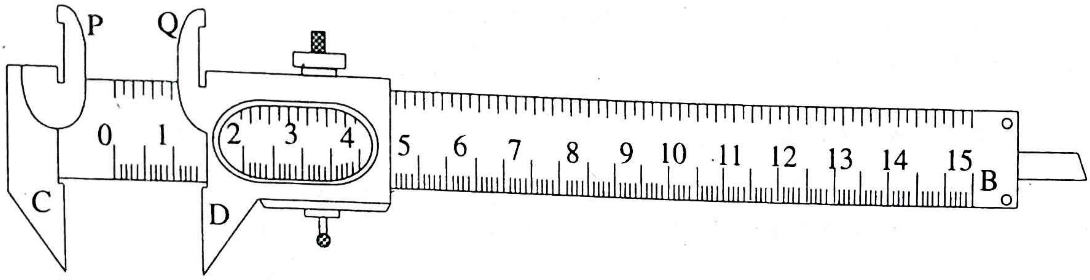

Fig. 2.4

Zero Error and its Correction

If the zero of the vernier coincides with the zero of the main scale when the two jaws are in contact, there is no error and the hence no correction in necessary. In case they do not coincide there is an error in the instrument due to which it reads either a little more or a little less than the correct value, depending on whether the zero of the vernier lies a little to right or a little to the left of the zero of the main scale. This is called the zero error which is positive in the former case and negative in the latter.

If positive, the error should be subtracted from the mean reading the instrument reads. Thus if the instruments reads 4.39 cm. and the error is + 0.05 cm, the actual length will be 4.39 – 0.05 = 4.34 cm.

If the error is negative, the actual length will be 4.39 + 0.05 = 4.44 cm. The quantity (i.e., 0.05 cm in this case) is called the zero correction which should always be added algebraically to the observed reading to get the correct value.

How to use a Vernier

(i) Find the number of smallest divisions in 1 cm on the main scale and hence note the value of 1 smallest scale div. (S.D.)

(ii) Find the no. of divisions on the vernier scale which coincide with a definite no. of divisions of the main scale div. Express it in terms of the value of one main scale div. This gives the value of the vernier constant (V.C.)

(iii) Note the zero error by bringing the two jaws of the callipers together in contact and write the zero correction.

(iv) Place the object to the measured between the jaws and adjust the movable jaw so as to grip the object gently without any undue pressure.

(v) Then note the main scale reading before the vernier zero and also note which of the vernier divisions coincides with a mm division of the main scale.

Experiment No. 2.1

(a) *To use a Vernier Callipers to determine the length, the external and internal diameter of the given tube and calculate its internal volume. Verify it by using a graduated cylinder.*

(b) *To determine the depth of the given hollow cylinder (calorimeter) with the help of Vernier Callipers.*

1. Apparatus Required

(i) Vernier Callipers (ii) Given tube (iii) Calorimeter.

2. Theory

The vernier constant (V.C.) of the callipers is the value of the difference between a vernier division and a main scale division expressed in terms of the value of 1 main scale division (S). Hence if n vernier divisions coincide with (n – 1) main scale divs.

1 .... division coincides ... $\left(\frac{n-1}{n}\right)$ ....

$\therefore$ Difference between a main scale and 1 vernier div. $= 1 - \frac{n-1}{n} = \frac{1}{n}$

$\therefore$ Vernier Constant (V.C.) $= \frac{1}{n} \times$ Value of 1 main scale division $= \frac{S}{n}$

$\therefore$ Length of the tube = Main scale reading + vernier reading $\pm$ Instrumental error

Let l = length of the tube

d_1 = external diameter of the tube

d_2 = internal diameter of the tube

We have external Volume $= \frac{\pi}{4} d_1^2 l$,

internal $= \frac{\pi}{4} d_2^2 l$

$\therefore$ Volume of the tube = External Volume – Internal Volume

$$= \frac{\pi}{4} d_1^2 l - \frac{\pi}{4} d_2^2 l$$

$$\therefore \quad V = \frac{\pi}{4} l \left(d_1^2 - d_2^2\right) = \frac{\pi}{4} l \,(d_1 + d_2)(d_1 - d_2)$$

3. Procedure

(i) The vernier constant of the instrument is determined in the usual way and the zero error if any is noted.

(ii) The experimental tube is next introduced lengthwise between the jaws of the callipers and held tight between them. The main scale reading immediately before the zero of the vernier is noted. Then the no. of divisions of the vernier coinciding with a certain main scale division is counted and noted. This reading multiplied by the vernier constant gives the value of the vernier reading which when added to the main scale reading gives the total value of the length of the tube. Another reading for its length is taken. This is repeated five times and the mean is calculated. The zero correction if any is applied.

(iii) Similarly the reading for the external diameter of the tube are taken at five different places along its length taking two observations at each place along two mutually perpendicular diameters, this time placing it vertically instead of lengthwise in between the jaws. The mean diameter is taken and the zero correction applied as before.

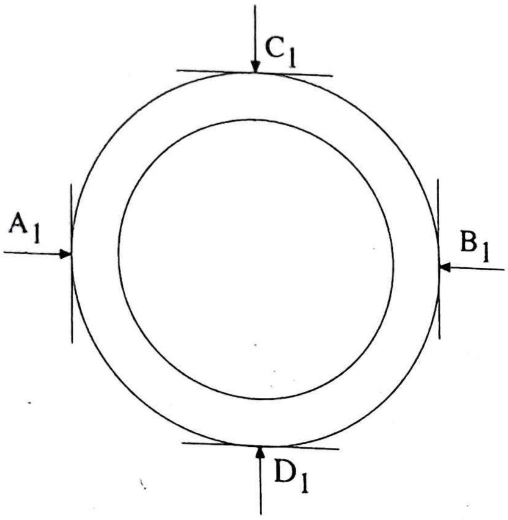

Fig. 2.5

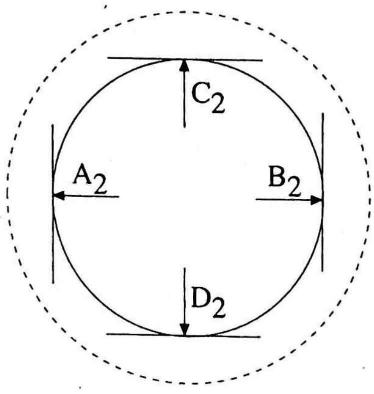

Fig. 2.6

(iv) To measure the internal diameter of the tube, the outward projected points of the jaws P and Q of the callipers (fig. 2.6) are introduced inside the given tube. The jaws are opened till projected points touch the diametrically opposite walls of the tube. The reading is taken. This is repeated 5 times by rotating the tube about its axis.

(v) The end B of the strip AB is kept at the top of the calorimeter and the jaw CD is opened to introduce the strip T till its end touches the bottom of the calorimeter. The reading is taken. This observation is repeated 5 times and the mean is taken. This gives the depth of the calorimeter.

4. Observations

Value of 10 divisions of the main scale = ... mm

.... 1 div. ....= .... mm

Vernier divs. coincide with .... main scale divs (n)

∴ 1 .... (v)

∴ Vernier constant (V.C.) = $S - V = \frac{S}{n}$

5. Zero Error

The zero of the vernier coincides with or is to the left or is to the right of the zero of the main scale by x div.

∴ Instrumental error = 0

or $- x \times$ V.C.

or $+ x \times$ V.C

∴ Zero correction = 0

or $+ x \times$ V.C.

or $- x \times$ V.C.

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Table No. 2.1

No. of Obs	Obs. for	Reading of the Main Scale cm (a)	Vernier Scale V	Value of V = (b)cm	Total a+b cm	Apparent mean cm	Corrected mean cm
1 2 3 4 5	Length						l
1 2 3 4 5	Ext. diameter						d_1
1 2 3 4 5	Int. diameter						d_2

6. Calculation

$$V = \frac{\pi}{4} l (d_1 + d_2)(d_1 - d_2) = \ldots\ldots\ldots \text{ c.c.} = \ldots\ldots\ldots \text{ c.c.} = \ldots\ldots\ldots \text{ c.c.}$$

Error and Order of Accuracy

Usually a reading error of ± 1 vernier division is likely to occur in any vernier instrumental. Besides, in a vernier callipers, an error may also arise while setting it due to variable pressure. The vernier is accurate enough to detect such small irregularities. These should be looked for.

The percentage error in V is the sum of the % errors in l and d.

Precautions

1. The zero error must be carefully determined before any measurement.
2. Extra pressure should not be applied to the jaws while holding the object to be measured.
3. The vernier should be tightly screwed in position before removing the object from the gap.

Exercises

1. What is a vernier and why is it so called ?
2. Define a vernier constant and the least count.
3. Why is it necessary to take more readings for the diameter than for the length ?
4. Look at the given:
   (a) Scale (b) Thermometer (c) Stop watch
   State the least count in each case.
5. Suppose you have a vernier callipers with the 20 main scale divisions amounting to 10 mm. 20 vernier division coincide with 19 m.s. divs. Calculate the vernier constant.

2.4 Screw Gauge (Micrometer)

Limitation of a Vernier Callipers

Vernier callipers can measure length upto one hundredth of a cm. When a greater accuracy is desired as in measuring small thicknesses of a thin glass plate or the diameter of a wire, an instrument called the screw gauge is used. A simple type of screw gauge is shown in fig. 2.7.

It consists of a U–shaped body of solid metal, one arm of which has a fixed plug having a plane face A. The other arm is attached to a hollow cylinder with a straight scale etched on it. This is known as the main scale. An accurate screw moves inside this hollow cylinder. The head of the screw carries a cap by which the cylinder is rotated.

The leveled edge C of the cylinder has a circular scale with 100 equal divisions engraved round it. As the head of the screw is turned, the circular scale moves across the fixed line of reference and the end of the screw moves towards or away from the plane face A. Thus the rotatory motion is converted into a linear one.

Instrumental Error

When the zero of the circular scale does not coincide with the zero of the main scale, the apparatus is said to have an instrumental error.

(i) If the zero of the circular scale is below the base line by x divisions.

The instrumental error = x × L.C.

∴ Correction = –x × L.C. (Least Count)

(ii) If the zero of the circular scale is above the base line by x divisions

Instrumental error = – x × L.C.

∴ Correction = +x × L.C. (Least Count)

Back–Lash Error

Sometimes the screw may not properly fit in the nut due to some looseness or fault between the screw and the nut. In such a case, equal amount of rotation of the screw head in opposite direction may produce unequal amount of linear motion of the point of the screw. Error due to this uncertainty is called Back–Lash error. It can be avoided by turning the Screw always in the same direction while taking a reading.

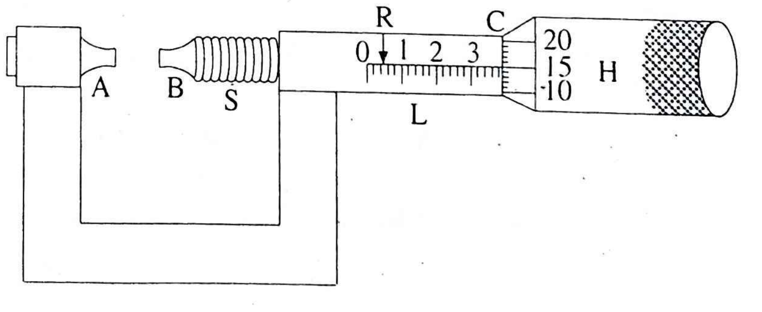


Fig. 2.7

Experiment No. 2.2

To use a micrometer screw gauge to determine (a) the cross section of the given rod. (b) volume of a steel ball.

1. Apparatus Required

(i) Micrometer screw gauge (ii) A glass rod (iii) Steel ball

2. Theory

The pitch of the screw is defined as the linear distance travelled by the screw gauge in one complete rotation of the circular scale. It is denoted by the letter P. The L.C. is the distance travelled by the screw when the circular scale is rotated through only one of its circular scale divisions, then the least count (L.C.) is given by

$$\text{L.C.} = \frac{\text{Pitch}}{\text{No. of circular scale divs.}} = \frac{P}{N}$$

If x be the linear scale of the rod, y be the circular scale reading, then

Required diameter of the rod (or of the Steel ball)

d = (Linear scale reading + Circular scale reading × L.C.) ± Instrumental error = $(x + y \times LC) \pm$ error

$\therefore$ Cross–section of the rod $= \frac{\pi d^2}{4}$ (or vol. of the ball) $= \frac{\pi d^3}{6}$

3. Procedure

(i) The value of 10 smallest divisions of the main scale is found out, from which the value of one div. is calculated. The total no. of circular divisions is noted.

(ii) The linear distance through which the circular scale moves along the main scale for 4 complete rotations of its circular head is found out, from which the distance for 1 complete rotation is calculated. This gives the Pitch of the screw. Hence the Least count is determined.

(iii) The instrumental error is next found out.

(iv) The given rod (or the ball) is held tight between the plane faces. The reading of the main scale immediately before the circular scale is read. The circular scale reading is next taken.

(v) Two readings in direction at right angles to each other are taken for each position.

(vi) Operations (iv) and (v) are repeated for at least 5 positions.

4. Observation

Value of 10 smallest divisions of the main scale = ...10... m.m.

$\therefore$ .... 1 .... division .... $= \frac{1.0}{10}$ mm

In 4 complete rotations, the circular scale moves through ...4... divs. of the main scale.

In 1 complete rotation, ...1... divs. = ...1... mm

$\therefore$ Pitch P = ...1...mm.

No. of circular scale divisions = N = ...100... divs.

$$\text{L.C. (Least count)} = \frac{\text{Pitch}}{\text{No. of cir. scale divs.}} = \frac{P}{N} = \frac{1}{100} \text{ mm} = 0.01 \text{ mm}$$

Instrumental Error

The zero of the circular scale is below or above the base line by x divs.

Instrumental erro = $+x \times$ L.C. or $+x \times$ L.C.

Correction = $-x \times$ L.C. or $+x \times$ L.C.

Diameter of the Rod (or the Ball)

Table No. 2.2

No. of Obs	Direction	Main Scale Reading x mm	Circular Scale Reading y	Value of y y × L.C. mm	Total = x + y × L.C. = d mm.	Apparent mean d cm	Corrected mean d cm
1	....						
2	....						
3	....						
4	....						
5	....						

(a) Cross–section of the rod = $\frac{\pi d^2}{4}$ sq. mm = ... sq.cm. = ... sq.m

(b) Volume of the ball = $\frac{\pi d^3}{6}$ Cu. mm = ... cc. = ... cu.m.

Precautions

(1) The screw should not be pressed too hard while finding the zero error or the diameter.

(2) The diameter should be measured in two mutually perpendicular directions.

(3) The screw should always be turned in the same direction in order to avoid the back–lash error.

(4) The zero error should be checked carefully and correction with proper sign should be applied.

Error and Order of Accuracy

The gauge pressure is just increased and the reading is noted. The error in the measurement of the diameter is the sum of the error in reading the micrometer open and closed.

Exercises

1. Define Pitch and Least count of Screw gauge. How can the least count be made small ?
2. What is Back–lash error ? How is it eliminated ?
3. What is an Instrumental error ?
4. A Screw gauge has 20 threads to a cm and the no. of divisions on the circular scale is 100. What is the least count ?
5. What is a Screw gauge ? Why is it called a Micrometer Screw gauge ?
6. In Measuring the diameter of a wire, why should you take two readings in directions mutually perpendicular to each other at a single place ?

2 Spherometer

A spherometer works on the principle of a screw. It can be used to measure the thickness of a Plate and also the radius of a spherical surface. The screw in this case is arranged vertically instead of horizontally and turns through a tripod.

The spherometer consists of a metal tripod provided with 3 equidistant pointed metal legs, A, B, C. It has an accurately cut screw ending in a pointed central leg. The screw has generally a pitch of 1 mm. or $\frac{1}{2}$ mm. It carries a circular scale at its top. The circular scale has generally 50, 100 or 200 equidistant divisions. The position of the circular scale may be read from a linear vertical scale fixed to one outer leg at right angles to the circular scale. The vertical scale is graduated in mm.

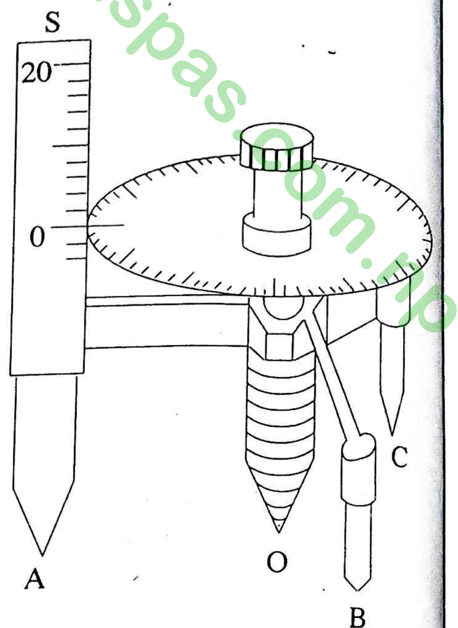


Fig. 2.8

The instrument is levelled when all the four legs touch a plane surface such as that of a glass plate. The three pointed legs of the tripod are equal in length. Their tips form an equilateral triangle and lie in the same plane.

When all the four legs are at the same level, the zero of the circular scale must lie against the zero of the vertical (Pitch) scale. In this case there is no zero error otherwise there is some zero error. For this purpose, the spherometer is placed on a glass plate.

Experiment No. 2.3

To use a spherometer to determine the

(i) thickness of the given plate.

(ii) radii of curvature of the given watch glass.

1. Apparatus Required

(i) Spherometer (ii) Base plate (iii) The given test plate (iv) Watch glass.

2. Theory

The pitch of the screw is defined as the linear distance travelled by the screw in one complete rotation of the circular scale. It is denoted by the letter P.

The least count of the apparatus is the smallest distance measurable by means of the apparatus. In the spherometer it is the distance travelled by the screw when the circular scale is rotated through its one circular scale division. Hence if P be the pitch of the screw and N be the circular scale divisions, then the least count L.C. is given by

$$\text{L.C. (Least count)} = \frac{\text{Pitch}}{\text{No. of cir. scale divs.}} = \frac{P}{N} = \ldots\ldots \text{ mm}$$

If x be the no. of complete rotations made, and y be the no. of additional circular scale division required in lowering the central leg from the initial position on the test plate to the final position on the base plate, the thickness of the plate is then given by:

$$\text{Required thickness} = (x \times P + y \times \text{L.C.}) \text{ mm.}$$

3. Procedure

(i) The value of 10 smallest divisions of the main (linear) scale is found out, from which the value of 1 div. is calculated. The total no. of circular scale divs. is noted.

(ii) Then the circular scale is lowered from a particular position on the linear scale through 4 complete rotations downward and the distance through which it moves is read from the scale. Then the pitch is calculated and hence the least count is determined.

(iii) The given test plate is placed on the base plate. The spherometer is placed so that the central leg lies on the test plate and the three outer legs on the base plate. The central leg should just touch the test plate. This can be tested by observing the rockey motion of the spherometer when the central leg just touches the test plate. It may also be confirmed by introducing a thin piece of paper in between the tip of the central leg and test plate. If the paper can not get in, the leg has touched the test plate.

(iv) In this position, the initial circular scale reading on the test plate is noted. The test plate is removed. The total no. of complete rotations lowered is noted. The final reading of the circular scale is also noted when the central leg just touches the base plate. This operation is repeated 5 times on one side of the plate.

(v) The plate is turned over and the above 5 readings are repeated.

(vi) The mean of these readings is taken. This gives the thickness of the plate.

4. Observations

Value of 10 smallest divisions of the main scale = ... mm.

∴ Value of 1 smallest division of the main scale = ... mm.

In 4 complete rotations, the circ. Scale moves through .... divisions of the main scale.

∴ In 1 complete rotation, ... divs. of the main scale.

∴ Pitch of the screw = ... (P) = ...

No. of the circular scale divs = N = ...

Least Count (L.C.) = $\frac{P}{N}$ = ... mm.

Table No. 2.3

No. of obs.	Initial circular scale reading on the test plate (a)	No. of complete rotations made (x)	Value of complete rotations = x × P. mm (1)	Final circular scale reading on the base plate (b)	No. of additional circular scale divs. N = (a-b)	Value of N = N × L.C. mm (2)	Total thickness = (1) + (2) mm	Mean Thck-ness
1								
2								
3								
4								
5								

The test plate is turned over

6								
7								
8								
9								
10								

(ii) Radii of curvature of the given watch glass

1. Apparatus

(i) Spherometer (ii) Base plate (iii) Watch glass

2. Theory

Same as in the previous expt, Add the following; The radius of curvature R of the given watch glass is given by

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

where 'a' is the distance between any two outer legs of the spherometer, h is the depth through which the central leg is lowered from the curved surface to the base plate.

3. Procedure

Operations (i) and (ii) are the same as in the previous expt.

(iii) The watch glass is placed on the base plate with its convex side upwards. The initial circular scale reading on the base plate is noted, the total no. of complete rotations made is also noted. This operation is repeated 5 times.

(iv) Next the initial reading is taken on the base plate and final reading on the concave surface, the total no. of complete rotations made being noted.

(v) The distance between any two outer legs is measured by pressing the spherometer legs on a sheet of paper, joining the prick marks.

(vi) The radius of curvature is then calculated by using the above given formula.

4. Observations

As in the above experiment

Table No. 2.4: Convex Surface

No. of obs.	Initial circular scale reading on the convex surface (a)	No. of complete rotations made (x)	Value of complete rotations made = x × P mm (1)	Final circular scale reading on the base plate (b)	No. of additional circular scale divs. N = (a-b)	Value of N = N × L.C. mm (2)	Total depth h = (1) + (2) mm	Mean depth h mm
1								
2								
3								
4								
5								

Table No. 2.5: Concave Surface

No. of obs.	Initial circular scale reading on the base plate (a)	No. of complete rotations made (x)	Value of complete rotations made $= x \times P$ mm (1)	Final circular scale reading on the concave surface (b)	No. of additional circular scale divs. N = (a-b)	Value of $N = N \times$ L.C. mm (2)	Total depth h = (1) + (2) mm	Mean depth h_2 mm
1								
2								
3								
4								
5								

Calculation: Distance between any two outer legs = a = ...

$$R = \frac{a^2}{6h} + \frac{h}{2} = \text{.........,} \qquad R_2 = \frac{a^2}{6h_2} + \frac{h_2}{2}$$

Error and Order of Accuracy

The screw must always be turned in the same direction to avoid Back–lash error.

Another error may arise when the zero of the circular scale is above (+ve) or below the zero line of the vertical scale (–ve) when the four legs are complanar.

∴ Correct reading = Observed reading – (± zero error)

The error is likely to occur as a result of a reading error of ± 1 circular scale division.

The percentage error in R is the sum of the errors in a and h.

Exercises

1. In a spherometer, the screw has 20 threads to a cm. and the no. of divisions on the circular scale is 100. Calculate the least count.
2. What do you mean by pitch and least count, zero error and Back–lash error in a spherometer.
3. Why is a spherometer so called ?
4. How can the accuracy of a spherometer be increased ?
5. How will you determine the volume of a glass plate ?
6. When is the zero error (a) positive (b) negative ?
7. How will you avoid the Back–lash error in a spherometer ?
8. A spherometer has its linear scale graduated in 2 divisions to a mm. and the circular scale has:

   (i) 100 divisions

   (ii) 50 divisions

   The circular scale moves through 1 div. in each rotation calculate the Pitch and the L.C. in each case.

2.6 Measurement of Area

The area of any regular figure can be determined by applying formula mentioned: In the case of irregular figures where the area is bounded by an irregular curved line, the area is best obtained by drawing the figure on a squared paper and counting the number of small squares.

If the squared paper (graph paper) is ruled every tenth of an inch, each small square = 0.01 sq. in, if it is ruled; every tenth of cm, each small square = 1 mm^2 = 0.01 sq. cm.

∴ The total area of the figure = no. of small squares × area of 1 small square. The boundary line will generally cut through several small squares and it is enough if less than half is omitted and more than half is counted as one.

Area of an irregular figure: – Graphical method.

A piece of graph paper is fixed on a drawing board. The given figure is placed on the graph paper and its outline is drawn. If n be the no. of each small square included within the outline and x = value of each small square, then area of the figure = nx.

Weighing Method

The given figure on a sheet of metal is of thickness say x c., x is determined by slide callipers or a screw gauge.

∴ Mass of the sheet m = vol. × density

$$= \text{area} \times \text{thickness} \times \text{density} = ax \times s$$

where a = area of the sheets

s = density of the material

$$\therefore \quad a = \frac{m}{xs}$$

Experiment No. 2.4

To determine the value of π with the help of a piece of a graph paper.

1. Apparatus Required

(i) Graph paper (ii) Instrument box

2. Theory

A circle is drawn on a graph paper. If A be the area of the circle graphically, r the radius of the circle.

$$A = \pi r^2$$

$$\therefore \quad \pi = \frac{A}{r^2} = \frac{ns}{r^2}$$

where n = no. of small squares included within the circle,

s = value of 1 small square.

3. Procedure

(i) A graph paper is fixed on the drawing board.

(ii) A circle of about 3 cm. radius is drawn on the graph paper with the help of a compass.

(iii) The circle is divided into four quadrants by drawing two mutually perpendicular diameters. Then the no. of the small squares intercepted by the boundary line is counted in each quadrant. Besides there may be a few small squares cut by the boundary line. While counting these, half or more than half of a small square is counted as one, and less than half is neglected.

(iv) Operations (ii) and (iii) are repeated thrice by drawing circles of different radii.

4. Observations

100 small squares in the graph paper = 1 sq in or 1 sq. cm. = $\frac{1}{100}$ = 0.01 sq. in or sq. cm.

Table No. 2.6

No. of circle	No. of quadrants	No. of complete small squares	No. of incomplate small sqs. counted as full	Total No.	Grand Total	Total area of the circle sq. cm A.	Radius of the circle r	$\pi = A/r^2$	Mean π
1	I								
	II								
	III								
	IV								
2	I								
	II								
	III								
	IV								
3	I								
	II								
	III								
	IV								

Correct value of $\pi = \frac{22}{7}$ = 3.14 ...... (C)

Observed value of π = ... (O)

% error = $\frac{C - O}{C} \times 100$ = ...

Exercises

1. Find the mass per unit area of the given piece of paper.

2.7. Measurement of Volume

The volume of a certain body is expressed in cubic cm. (c.c) in C.G.S. unit and cubic *ft*. (cu. *ft*) in F.P.S. unit

1. Volume of Regular Bodies

(i) a cube = $(\text{length})^3$

(ii) a cylinder = $\pi r^2 h$ where r is the radius of the cylinder

h is the length of the cylinder.

(iii) cone = $\frac{1}{3}\pi r^2 h$ r is the radius of the base.

h is the height of the cone.

(i) Volume of the irregular bodies:

The volume of irregular bodies may be determined in the laboratory by any one of the following ways:

$$\text{Mass} = \text{Volume} \times \text{Density}$$

$$\therefore \quad \text{Volume} = \frac{\text{Mass}}{\text{Density}}$$

(ii) Applying Archimedes' principle,

Apparent loss in wt. (in C.G.S. unit) when immersed in water = Vol. of the body.

(iii) Displacement of water.

Experiment No. 2.5

To determine the Volume of a Solid by Displacement of water.

1. Apparatus Required

(i) A measuring cylinder, (ii) A piece of thread or a rod.

2. Theory

Any solid insoluble in water when completely immersed in water displaces its own volume of water. Hence if X c.c. be the reading of the water level in the cylinder before the introducing of the solid and y that after introducing of the solid, then the volume of the solid body

$$V = (y - x) \text{ c.c.}$$

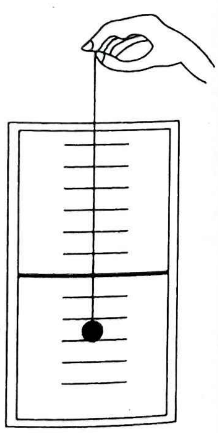


Fig. 2.9

3. Procedure

(i) The measuring cylinder is partly filled with water and the reading of water level is noted.

(ii) The given solid is tied to a piece of thread and is immersed in the cylinder as shown in figure 2.9.

(iii) The reading of water level is again noted after the introducing of the solid.

(iv) Operations (i), (ii), (iii) are repeated 5 times by adding some more water into or taking away some water from the cylinder.

4. Observations

Value of 10 divs. of the measuring cylinder = ... c.c.

∴ Value of 1 div. of the measuring cylinder = ... c.c.

Table No. 2.7

No. of obs.	Reading of Water Level		Difference	Mean
	Before introduction of solid x c.c.	After introduction of solid y c.c.	V = y − x c.c.	V c.c.
1				
2				
3				
4				
5				

Error

Here the error may arise due to defective observation taken at the lower meniscus of water. It may, however, be eliminated by taking the reading exactly at the lower meniscus, which may vary slightly for different observers.

Chapter 3
Measurement of Mass

Mass and Weight

The quantity of matter contained in a body is called its mass. The force of attraction exerted on it by the earth is called its weight. This pull is directly proportional to its mass. As weight is a pull, it is represented in unit of force. Weight changes from place to place depending on the value of acceleration due to gravity at the place where as its mass is sensibly constant.

Unit of Mass

The Standard Kilogram and Pound: The standard unit of mass is the kilogram, a block of platinum preserved at the International Bureau of Weights and Measures near Paris. The kilogram is divided into one thousand equal parts called grams, the gram being the mass of 1 cubic centimeter (1 c.c.) of pure water at 4°C.

Then 1 kilogram (kg) = 1000 gram (gm).

1 gm = 1000 miligram (mg).

The standard pound is defined in terms of the relation, 1 *l*b = 4.536 kg.

1 *l*b = 16 oz = 453.6 gm.

∴ 1 oz = 28.35 gm.

1 kg = 2.205 *l*b

Weight Box: It is a wooden box which has suitable compartments generally covered with velvet to contain standard weights, weights should be properly handled with forceps or tongs only, thus avoiding chances of soiling. The number punched on the weights indicates their values. Riders of bent aluminum wire usually in mg are also provided. The weight should be placed in their proper places, after use.

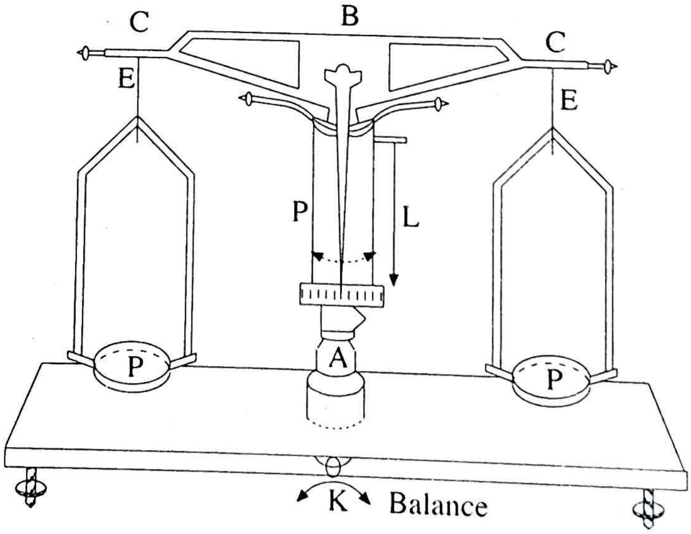


Fig. 3.1

The weights in a weight box are arranged in the following order:

Weight in gm: 100, 50, 20, 20, 10, 5, 2, 2, 1

Weight in mg: 500, 200, 100, 50, 20, 20, 10, 10, 5

For higher accuracy, riders are used.

An Ordinary Balance

The Common Balance

It is an instrument which provides us with a ready means of measuring the mass of a body. We do not measure the weight of a body directly with it. What we do is its mass is determined by comparison with a standard mass, called a weight in a Weight Box.

The common balance is just a lever with its fulcrum at the mid point.

The essential parts of an ordinary balance are:

1. A horizontal rigid beam B usually of aluminum or brass or nickel plated iron graduated on either side. It runs freely about a fixed point of support at the fulcrum which is a sharp edge standing on a flat plate of steel or agate fixed on the top of the pillar of the balance.
2. Two scale pans of equal weight are suspended from stirrups (or hangers) carried by knife edges at the two extremities of the beam.
3. **The beam:** has two smaller nuts C at its ends. Any one of them or both may be adjusted as necessary to keep the balance of the two sides of the beam.
4. **The pillar:** It is a vertical central rod P on the top of which the central knife edge of the beam rests on the plate. It can be raised or lowered by the base key K turning it to the right or left.
5. **The pointer and the scale:** There is a light aluminum or steel tapering strip held at the middle of the beam with its pointed end vertically downwards and capable of moving over a graduated short scale (above A) usually of ivory with its zero at the middle.
6. **The plumb line and levelling screws:** The plumb line L suspended alongside the pillar points to the conical metal piece at the base such that when the pillar is vertical, the plumb line bob and the metal cone appear in line with each other.

   There are three screws fixed at the vertices of an equilateral triangle at the base of the balance. Levelling is done by the help of these screws.
7. The whole apparatus is enclosed in a rectangular wooden casing with glass sides, making the balance vesible from outside and making it independent of external air currents.

To keep the instrument free from moisture, drying agents like calcium chloride are sometimes kept within the enclosure.

Principle of Weighing

Let A and B be the two knife edges while C is the fulcrum. When AB is horizontal, the turning moments of the two forces (Weight of the body and wt. of the standard weights), called the Resistance and Effort respectively are equal.

Thus, $mg \times l = m'g \times l'$

where m and m' are the masses of the resistance and effort and l and l' are the corresponding lengths of the arms. But since $l' = l$

m = m' i.e. the mass of the load = mass of the balancing weight

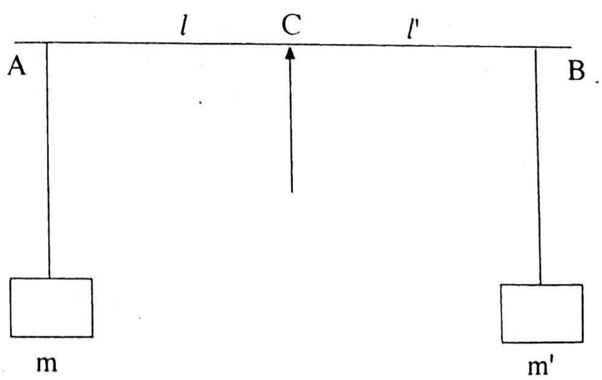


Fig. 3.2

Rules to Observe in Weighing

1. Observe carefully whether the parts of the balance are in their proper place and specially whether the stirrups are over the knife edges.
2. Level the apparatus properly.
3. Take out the pans, clean them with a dry cloth and reset them in their places.
4. Always place the standard weight on the R.H.S. pan and the load (to be weighed) on the L.H.S. pan.
5. Begin with a weight greater than that of the body and try weights in a gradual diminishing order.
6. Do not place weights on the pan or remove them from the pan while the beam is swinging, but bring the beam to rest by turning the handle before adding or removing weights.
7. Do not handle the weights (both large and small) with your fingers but use the forceps only. Touch of the hand should always be avoided.
8. Count the weights on the pan and note down the total. Check also the vacant places in the box and make sure that these total agrees with the previous one.
10. If the body to be weighed is hot, wait till it becomes cold.

Experiment No. 3.1

To weigh a body by the method of equal deflection

1. Apparatus Required

(i) Balance, (ii) Weight box, (iii) The given body

2. Theory

See Principle of weighing

3. Procedure

(i) The front door of the glass case is opened. The balance is levelled properly with the help of the levelling screws. Then the plumb line is adjusted.

(ii) The base key is gently raised and the pointer observed if it moves freely over the scale or not.

(iii) The beam is lowered. The screw riders (only one or both) should be adjusted. The beam is raised again and observe whether the pointer moves over equal divisions on both sides of the central mark. In observing the pointer, the line of sight should be perpendicular to the scale, thus avoiding parallax.

(iv) The body to be weighed is placed in the middle of the L.H.S. pan and a weight greater than the probable maximum weight of the body is placed in the middle of the R.H.S. pan.

(v) The beam is cautiously raised and the deflection of the pointer noted. Left deflection indicates overweighing while the right deflection indicates under weighing the beam is then lowered and weights are adjusted accordingly. The weights in the descending order are tried till the pointer oscillates over equal divisions on either side of the middle of the scale showing thereby that the weights on the two sides have been balanced.

(vi) Results are entered in a tabular form as shown below.

(vii) The weights are removed from the pan and replaced in their proper positions in the weight box and the door of the balance closed.

4. Observations

Table No. 3.1

wts. on the R.H.S. pan gms.	mgms.		
gms.	mg.ms	To the left	
50	×	To the right	too small
20	×	To the right	too large
20 + 20	×	To the right	too large
20 + 10	×	To the right	too small
20 + 10 + 5	×	To the right	too small
20 + 10 + 2	×	To the right	too large
20 + 10 + 1 = 31	×	To the right	too small
	500	To the right	too small
	500 + 200	To the right	too small
	500 + 200 + 200	To the right	too small
	500 + 200 + 200	To the left	too large
	500 + 400 + 50	To the left	too small
	500 + 450 + 20 + 10	equal on either side	Balanced

∴ Total mass of the body = 31 gm and 980 mg = 31.980 gm

Precautions

1. The beam should be lowered when the pointer during oscillation is crossing the middle of the scale.
2. The heavy weights are placed in the middle and smaller ones around them.
3. The weights are to be taken out or placed on the pan only when the beam is at rest.
4. Always a forcep is to be used in lifting the weight.
5. The beam is to be lowered when the expt. is over.

How to use a Rider

Every sensitive balance has its right arm usually divided into 10 equal parts. A rider (generally of 10 gmms) placed on any one of the marks is equivalent to adding 1 mg on the right. Placing the rider on the 5^{th} mark means addition of 5 mg on the right and so on.

Experiment No. 3.2

To verify the principle of moments and hence determine the weight of the given body.

1. Apparatus Required

(i) A meter scale (ii) Knife edge (iii) Slotted weights (iv) Twin thread (v) Unknown body

2. Theory

Principle of Moments

The Principle of Moments states that "If a body is in such a rotational equilibrium that it will neither rotate nor rotate at a uniform rate, the sum of the clockwise moments is equal to the sum of the anti-clockwise moments." This Principle may be utilised to find the magnitude and direction of an unknown force acting on a body in equilibrium.

In the diagram if P and Q be two forces acting at A and B of a rigid body are in equilibrium about the point O then by the Principle of moments.

$$P \times OA = Q \times OB \qquad \ldots(1)$$

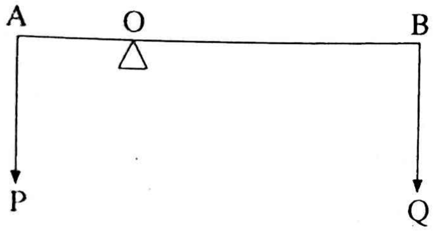


Fig. 3.3 (a)

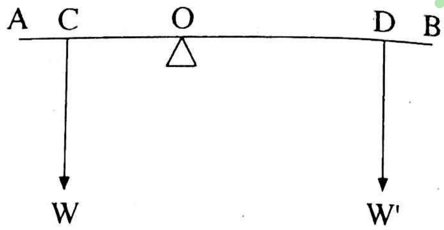


Fig. 3.3 (b)

If W be the unknown load and W' be the known load, and if W and W' acting at C and D keep the body in equilibrium about O, then

$$W \times OC = W' \times OD$$

$$\therefore \quad W = \frac{OD}{OC} \times W' \qquad \ldots(2)$$

3. Procedure

1. A meter scale is taken. Its center of gravity (C.G.) is marked by balancing it about a knife edge.
2. Then two equal wts. of say 10 or 20 gms. each are suspended from two points at equal distances from the C.G., distances OA and OB are noted. The moments of the forces about the C.G. are calculated as in equation (1).
3. Operations (2) is repeated by suspending two unequal wts. from two points at required distances from the C.G., always keeping the scale horizontal. This is repeated again by suspending more than one or two wts. about the C.G. and adjusting the distances as found necessary.
4. Lastly the unknown load is suspended on one side and the known body on the other.
5. Observations are tabulated as follows

Table No. 3.2

No. of obs.	Wts. on the		Distances from C.G. of		Sum of moments of forces on the		Remarks	Unknown load
	Left of C.G. W	Right of C.G. W'	W	W'	Left	Right		

Precautions

1. The C.G. of the scale should be carefully marked. The scale must be allowed to rest on a sharp knife edge exactly at its C.G.
2. The wts. should be suspended away from the C.G.
3. In the position of equilibrium, the meter scale should be horizontal.
4. The loop of the thread in each case should be parallel to the marking on the scale.
5. The expt. should not be performed under the fan.

Error and Order of Accuracy

The error in noting the distance of the point of suspension of the weight from the C.G. of the scale.

Experiment No. 3.3

To verify the law of Parallelogram of forces and hence determine the weight of the given body.

1. Apparatus Required

(i) Parallelogram Law Apparatus (Board with suitable pulleys),

(ii) Necessary slotted weights of 10 gms, 20 gms, 50 gms, etc.

(iii) Twine thread.

2. Theory

The Law of Parallelogram of forces states that if two forces acting simultaneously on a particle, be represented by two adjacent sides of a parallelogram, their resultant will be represented by the diagonal of the parallelogram drawn from the same point.

If the two forces be denoted by P and Q and θ be the angle between them, their resultant is given by

$$R^2 = P^2 + Q^2 + 2PQ \cos \theta \quad \ldots (1)$$

If this relation is found to be true, the law is verified.

Otherwise, if P, Q and R be the forces represented by OA, OB and OC of the parallelogram OACB, when in equilibrium, the sides of the parallelogram OACB should be proportional to the forces acting along them so that

$$\frac{P}{OA} = \frac{Q}{OB} = \frac{R}{OC} \quad \ldots (2)$$

If the relation (2) is found to be true, the law is verified.

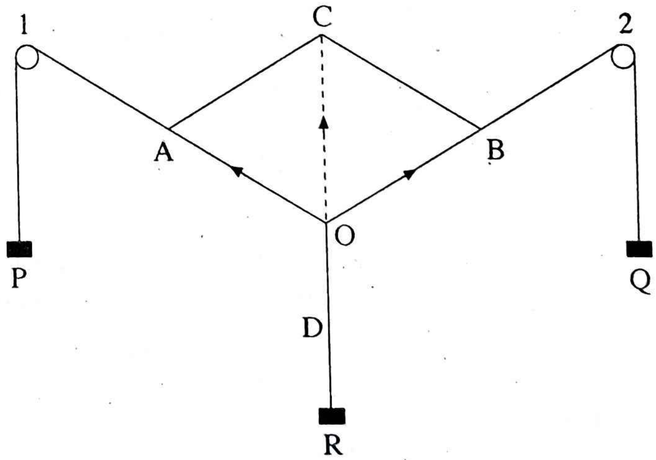


Fig. 3.4

3. Procedure

(i) The given apparatus is fixed on the wall of the room. The clamps with pulley are fixed as shown in fig. 4.4. A sheet of paper is fixed on the board.

(ii) Three suitable piece of twine thread are taken and tied into a knot at O. Two pieces are passed over the pulleys 1 and 2.

(iii) Weights of say 25 gms are suspended from the portions of the thread passing over pulleys 1, 2 and the knot.

(iv) Some lighting arrangement is made so that the shadow of the portions of the thread may be distinctly visible on the paper. Pencil marks are made on the paper, one just at the position of the shadow of the knot, two each on the shadow of the portions represented by OA, OB and OD. These are marked 1, 1, 1.

(v) The distance between the pulley is slightly increased or decreased. Operation (2), (3) and (4) are represented changing the weights in operation (3) to some other values. This time the pencil marks are marked 2, 2, 2. In this way about 5 sets of observations are taken. After this 2 or 3 sets of observations are taken by suspending the unknown load X in place of P, Q or R.

(vi) The sheet of paper is removed and fixed on the drawing board. Pencil marks (1, 1, 1) are joined to the position of the knot. The line OD is produced backwards to C so that OC is not less than 5 cms. Taking OC as the diagonal, draw a parallelogram OACB with the help of set squares.

(vii) OA, OB and OC representing P, Q and R respectively are measured. The ratios $\frac{P}{OA}, \frac{Q}{OB}, \frac{R}{OC}$ are calculated.

(viii) Operations are noted as shown below:

Table No. 3.3

No. of obs	P gm.	Q gm.	R gm.	OA cm.	OB cm.	OC cm.	$\frac{P}{OA}$	$\frac{Q}{OB}$	$\frac{R}{OC}$	Remarks
1	25	25	25							
2										
3										
4										
5										
6	×									
7		×								
8			×							

Conclusion

Thus since $\frac{P}{OA} = \frac{Q}{OB} = \frac{R}{OC}$

The law of Parallelogram of forces is verified. Otherwise measuring the angle θ between OA and OB, in each of the observations, the law can be verified by checking the validity of the relation

$$R^2 = P^2 + Q^2 + 2PQ \cos \theta.$$

Precautions

1. The board should be perfectly vertical.
2. The pulley should be frictionless.
3. Hangers should not touch the board.
4. Suitable scale (neither too large nor too small) should be chosen.
5. The direction of the forces should be shown by arrow heads.

Error and Order of Accuracy

Hence the error may creep in while making pencil marks on the paper at the position of the shadow of the thread and completing the parallelogram.

Exercise

1. Distinguish between Moment of a force and Momentum of a body. State their units and dimensions.
2. What is Torque ?
3. What is a Couple of forces ?
4. Three forces in one plane act upon a rigid body. What are the conditions for equilibrium ?
5. State the principle of moments. How would you apply the principle to determine the sp. gr. of a solid ?
6. What is Center of gravity of a body ?
7. A rod weighs 40 kg. With a 15 kg wt. at one end, it balances at a point 4 m from the same end. Find the length of the rod.
8. Two bodies in free space have masses of 6 kg and 9 kg respectively and are 8 m apart. Where is their Centre of mass ?
9. A nail projects horizontally from a vertical wall. A string is attached with its head and the string is pulled at an angle of 60° to the wall with a force of 10 kg wt. Calculate the force tending to bend the nail and the force tending to pull the nail out of the wall.
10. Distinguish between vectors and scalars. Give three examples of each.
11. State the law of Parallelogram of Forces, Triangle of Forces and Lami's theorem.
12. Suppose the rain is falling vertically downwards. State why a person holds his umbrella straight while standing and at some angle while walking ?
13. Define force. State its units and dimensions.
14. Suppose two forces of 25 N and 80 N simultaneously act on a body. What will be the maximum and minimum force ?

Experiment No. 3.4

To determine the coefficient of Friction between the given surfaces by

(i) *Horizontal plane method,*

(ii) *Inclined Plane method.*

(i) *Horizontal plane method*

1. Apparatus Required

(i) Friction apparatus adjustable for Horizontal and Inclined Position (ii) Spring Balance

(iii) Scale (iv) Standard Weights of 25 and 50 gms. (v) Weight Box.

2. Theory

According to one of the laws of limiting friction, the force of friction (F) is directly proportional to the normal reaction (R).

i.e. $F \propto R$

or $F = \mu R$ ... (1)

$\therefore \mu = \frac{F}{R}$

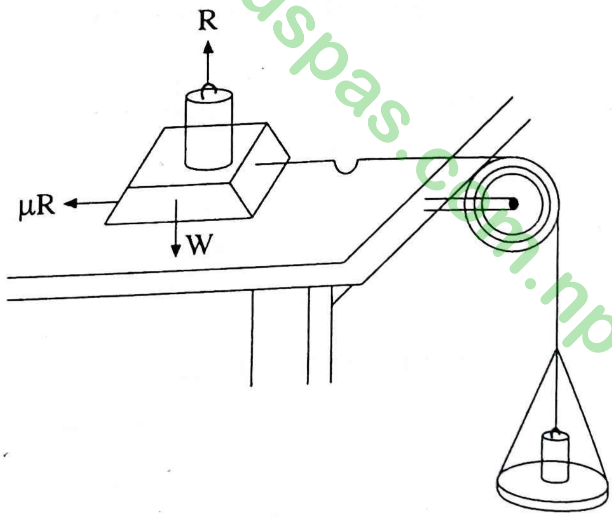


Fig. 3.5

where μ is called the coeff. of friction between the given surfaces. Eqn (1) is similar to $y = mx$ which is the eqn. of a st. line passing through the origin. Hence the graph of F against R should be a st. line passing through the origin. From the graph, μ may be found out from the slope.

$$\therefore \mu = \frac{F}{R}.$$

3. Procedure

(i) The friction table is levelled properly with the help of a spirit level.

(ii) The wooden box and the scale pan are separately weighed in a spring balance or an ordinary rough balance. The weights are noted.

(iii) The wooden box is placed on the table and its position is marked by a pencil or chalk. One end of a piece of twine thread is tied to the hook on the box and the other end, after being passed over a pulley at the end of the table, is tied to the scale pan. The portion of the thread between the hook and the pulley should be made horizontal.

(iv) Now a known weight say 50 gm is placed in the box. Weights from the weight box are gradually added on the scale pan until the box slides over the table with uniform velocity on gentle tapping. The weights are noted.

(v) Operation (iv) is repeated for at least 5 or 7 observations, each time increasing the load on the box by 50 gms. Observations are noted as shown below.

(vi) Then a graph of F against R is plotted and μ in calculated from the graph also.

4. Observation

wt. of the box = w_1 = ... gms

wt. of the scale pan = w_2 = ... gms

Table No. 3.4

Surfaces in contact	No. of obs	Wt. on the box a gms	Normal Reaction $R = w_1 + a$ gms	Wt. on the scale pan. gms.	Force of friction $F = w_2 + b$	$\therefore \mu = \frac{F}{R}$	Mean μ
Wood on Wood	1						
	2						
	3						
	4						
	5						
	6						
	7						

From the graph,

$\therefore \mu = \frac{F}{R} = ...$

(ii) *Inclined Plane Method*

1. Apparatus Required

Friction Apparatus adjusted for inclined position.

2. Theory

When the wooden box of wt. wg is just on the point of the sliding down the inclined plane, suppose θ is the angle of inclination of the plane. The wt. wg will be vertically downwards through the C.G. of the box

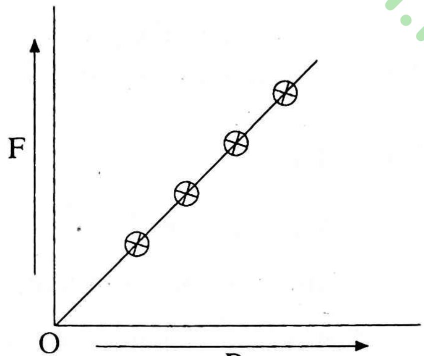


Fig. 3.5 (a)

Then resolved part of wg along the direction opposite to the normal reaction

$$R = wg \cos\theta \quad \ldots(i)$$

The resolved part of wg down the plane = wg sin θ

$$\therefore \quad F = wg \sin\theta \quad \ldots(ii)$$

Dividing (ii) by (i)

$$\frac{F}{R} = \frac{wg. \sin\theta}{wg. \cos\theta} = \tan\theta$$

$$\therefore \quad \mu = \frac{F}{R} = \tan\theta = \frac{AB}{OA}$$

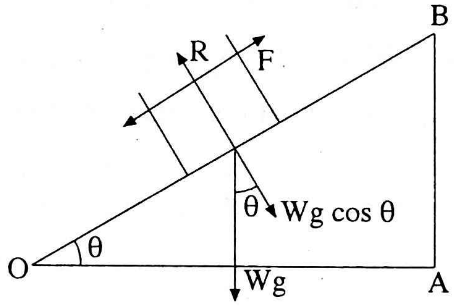


Fig. 3.5(b)

3. Procedure

(i) The wooden box is placed somewhere on the inclined plane and its position is marked.

(ii) The inclination is gradually increased more and more until the box begins to slide down with a slow uniform velocity. The height AB and the base OA are measured and θ is calculated.

(iii) Operation (ii) is repeated for at least 5 or 7 times with different wts. placed on the box. The height and the base are measured each time and tan θ is calculated.

4. Observations

Table No. 3.5

Surfaces in contact	No. of obs. gm.	Wts. on the box gm.	Height AB cm.	Base OA	Mean $\mu = \frac{AB}{OA}$

Precautions

(i) The horizontal table should be horizontal and clean.

(ii) The thread between the pulley and the box should be horizontal.

(iii) The scale pan should not touch the working table.

(iv) The box on the horizontal table should be tapped gently.

Errors and Order of Accuracy

The line with the greatest and the least slopes which agree with the plotted points are drawn. Then the error in μ is found from the variation in slope.

Exercise

1. What is friction ?
2. Distinguish between Static friction, Sliding friction and Rolling friction.
3. Define coefficient of friction and Angle of uniform slip.
4. State the laws of Limiting friction ?
5. State the significance of friction in everyday life ?
6. What happens to the energy expended against friction ?
7. Why should one take short steps than long ones while walking on ice ?
8. A 800 N – piano is moved 15 m across the floor by a horizontal force of 250 N. Find the coeffs. of the friction. What happens to the energy expended ?
9. A body of mass 20 kg just slides down a rough inclined plane of 5 in 13. Calculate the coeffs. of friction.
10. A body of mass 25 kg slides down an inclined plane without acceleration when the horizontal is 10°. Find the acceleration when the inclination of the body when the inclination is changed to 30°.

Hydrostatics

Density: The density of a substance may be defined as its mass per unit volume and is expressed in gms. per c.c. in C.G.S. unit *l*bs. per cu. *ft*. in F.P.S. unit, kg m^{-3} in S.I. units

If M be the mass of the substance and V its volume, density D is given by

$$D = \frac{M}{V} \text{ gm/c.c. in C.G. S units or kg/m}^3 \text{ in S.I. units}$$

or *l*bs. cu. *ft*. in F.P.S. units

Specific Gravity: The Sp. gr. of a substance is defined as the ratio of the weight of a certain volume of the substance to the weight of an equal volume of pure water at 4°c. It is also known as Relative density and is expressed as

$$\text{Sp. gr.} = \frac{\text{wt. of a certain volume of the substance}}{\text{wt. of the same volume of water at 4 °C}}$$

$$\text{or} \quad S = \frac{\text{wt. of unit volume of the substance}}{\text{wt. of the unit vol. of water at 4 °C}}$$

$$= \frac{\text{Density of the substance}}{\text{Density of water at 4 °C}}$$

$$= \frac{\text{Density of the substance}}{\text{Density of water at 4 °C}} \times \frac{\text{Density of water at t °C}}{\text{Density of water at 4 °C}}$$

$$= \text{Observed sp. gr} \times \text{sp. gr of water at t °C}$$

Since density of water at 4 °C = 1 gm/c.c. in C.G.S. unit, or 1000 kgm^{-3} in S.I. units. The Sp. gr. of a substance is numerically equal to its density in C.G.S. units.

But in F.P.S unit, density of water = 62.5 in F.P.S units.

$$\therefore \quad S = \frac{\text{Density of the substance}}{62.5}$$

$\therefore$ Density of the substance = S × 62.5 in F.P.S. units

Density has a unit but sp. gr. has no units.

Sp. gr is a pure number.

The density of a substance is different in different system of units but its Sp. gr is the same in all systems since it is a pure number and dimensionless.

Density of water is different at different temperature.

Experiment No. 3.5

To verify Archimedes' Principle

1. Apparatus Required

(i) A sinker (a piece of solid glass or a metal piece or piece of porcelain),

(ii) Hydrostatic Balance with weight box and Hydrostatic Bridge.

(iii) A measuring cylinder.

2. Theory

Archimedes' Principle states, "When a body is wholly or partly immersed in a liquid, it will displace a volume of a liquid equal to the volume of the immersed portion and will lose a part of its weight which is equal to the weight of the liquid displaced."

Thus let wt. of the sinker in air = w gm. wt.

.... water = w_1 gm. wt.

$\therefore$ Loss of ωt in the water = $(w - w_1)$ = ... gm. wt.

$\therefore$ density of water at lab. temp. = ρ_t (from physical table)

Volume of the water displaced when the sinker is completely immersed in it = V c.c.

$\therefore$ wt. of the water displaced = $V \times \rho_t$ gm. wt

where ρ_t = density of water at the lab. temp.

According to the Archimedes' principles we must have

$$(w - w_1)g = V \times \rho_t g$$

$$\therefore \quad w - w_1 = V \times \rho_t$$

3. Procedure

(i) The sinker is suspended from one arm of the Hydrostatic balance and weighed in air, taking care to place a piece of suspension wire on the other arm for compensation.

(ii) The sinker is then allowed to immerse completely in water contained in a beaker placed on the bridge across the pan of the balance. It is counterpoised by putting weights on the other pan. Thus the wt. of the sinker in a water is noted.

(iii) The measuring cylinder is taken. It is filled slightly more than half of the water. The initial reading of the water level is noted. The sinker is tied with a piece of thread and is allowed to completely immerse in water in the measuring cylinder. The final reading of the water level is noted after immersing the sinker. The difference between this and the previous reading gives the total volume of the sinker and hence the volume of the water displaced by it when completely immersed in water.

(iv) Operations (ii) and (iii) are repeated about 5 times. Then mean volume is found out.

(v) Temperature of water is noted and density of water at the lab. temp. is found out from the tables.

4. Observations

wt. of the sinker in air = w = ... gm. wt

.... water = w_1 = ... gm. wt.

∴ Loss of wt. in water = $w - w_1$ =...... gm. wt.

Temp. of water in the lab = t °C = ...

∴ Density of water at the lab. temp. = ρ_t

(from physical tables) = ...

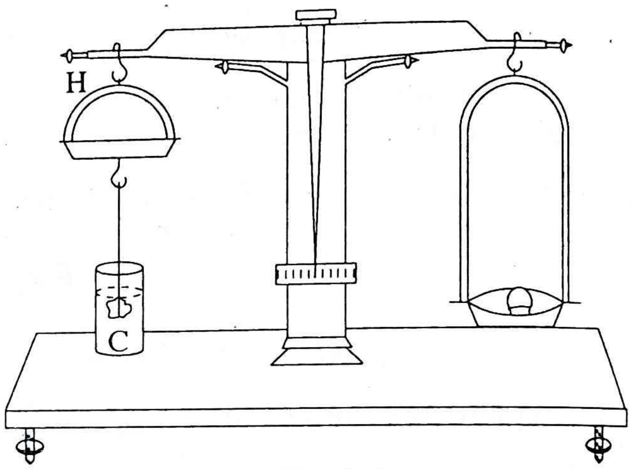


Fig. 3.6

Obs. for the vol. of the sinker

Table No. 3.6

No. of obs.	Reading of the water level before introducing the sinker (a)	Reading of the water level after introducing the sinker (b)	V = Difference = (b – a) c.c.	V c.c
1				
2				
3				
4				
5				

∴ Volume of water displaced = V c.c. = ...

wt. of water displaced = $V \times \rho_t$ = ... gm. wt.

= ....

Experimentally, we have

$$w - w_1 = V \times \rho_t$$

Conclusion

Hence Archimedes' Principles is verified.

Experiment No. 3.6

To determine the sp. gr. and the length of the given Tangle of wire.

1. Apparatus Required

(i) Tangle of wire. (ii) Hydrostatic Balance, weight Box (iii) Beaker

(iv) Hydrostatic Bridge (v) Suspensions wire (vi) Screw gauge

2. Theory

Let the wt. of the tangle of the wire in air = w gm. wt.

Let the wt. of the tangle of the wire in water = w_1 gm. wt.

∴ Loss of the wt in water = $w - w_1$ gm. wt. = wt mass of water displaced.

= Vol. of water displaced × density of the water gm. wt.

or $w - w_1$ = vol of the tangle × ρ_t

where ρ_t is the density of water at the lab temp.

∴ density of the tangle $= \frac{\text{wt of the triangle}}{\text{wt of water displaced}} = \frac{w}{w - w_1} \times \rho_t$ ... (1)

and vol. of the tangle of wire $= \frac{w - w_1}{\rho_t}$

or cross section × length $= \frac{w - w_1}{\rho_t}$

or $\frac{\pi d^2}{4} \times l = \frac{w - w_1}{\rho_t}$

∴ $l = \frac{4\,(w - w_1)}{\pi d^2 \times \rho_t}$

This gives the length of the tangle.

3. Procedure

(i) The given tangle of wire is first of all weighed in air. Then it is suspended by a piece of wire from the stirrup at the left arm of the hydrostatic balance. An equal length of the wire is placed on the right arm of the balance.

(ii) A beaker containing water is placed on the bridge placed across the left pan. The tangle is allowed to immerse and thus its weight when b immersed in water is noted. Then the sp. gr. is calculated.

(iii) The diameter of the wire forming the tangle is measured by means of a screw gauge at 5 different positions and observations are entered. The mean diameter is found to be 'd' cm. Then the length of the wire is calculated by using the formula given under the theory above.

4. Observations

wt. of the tangle in air = w = ... gm. wt.

wt. of the tangle in water = w_1 = ... gm. wt.

∴ Loss of wt. in water = $w - w_1$ = ...

= wt. of water displaced.

$$\therefore \quad \text{Sp. gr.} = \frac{w}{w - w_1} \times S_t$$

Where S_t is the sp. gr of the water at the lab. temp.

For measuring the diameter, the observations are recorded as in expt. on diameter measurement by screw gauge.

Let the diameter, obtained = d = ... cm. using the equation $l = \frac{4 (w - w_1)}{\pi d^2 \rho_t}$. Thus the length of the tangle of wire can be calculated.

Experiment No. 3.7

To use a Hydrostatic Balance to determine the Specific gravity of

(i) a solid heavier than and insoluble in water

(ii) a solid lighter than and insoluble in water

(iii) a liquid

(iv) a solid heavier than and soluble in water.

The sp. gr. of substance may be defined as:

$$S = \frac{\text{wt. of a certain vol. of the substance}}{\text{wt. of an equal vol. of water at 4 °C}}$$

$$= \frac{\text{wt. of a certain vol. of the substance}}{\text{wt. of the same vol. of water at t °C}} \times \frac{\text{wt. of the same vol. of the water at t °C}}{\text{wt. of the same vol. of water at 4 °C}}$$

$$= \frac{\text{wt. of a certain vol. of the substance}}{\text{wt. of the same vol. of water at t °C}} \times S_t$$

where S_t is the sp. gr. of water at the laboratory temp t °C

The sp. gr. of a substance may be determined by using a Hydrostatic balance which is an ordinary Physical balance with a little extra arrangement of a Hydrostatic bridge placed across a pan without touching any part of the balance. This enables us to weigh a body while immersed in water or any other liquid in a beaker placed in the bridge.

(i) a solid heavier than and insoluble in water

Theory

The solid is first weighed in air and then in water. The temp. of water is noted by a thermometer. Calculation is made according to the following theory:

Wt. of the solid in air = w gm. wt.

Wt. of the solid in water = w_1 gm. wt.

$\therefore$ Loss of wt. in water = $w - w_1$ = gm. wt.

= wt. of an equal vol. of water displaced,

$$\therefore \quad \text{Sp. gr. of solid} = \frac{\text{wt. of the solid}}{\text{wt. of equal vol. of water displaced}} \times S_t$$

$$= \frac{w}{w - w_1} \times S_t$$

where S_t is the sp. gr. of water at the lab temp.

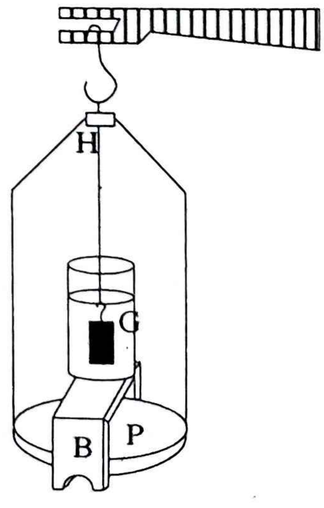


Fig. 3.7

Precaution

The solid while being immersed should be completely within the liquid and should not touch any side of the beaker. A piece of the thread equal to that used for suspending the solid should be used on the other pan for compensation.

(ii) a solid lighter than and insoluble in water

Theory

The solid being lighter than water cannot be immersed in water. So a sinker is used. This is an auxiliary solid which when tied with the experimental solid will sink in water. It should be insoluble in water. The solid is first of all weighed in air. The sinker is attached to the solid such that the system may be weighed with the solid in the air and the former immersed in water. Lastly the solid and the sinker are tied together and weighed. The combination is immersed together in water and weighed. The following theory is used:

wt. of the solid in air = w gm. wt.

wt. of the solid in air + sinker in water = w_1 gm. wt.

wt. of the solid in water + sinker in water = w_2 gm. wt.

∴ Loss of wt. in water = $(w_1 - w_2)$ gm. wt.

$$\therefore \text{ Sp. gr. of solid} = \frac{\text{wt. of the solid}}{\text{wt. of eq. vol. of water displaced}} \times S_t = \frac{w}{w_1 - w_2} \times S_t$$

Precaution

If the solid contains some pores in it, before taking the third weight, it should be heated in boiling water to remove all the air bubbles in it, otherwise the air bubbles also will exert some upthrust which is not desirable.

(iii) a liquid

Theory

In order to determine the sp. gr. of liquid by Hydrostatic Balance, an auxiliary solid which is insoluble in liquid and in water is taken. It is weighed in air, in water and in the experimental liquid. The result is calculated according to the following theory.

Theory

wt. of the solid in air = w gm. wt.

wt. of the solid in water = w_1 gm. wt.

wt. of the solid in liquid = w_2

∴ Loss of wt. in liquid = $w_1 - w_2$

= wt. of equal vol. of liquid displaced

and loss of wt. in water = $w - w_1$ = wt. of the equal vol. of water displaced

$$\therefore \text{ Sp. gr. of liquid} = \frac{\text{wt. of liquid}}{\text{wt. of equal vol. of water}} \times S_t = \frac{w - w_2}{w - w_1} \times S_1$$

Precautions

as in (i) above

(iv) solid heavier than and soluble in water.

Theory

In this case, the definition given above should be slightly modified.

$$\text{Sp. gr. of a solid} = \frac{\text{wt. of a certain vol. of the solid}}{\text{wt. of the same vol. of water at 4 °C}}$$

$$= \frac{\text{wt. of a certain vol. of the solid}}{\text{wt. of the same vol. of liquid}} \times \frac{\text{wt. of the liquid}}{\text{wt. of the same vol. of water}}$$

$$= \frac{\text{wt. of a certain vol. of the solid}}{\text{wt. of the same vol. of liquid}} \times \text{Sp. gr. of liquid}$$

This we are doing since the solid is soluble in water.

The solid is weighed in air and then in the experimental liquid.

wt. of the solid in air = w gm. wt.

wt. of the solid in liquid = w_1 gm. wt.

∴ Loss of wt. in liquid = $w - w_1$ gm. wt. = wt. of equal vol. of liquid displaced.

∴ Sp. gr. of the solid with the respect to liquid = $\frac{w}{w - w_1}$

Hence the sp. gr. of the solid with respect to water = $\frac{w}{w - w_1} \times$ sp. gr. of the liquid.

The sp. gr. of liquid is determined as in (iii) above.

Exercise

1. (a) Define density and the sp. gr.
   (b) Why is the density of one substance different from that of the other ?
   (c) What is the unit of the density and sp. gr ?
2. Does density depend on temperature ? If so, how ?
3. State Archimedes' Principle. What is Buoyancy ?
4. Can you know by applying Archimedes' Principle whether a given body is solid or hollow ? If, so, how ?
5. State the law of floatation.
6. Why is it necessary to heat cork in boiling water, while determining its sp. gr. ?
7. What is the difference between a Hydrostatic balance and an ordinary Physical balance ?
8. Why is it necessary to apply temperature correction in sp. gr. determination ?
9. Can you determine the diameter of a glass rod using a Hydrostatic balance ?
10. How will you determine the Sp. gr. of a wooden cube without using a balance ?
11. Is it easier to float in fresh water or in sea water ? Why ?
12. Why should the air bubbles stick to the side of a solid when immersed in water be removed ?

Problems

1. A body weighs 25.5 gms in air and 15.9 gms. in water. Find its volume and sp. gr.
2. A porcelain piece weighs 12.5 gms. in air and 7.9 gms. in water and 8.8 gms. in a liquid. Calculate the volume of the porcelain and sp. gr. of the liquid.
3. A metal cube of side 2.5 cm. suffers a loss of weight of 9 gms. Find the density of the liquid.
4. A piece of wax weighing 4.4 gms. in air is attached to a piece of lead and the two together are found to weight 19.88 gms. in water. If the weight of the piece of lead alone in water is 20.48 gms., find the Sp. gr. of wax.
5. A piece of alloy consisting of gold and silver weighs 20 gms. in air and 18.7 gms. in water. How much gold is there in the alloy ?

   [Given: Sp. gr. of gold= 19.3 and that of silver = 10.5]
6. A silver ornament, suspected to be hollow, weights 288.75 gms. in air and can displace 30 c.c. of water. Given the sp. gr. of silver to be 10.5, find the volume of the cavity.
7. A piece of lead weighs 100 gms. in water. What does it weigh in air ?

   [Density of lead = 11. 3 gm/c.c.]

Experiment No. 3.8

To use a specific gravity bottle to determine the

(i) Sp. gr. of a liquid *(ii) Sp. gr. of a solid* *(iii) Diameter of steel balls.*

(i) Sp. gr. of Liquid

The Sp. gr. of a solid a liquid may be determined by using a Sp. gr. bottle also. The Sp. gr. bottle is a small flat bottomed glass with a narrow neck. It has a ground glass stopper having a capillary bore running through its length. If the stopper is carefully inserted into the bottle filled to its top with a liquid, the excess liquid will escape through the hole in the stopper leaving the bottle completely filled with the liquid.

The bottle is first of all washed with dilute sodium hydroxide, then dilute nitric acid and finally rinsed with distilled water. It is filled with water. It is weighed after soaking water from the outer surface by a piece of cloth. Let it be w_1. Water is poured out. It is dried by passing hot air into it. It is cooled and weighed.

It is then filled with the experimental liquid and weighed again. The result is calculated as follows.

Theory

Wt. of the empty bottle = w gm. wt.

Wt of the bottle + water = w_1 gm. wt.

Wt. of the bottle + liquid = w_2 gm. wt.

∴ Wt. of water = $w_1 - w_2$ gm. wt.

Wt. of the same vol. of liquid = $w_2 - w$ gm. wt.

∴ Sp. gr. of liquid $= \frac{w_2 - w}{w_1 - w} \times S_t$

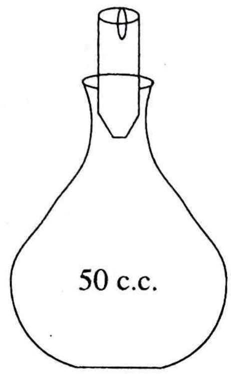


Fig. 3.8

(ii) Sp. Gr. of Solid

Theory

The Sp. gr. of a solid may be defined as

$$S = \frac{\text{wt. of a certain vol. of the solid}}{\text{wt. of the same vol. of water } 4\ °C} = \frac{\text{wt. of a certain vol. of the solid}}{\text{wt. of the water at } t\ °C} \times S_t$$

where, St is the Sp. gr. of water at the lab temp. t °C

The Sp. gr. bottle is cleaned as in (i) above. It is weighed empty. About one third or one fourth of it is filled with the solid in question. It is weighed again. The remaining portion of the bottle is filled with water. (If the solid is soluble in water, in water, some liquid in which the solid is insoluble, should be used). It is weighed. The contents of the bottle are poured out. It is filled completely with water and weighed once more. The result is calculated as shown below:

Wt. of the empty bottle = w

Wt. of the bottle + solid = w_1

Wt. of the bottle + solid + water filling the rest of the bottle = w_2

Wt. of the bottle + water filling the bottle completely = w_3

∴ Wt. of solid = $w_1 - w$

Wt. of water alone filling the bottle completely = $w_3 - w$

Wt. of water filling the bottle partly (when the solid was inside) = $w_2 - w$

∴ Wt. of that much water whose volume is the same as that of the solid itself

$$= (w_3 - w) - (w_2 - w_1)$$

$$\therefore \text{ Sp. gr. of solid} = \frac{\text{wt. of solid}}{\text{wt. of water displaced}} \times S_t$$

$$= \frac{w_1 - w}{(w_3 - w) - (w_2 - w_1)} \times S_t$$

Precaution

There should not be any air bubbles in the bottle while weighing it with water. It should be held in the neck.

(iii) Diameter of Steel Balls

Procedure as in (ii) above.

Theory

Wt. of the empty bottle = w

Wt. of the bottle + n balls = w_1

Wt. of the bottle + n balls + water filling the rest of the bottle = w_2

Wt. of the bottle + water filling the bottle completely = w_3

∴ wt. of water alone filling the bottle = $w_3 - w$

Wt. of water filling the bottle partly when the balls were inside = $w_2 - w_1$

∴ wt. of that much water whose volume is the same as that of n balls

$= (w_3 - w) - (w_2 - w_1)$

= wt. of water displaced

= vol. of water displaced × St, where St is the Sp. gr. of water at temp t.

vol. of n balls × St. $= (w_3 - w) - (w_2 - w_1)$

$\therefore$ vol. of n balls $= \frac{(w_3 - w) - (w_2 - w_1)}{S_t}$

or vol. of 1 ball $= \frac{(w_3 - w) - (w_2 - w_1)}{n \times S_t}$

But vol. of a spherical ball $= \frac{\pi}{6} d^3$ where d is its diameter.

$\therefore \frac{\pi}{6} d^3 = \frac{(w_3 - w) - (w_2 - w_1)}{n \times S_t}$

$\therefore d^3 = \frac{6 (w_3 - w) - (w_2 - w_1)}{\pi n S_t}$ from which d may be calculated.

Experiment No. 3.9

To use a Nicholson's Hydrometer to determine the sp. gr. of

(i) a solid

(ii) a liquid

(a) without weighing the hydrometer (b) weighing the hydrometer.

1. Apparatus Required

(i) Nicholson's Hydrometer (ii) a tall jar (iii) weight box

(iv) solid (v) a bent wire or a slotted card board.

A Nicholson's hydrometer is a constant immersion type of hydrometer. Its working depends on the principle of floatation which states:–

"When a body floats in a liquid, the weight of the floating body is equal to the weight of the liquid displaced".

It consists of a hollow metal cylinder with a solid stem attached to its upper end. The upper end carries a pan at its top. The stem has a scratch mark at one position along its length. The cylinder has a conical bowl at its lower end. The bowl has a horizontal platform and is made heavy by making it a solid piece or filling it with lead shots so as to bring down its centre of gravity to enable it to float vertically in a stable way in any liquid in which it is placed.

All solder joints should be made air tight.

2. Theory

The sp. gr. is defined as the ratio of a certain volume of the substance to the wt. of an equal volume of water at 4 °C.

Let the wt. reqd. to sink the hydrometer up to mark in water = w gm. wt.

wt. reqd. to sink the hydrometer upto mark in water with solid on the upper pan = w_1 gm. wt.

wt. reqd. to sink the hydrometer upto mark in water with solid on the lower pan = w_2 gm. wt.

∴ Loss of wt. in water = $w_2 - w_1$

= wt. of an equal volume of water displaced.

∴ sp. gr. of solid = $\dfrac{\text{wt. of the solid}}{\text{wt. of an equal vol. water 4 °C}}$

$$= \frac{w - w_1}{w_2 - w_1} \times S_t \quad \ldots (1)$$

where S_t is the Sp. gr of water at temp. of the laboratory.

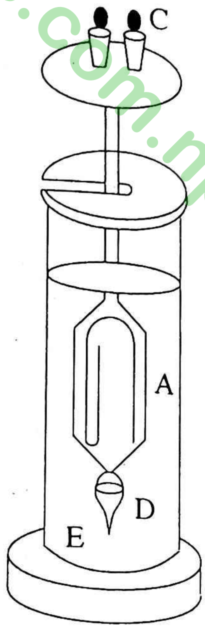


Fig. 3.10

3. Procedure

(i) The tall jar is filled with water. The bent wire or the slotted cardboard is placed on the upper end of the jar. The hydrometer is floated vertically without touching the bent wire or the slotted cardboard or the side of the jar. There should not be any air bubbles on the body of the hydrometer.

(ii) Standard weights are gradually placed on the upper pan so as to sink the hydrometer upto its index mark. The wts. are noted. Let the total wt. be ω.

(iii) The weights are removed. The experimental solid taken should not be so large as to sink the hydrometer without placing any wts. on the upper pan. Then wts. are again placed on the upper pan with the solid on it so as to sink the hydrometer upto the same index mark as before. Let the total wt. be w_1.

(iv) The solid is then transferred to the lower pan. Again sufficient wts. are placed on the upper pan to sink the hydrometer upto its index mark. Let this wt. be w_2.

(v) The temp. of water in jar is noted. The Sp. gr. of water at the lab. temp. is obtained from the tables.

(vi) Substituting the known values in the eqn. (i) the Sp. gr. is calculated. The operation may be repeated for a second set of readings.

4. Observations

wt. reqd. to sink the hydrometer upto mark in water = w gm. wt.

wt. reqd. to sink the hydrometer upto mark in water with the solid on the upper pan = w_1 gm. wt.

wt. reqd. to sink the hydrometer upto mark in water with the solid on the lower pan.

= w_2 gm. wt = ...

∴ wt. of the solid in air = $w - w_1$ = ... gm. wt = ...

Loss of wt. in water = $w_2 - w_1$ gm. wt. = ... gm. wt = wt. of the displaced water.

Temp. of water in the lab = t °C = ...

Sp. gr of water at t °C = ...

∴ Sp. gr. of the solid = $\dfrac{w - w_1}{w_2 - w_1} \times S_t$ = ...

5. Precautions

(i) The hydrometer must be allowed to float vertically.

(ii) There should be no air bubbles on the body of the hydrometer. If there be air bubbles, they should be removed by means of a brush. Besides it is advisable to suspend the solid from, instead of directly placing it on, the lower pan, because it is likely that there may be air bubbles on the surface of contact between the solid and the lower pan.

(iii) If the solid taken contains pores in it, it should be heated about 10 to 15 minutes in boiling water so as to remove air bubbles it may contain before placing it on the lower pan, otherwise air bubbles may exert upthrust, which may affect the result appreciably.

(iv) If the solid is soluble in water, the jar should be filled with a liquid in which the solid is insoluble. The final result obtained must be multiplied by the Sp. gr. of the liquid taken.

(ii) a liquid (a) without weighing the hydrometer

Apparatus Required

Same as for solid.

To determine the Sp. gr. of a liquid without weighing the hydrometer, an auxiliary solid which is insoluble in water and in the experimental should be taken.

The auxiliary solid is placed on the upper pan and the necessary weights are placed on the upper pan so as to sink the hydrometer in water upto its index mark. The solid is then transferred to the lower pan. Placing wts. of upper pan, the hydrometer is again allowed to sink upto its index mark in water. The operations are repeated in the experimental liquid. Observations are noted as shown below:

Theory and Observations

Let the wts. reqd. to sink the Hydrometer in water upto its index mark with the aux. solid on the upper pan = w_1 = ...

wts. reqd. to sink the Hydrometer in water upto its index mark with the same solid on the lower pan = w_2 = ...

∴ Loss of wt. in water = $w_2 - w_1$ = wt. of water displaced.

Similarly,

wts. reqd. to sink the Hydrometer in the liquid upto its index with the same solid on the upper pan = w_3

wts. reqd. to sink the hydrometer in the liquid with the same solid on the lower pan = w_4 ....

∴ Loss of wt. in liquid = $w_4 - w_3$ = ... = wt. of the same volume of liquid displaced.

$$\therefore \text{ Sp. gr. of the liquid} = \frac{\text{wt. of the liquid}}{\text{wt. of the same vol. of water}} = \frac{w_4 - w_3}{w_2 - w_1} \times S_t$$

(ii) a liquid (b) weighing the hydrometer

Apparatus Required

Same as (i)

The hydrometer is first weighed in a rough balance. It is then allowed to sink up to its index mark in water and then in the experimental liquid. The observations are noted as shown below:

Let. wt. of the Nicholson's hydrometer = W ....

wts. reqd. to sink the hydrometer upto its index mark in water = w_1 = ...

wts. reqd. to sink the hydrometer upto its index mark in liquid = w_2 = ...

∴ wt. of the body floating in the water = $W + w_1$ = ...

= wt. of the water displaced and wt. of the body floating on the liquid = $W + w_2$

= wt. of the liquid displaced.

∴ with temp. correction

∴ Sp. gr. of liquid = $\frac{\text{wt. of the liquid}}{\text{wt. of the same vol. of water displaced}} = \frac{W + w_2}{W + w_1}$

N.B. Determination of the weight of the Nicholson's Hydrometer.

Hints: The Sp. gr. of a liquid is determined by using the Hydrometer without weighing it. Using the same liquid another set of readings is taken as in (ii) (b) above.

The S $= \frac{W + w_2}{W + w_1} \times S_t$ = ...

where S, w_1 and w_2 being known, W can be calculated.

Chapter 4
Measurement of Time

4.1 The main principle in the measurement of time is based on the fact that a pendulum has a definite period of oscillation. It is used in the construction of clocks and watches. In a watch, minute hand and the second hand move under the control of a balance wheel which keeps oscillating by a mechanism attached to a spring. The spring when wound and released supplies the necessary energy for oscillation.

4.2 The simple Pendulum

An ideal simple pendulum is a heavy particle suspended from a rigid support by means of an inextensible but perfectly flexible, weightless string. In practice however a small heavy metal ball, called the bob, is suspended by a fine thread from a stand to serve as a simple pendulum.

4.3 Effective length

It is the distance between the point of suspension and the centre of gravity of the bob.

4.4 Amplitude

It is the maximum angular displacement of the bob from its undisturbed position on either side.

4.5 Time period

It is the time taken for a complete oscillation means two swings – one forward and the other backward.

Experiment No. 4.1

(a) *To study the relation between the length and time period of a simple pendulum*

(b) *To plot a graph between l & t as well as between l and t^2 and determine the length of Seconds pendulum*

(c) *To determine the value of 'g' in the laboratory.*

1. Apparatus Required

(i) A simple pendulum (ii) Clamp and thread

(iii) Stop watch or clock (iv) Meter scale.

2. Theory

A simple pendulum is a heavy material bob suspended from a rigid support by means of a light, inextensible and flexible string.

A Seconds pendulum is that pendulum for which the time period i.e. time for one complete oscillation is 2 seconds. The time period 't' of oscillation of simple pendulum is given by

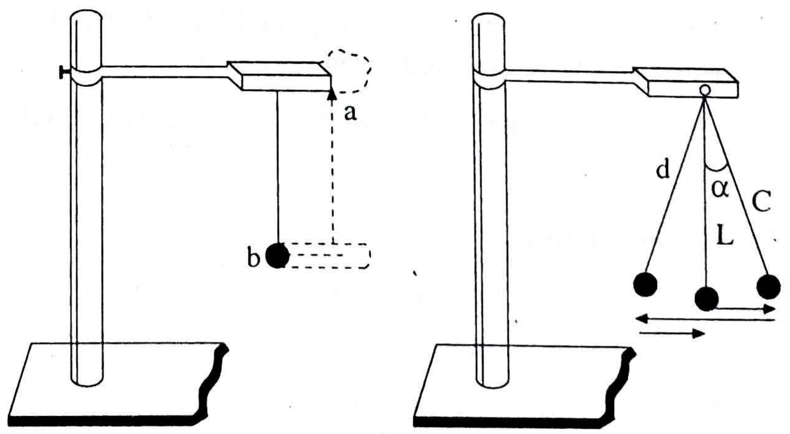


Fig. 4.1

$t = 2\pi \sqrt{\frac{l}{g}}$ where t = time period.

l = effective length

= distance between the point of support and the centre of gravity of the bob.

g = acceleration due to gravity

or $t^2 = \left(\frac{4\pi^2}{g}\right) \times l$ ...(1)

which resembles the equation of a st. line passing through the origin.

Hence the graph of l and t^2 should be a st. line passing through the origin.

from (1) $$g = 4\pi^2 \times \frac{l \text{ cms}}{t^2 \text{ sec}^2} \quad \text{... (2)}$$

For a Seconds pendulum, t = 2 secs.

∴ from (1) above, $$4 = 4\pi^2 \frac{l}{g}$$

∴ $$l = \frac{g}{\pi^2} \quad \text{... (3)}$$

The length of the second pendulum can be determined in the laboratory by extrapolating the value of l corresponding to $t^2 = 4$ from the graph of l and t^2 corresponding to t = 2 from the graph of l and t.

3. Procedure

(i) The vertical diameter of the bob is determined by means of a vernier callipers 5 times and the mean is taken.

(ii) The length L of the pendulum is taken from the point of support to the lower edge of the bob so that the effective length is obtained by subtracting the vertical radius from L. The effective length is adjusted to be 40 cm. for the 1st observation.

(iii) The bob is displaced slightly from original position. The time for 20 complete oscillations is found out by means of a stop watch or clock, this is repeated twice for each length. The time period is then calculated.

(iv) Operations (ii) and (iii) are repeated for effective lengths 60 cm. etc. Seven observations are taken, observations are entered as shown below.

(v) Graph of (i) l and t (ii) l and t^2, are drawn. The length of the Seconds pendulum is extrapolated from each graph.

4. Observations

Vertical diameter of the bob = ... cm.

∴ Vertical (r) = ... cm.

Value of 10 divs. of the stop clock or watch = ... secs.

∴ .... 1 div., ... = ... sec.

Table No. 4.1

No. of obs.	length L bet the point of support and lower edge of the bob. = L cm.	Effective length l = L − r cm	Time for 20 oscillations t secs.	Time period t secs.	t^2	$\frac{l}{t^2}$	Mean $\frac{l}{t^2}$	$g = 4\pi^2 \frac{l}{t^2}$
1	40 + r	40	....					
2	60 + r	60	....					
3	80 + r	80	....					
4.	100 + r	100	....					
5.	120 + r	120	....					
6.	140 + r	140	....					
7.	160 + r	160	....					

Calculation

(1) From the graph of l and t^2, we have

l = ... when $t^2 = 4$

∴ the length of the second pendulum = ... cm

Also from the graph of l and t, we have

l = ... when t = 2 secs.

∴ the length of the second pendulum = ... cm.

(2) Thus mean value of $\frac{l}{t^2}$ = ...

$$g = 4\pi^2 \times \frac{l}{t^2} \; .... \; \frac{cm.}{sec^2} = m/sec^2$$

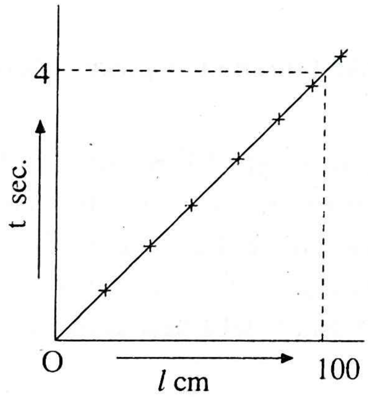


Fig. 4.2 (a)

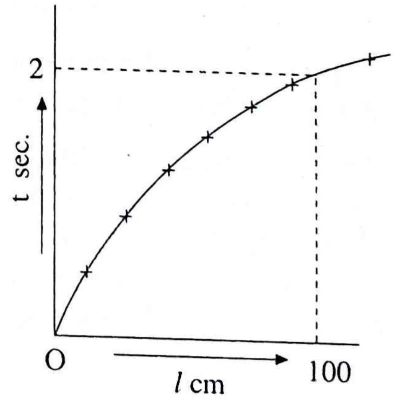


Fig. 4.2 (b)

Precautions

1. The amplitude of vibration should be very small, within 4° if possible.
2. The stop clock should be started and stopped carefully.
3. While drawing graphs, scale should be so chosen as to cover the whole paper.

Errors and Order of Accuracy

The error in timing occurs when the clock is started and when it is stopped. The no. of swings should be large enough to diminish the error. Due to the finite size of the bob, there is error in measuring *l*. If the clamp is not rigid enough, the effective length of the pendulum is increased.

The change in the slope of the line, t^2 caused by lines of greatest and least slope is found out, the error in g is then

$$4\pi^2 \times \frac{1}{\text{error in slope}}$$

Exercises

1. What is a Simple Pendulum ?
2. Define effective length time period and amplitude of vibration ?
3. Distinguish between gravitation and gravity.
4. What do you understand by acceleration due to the gravity ?
5. If your pendulum bob were a hollow one and half filled with mercury, will the effective length increase or decrease ?
6. Why should the amplitude of vibration be as small as 4° ?
7. What is the value 'g' in your lab. Should it be 9.8 m/s^2, more or less than this ?
8. What type of graph do you expect between (i) *l* and t, (ii) *l* and t^2, and why ?
9. Is it possible to determine the height of a place using a pendulum ? If so how ?
10. Calculate the length of the Seconds' Pendulum at a place where the value of g is (a) 9.8 m/s^2 (b) 9.7 m/s^2
11. The following table gives the value of T, the timing of a complete small angled oscillation of a simple pendulum corresponding to its various lengths.
12. A second Pendulum at a place where g is 9.8 m/s^2 is taken to another place where g is 9.75 m/s^2. How many seconds will it gain or lose day ?
13. Calculate the period of oscillation of a simple pendulum of length 15 m with a bob of mass 1.2 kg. What assumption is made in this calculation ? (g = 10 m/s^2). If the bob of this pendulum is pulled side a horizontal distance of 15 cm and then released, what will be the value of the kinetic energy and (ii) the velocity of the bob at the lowest point of the swing ? (iii) After 50 complete swings, the maximum horizontal distance of the bob has become 7.5 cm, what fraction of the initial energy has been lost ?
14. What is simple harmonic motion ? State its characteristics.
15. What is Compound Pendulum ?

Chapter 5
Atmospheric Pressure

5.1 Atmospheric Pressure

It is the pressure exerted by the atmospheric air due to its own weight. It is measured in terms of the mercury column that it can support and is expressed in dynes/cm^2 or Newton/meter^2. The atmospheric pressure (p) is given by $P = hd\ g$ ……… (i) where h is the height of the mercury column, d the density of mercury and 'g' the acceleration due to gravity. The standard value of P at the sea level corresponds to the value of h equal to 76 cm. or 76 m. of mercury. It is called the normal atmospheric pressure or standard atmospheric pressure in (i) d and g are constants, Press. $p \propto h$.

Hence it is usually measured in terms of the height of the mercury column that in the unit of force.

Barometer

It is an instrument used for measuring the atmospheric pressure.

Experiment No. 5.1

To study the parts of Fortin's Barometer and determine the atmospheric pressure in the laboratory.

1. Apparatus Required

Fortin's Barometer

2. Description of the Apparatus

The Fortin's Barometer has a metre long glass tube filled with pure and dry mercury. It is inverted over a trough of mercury, closed at its lower end. The level mercury in it can be raised or lowered by means of a base screw. The empty space between the top of the tube and the mercury meniscus is called the Toricellian Vacuum.

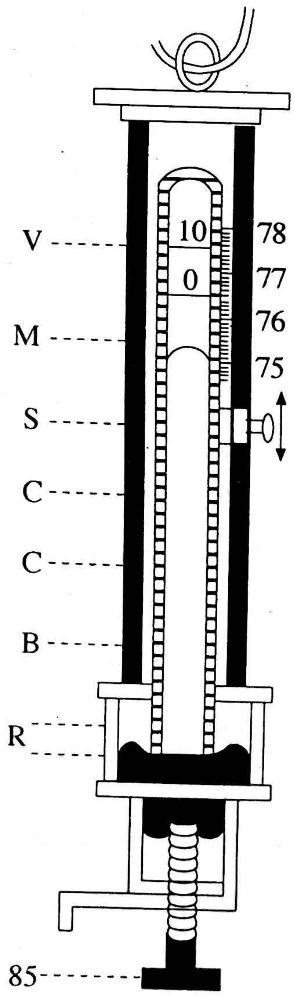


Fig. 5.1

3. Theory

The Barometric height is the distance of the mercury meniscus and the level of mercury in the trough. The pressure due to this column of mercury is the atmospheric pressure at the time of observation. If H = observed Barometric height at the room temp. t, H_0 = Barometric height corrected to 0 °C then,

$H_0 = H_t\{1 - (\gamma - \alpha)\ t\}$ where γ = coeff. of real expansion of mercury

α = coeff. of linear expansion of the scale.

Pressure exerted = $H_t\rho_0 g = H_0\{1-(\gamma-\alpha)t\}\rho_0 g$, ρ_0–density of mercury at 0 °C.

g = acceleration due to gravity

4. Procedure

(i) The vernier constant is determined . The room temp. is noted.

(ii) The vernier scale is adjusted by the rack and pinion arrangement and kept just above the mercury meniscus.

(iii) The reading of the main scale and the vernier scale is noted.

(iv) Operations (ii), (iii) and (4) are repeated 5 times.

(v) The room temp. is again noted at the end of the expt.

5. Observations

Value of ... divs. of the main scale = ... value of 1 div. .... = ... 25 divs. of the vernier coincide with 24 divs. of the main scale

$\therefore$ 1 .... $\frac{24}{25}$ ....

$\therefore$ Difference bet. a vernier and a main scale div. = $\left(1 - \frac{24}{25}\right)$

$\therefore$ Vernier constant (V.C.) = $\left(1 - \frac{24}{25}\right) \times$ value of 1 smallest div.

$= \frac{1}{25} \times$ value of 1 smallest div. of the main scale.

Temp. at the start of the expt. = t_1 °C

.... end .... t_2 °C

Average temp. during the expt. $\frac{t_1 + t_2}{2} = t$ °C

Table 5.1

No. of obs	Reading of the main scale	Reading of the vernier scale	value of vernier scale reading	Total reading	Mean H_t	$H_0 = H_t \{1-(\gamma-\alpha)t\}$
1						
2						
3						
4						
5						

Precautions

1. The Barometer should be vertical ?
2. The ivory pin should just touch the mercury surface.
3. The zero of the vernier should be so adjusted as to graze tangentially along the upper meniscus of mercury.

Oral Questions

1. What is a Barometer ?
2. What is an Aneroid Barometer ?
3. What is the average atmospheric pressure ?
4. What is the average atmospheric pressure on your body.

5. What is the unit of Atmospheric Pressure ?
6. How is it that water does not boil exactly at 100°C at Kathmandu ?
7. Why do you use mercury in a Barometer ? Could you use water ?
8. Will the barometer reading be the same always ?
9. What are the uses of barometer reading ?
10. How does the barometer help to determine the boiling point of water ?

Experiment No. 5.2

To use a Boyle's Law Apparatus to

(i) Verify Boyle's Law.

(ii) Determine the Atmospheric Pressure in the laboratory without reading Barometer.

(i) To verify Boyle's Law

1. Apparatus Required

(1) Boyle's Law Apparatus

(2) Fortin's Barometer

(3) Thermometer.

Description of the Apparatus: The Boyle's Law apparatus consists of a long glass tube graduated in c.c. and provided with a stop cock L, the other end being connected by means of a pressure tubing to a similar glass tube PP, open at the top and exposed to the atmosphere. The closed tube is usually fixed while the tube PP can slide along a vertical scale and can be fixed at any desired position. Some part of the tubes and the entire pressure tubing are filled with clean and dry mercury. A certain volume of air is introduced into the tube LL' by opening the stop cock. The position of the Hg. levels in both the tubes can be read on the graduated metre scale fixed on the board holding the tubes.

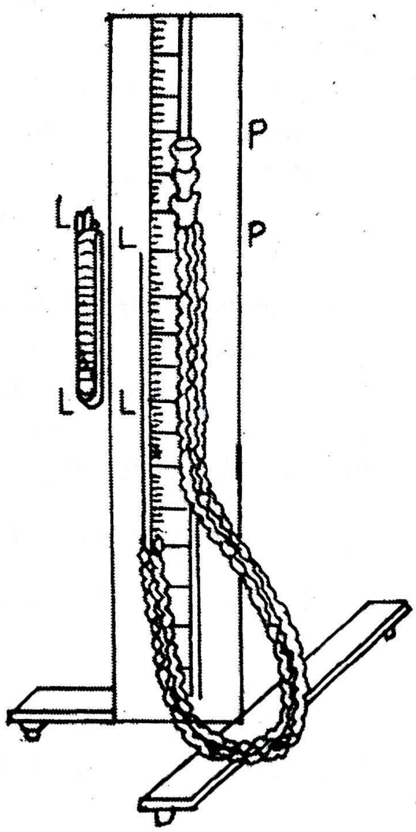


Fig. 5.2

2. Theory

Boyle's Law states

"Temperature remaining constant, the volume of a certain mass of gas varies inversely as its pressure".

Mathematically it may be stated as $V \propto \frac{1}{P}$ where v is the vol. of the gas and p is its pressure

$$V = \frac{1}{P}$$

or $$PV = K \quad \text{... (i)}$$

Thus $P_1V_1 = P_2V_2 = P_3V_3$ etc. K const. This is similar to the eqn. xy = k which represents a rectangular hyperbola. So if Boyle's Law be true, the graph of P and V must be a rectangular hyperbola. Next from (i),

$$P = K \times \frac{1}{V} \qquad \cdots(ii)$$

which is similar to the equation y = mx. This represents a st. line passing through the origin. Thus a graph of p and $\frac{1}{V}$ must be a st. line passing through the origin.

3. Procedure

(i) The atmospheric pressure in the laboratory is first determined by Fortin's Barometer. This reading is taken at the beginning and at the end of the expt. the temp. of air in the lab. in the beginning and the end of the expt. is noted.

(ii) The stop cock in the closed tube of the Boyle's Law apparatus is opened to introduce air at the atmospheric pressure into the tube. The stop cock is then closed. The volume of air in the closed tube is noted. The readings of the mercury levels in the closed tube and the open tube are taken. In this case the readings will be the same. These readings will be at the atmospheric pressure.

(iii) Next the open tube is slowly raised by about 2 to 3 cm. at a time. When the Hg–levels will be steady, the volume of air in the closed tube is noted. The difference of Hg–levels is noted. This added to the Barometric reading gives the total pressure of the enclosed air. This operation is repeated 3 to 4 times. These readings will be at the pressures above the atmospheric pressure.

(iv) The open tube is then lowered and then placed at a position about 2 to 3 cm. below the level of Hg in the closed tube. The volume of air is noted and the Hg – levels in both the tubes are also read. The difference is found out. The barometric reading minus the difference gives the total pressure of the enclosed air. This operation is also repeated 3 to 4 times. These readings will be at pressures below the atmospheric pressure.

(v) Then a graph of V against P is drawn. It will be a rectangular hyperbola. Another graph of $\frac{1}{V}$ against the total pressure P is drawn. It will be a straight line passing through the origin. This verifies Boyle's Law.

4. Observation

Temp. at the beginning of the expt. = t_1 = …… and at the end of the expt. t_2 =

Average temp. t during the expt. = $\frac{t_1 + t_2}{2}$ = ………

Barometric Reading = ………

Table No. 5.2

Reading at the	Main scale reading	Vernier scale reading	Total	Mean Barometric height (H)
Beginning of the expt.				
End of the expt.				

Table No. 5.2(a)

Reading	No. of obs.	Volume of air in the closed tube v.c.c.	Reading of Hg–Level in the		Diff. of press = a ~ b = p cm	Total press. = H ± p = P cm.	PV	$\frac{1}{V}$	Remarks
			closed tube a	open tube b					
At Atm. Press.									
Above Atm. Press									
Below Atm. Press									

Conclusion

The graph of (i) P and V is found to be rectangular hyperbola and that of (ii) P and $\frac{1}{V}$ a st. line passing through the origin as expected. Hence Boyle's Law is verified.

(ii) Determine the Atmospheric pressure in the laboratory without reading a Barometer.

1. Apparatus Required

(i) Boyle's Law apparatus (ii) Thermometer

2. Theory

According to Boyle's Law, temperature remaining constant, the vol. V of a certain mass of gas is inversely proportional to its pressure P.

$$V \propto \frac{1}{P} \quad \text{or} \quad V = K\frac{1}{P}$$

$$PV = K \qquad \ldots (1)$$

i.e. $P_1V_1 = P_2V_2$ = etc. constant

Hence if P is the atmospheric pressure, and p be a slight change of pressure so that the total press. = P + p. Let V be the corresponding pressure, then by applying Boyle's Law,

we have,

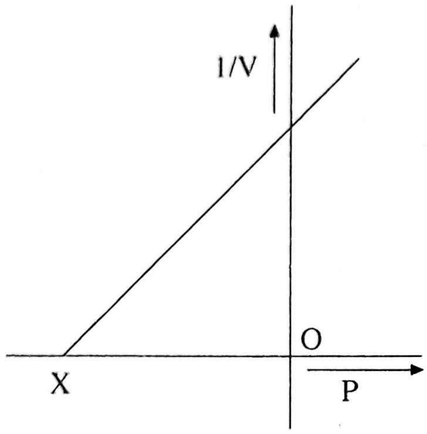
$$(P + p)V = K$$

or $$P + p = K \times \frac{1}{V}$$

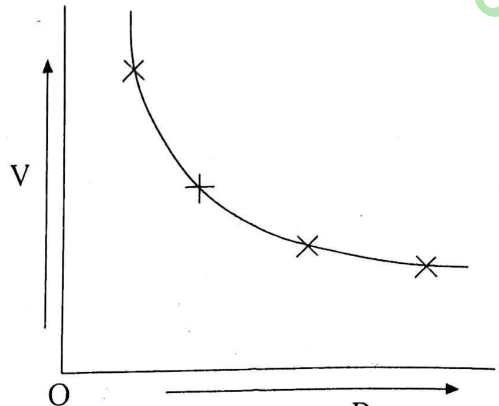
or $$p = K \times \frac{1}{V} - P = K \times \frac{1}{V} + (-P)$$

or $$p = K \times \frac{1}{V} + (-P) \qquad \ldots(2)$$

Which is similar to y= mx + c, representing a st. line not passing through the origin. Hence the graph of p and $\frac{1}{V}$ will be a st. line not passing through the origin as shown in the figure 5.3.



5.3(a)



5.3(b)

Fig. 5.3

When the graph is produced backwards, it will meet the x–axis at X where

$$P = -OX, \frac{1}{V} = 0.$$

Hence from the eqn. $p = K\frac{1}{V} + (-P)$, we get,

$$-OX = K \times O - P$$

$$\therefore \quad P = OX$$

This gives the atmospheric pressure in the laboratory.

3. Procedure

(i) The stop cock in the closed tube of the Boyle's Law apparatus is opened to introduce air at the atmospheric pressure into the tube. The stop–cock is then closed. The volume of air in the closed tube is noted. The readings of the Hg–levels in the closed tube and the open tube are taken. The difference of the Hg–levels in the two tubes will be zero in this case. These readings are at the atmospheric pressure.

(ii) Next the open tube is slowly raised by about 2 to 3 cms. at a time. When the Hg–levels will be steady, the volume of air in the closed tube is noted. Then the readings of the Hg – levels is noted. This operation is repeated 3 to 4 times. These reading will be at pressures above the atmospheric pressure.

(iii) The open tube is then lowered and then placed at a position about 2 to 3 cms. below the level of Hg in the closed tube. The volume of air is noted and the Hg. levels in both the tubes are also read. The difference of levels is noted This operation is also repeated 3 to 4 times. These readings will be at pressures below the atmospheric pressure.

(iv) Then a graph of p (diff. of Hg – levels) and $\frac{1}{V}$ is drawn. It will be a st. line not passing through the origin. On producing backwards, it will intersect the x–axis at X as shown in the fig. 5.3. The atmospheric pressure is extrapolated as OX.

Table 5.3

Reading	No. of obs.	Vol. of air in the closed tube	Reading of Hg-levels in the closed tube a	Reading of Hg-levels in the open tube b	Diff. of Prerss. = a ~ b = p cm	$\frac{1}{V}$
At Atm. Pressure	1					
Above Atm. Pressure	2 3 4 5					
Below Atm. Pressure	6 7 8 9					

Conclusion from Graph

The graph of P and $\frac{1}{V}$ is thus a st. line not passing through the origin.

∴ Atmospheric pressure from the graph = p = OX = ... cm.

Exercises

1. Why should the mercury level in a barometer be adjusted so as to just touch the ivory point ?
2. State Boyle's law. Is it true for all temperatures and pressures ?
3. In verifying Boyle's law, why the volume of air should not be changed suddenly ?
4. State the nature of the graph between (i) P an V (ii) P and $\frac{1}{V}$ (iii) PV and P.
5. What is Normal Atmospheric Pressure ?

Chapter 6
Properties of Matter
(a) Elasticity

6.1 It is the property possessed by a material by virtue of which it changes its shape and size on the application of some deforming force and tends to recover its original position when the external force is withdrawn. It is measured by the ratio of stress to strain.

There are Three Types of Strain

(i) Elongation or linear strain (ii) Volume or bulk strain (iii) Shearing strain

6.2 Hooke's Law

If stress is applied on a body within a certain limit called the elastic limit which depends on the nature of the material, the strain produced is directly proportional to the stress applied i.e.

Stress $\propto$ Strain

or Stress $\propto$ K (constant) Strain

where K = modulus of elasticity

In the case of linear strain, this ratio is called Young's modulus of elasticity (y). Suppose a wire of length L and cross section a, is stretched by an amount x by a force F acting along its length, then

$$Y = \frac{\text{Tensile Stress}}{\text{Tensile Strain}}$$

$$= \frac{\frac{F}{a}}{\frac{x}{L}} = \frac{FL}{ax}$$

Experiment No. 6.1

To study graphically the stress to strain r elationship and determine the Young's Modulus of Elasticity of wire by Vernier apparatus.

1. Apparatus Required

(i) Vernier apparatus (ii) A long pole (iii) Micrometer screw gauge

(iv) Standard stretching weights, each of 0.5 kg or 1.0 kg. wt.

2. Theory

According to Hooke's Law, stress $\propto$ strain, within elastic limit. When the stress is applied at the end of a wire, tensile stress = Y × longitudinal strain.

or $$Y = \frac{\text{Tensile Stress}}{\text{Longitudinal Strain}}$$

where the constant Y is called the Young's modulus of elasticity of the wire. Now if w be the weight in kg. suspended from the end of a wire of cross – section a (= πr^2, r being its radius), and original length L and if x be the elongation produced, then tensile stress = $\frac{wg}{a} = \frac{wg}{\pi r^2}$ and longitudinal strain $\frac{x}{L}$

$\therefore$

$$Y = \frac{wg}{\pi r^2} \div \frac{x}{L} = \frac{wgL}{\pi r^2 x} \qquad \ldots(1)$$

or

$$x = \frac{gL}{\pi r^2 y} w \qquad \ldots(2)$$

which being of the form y = mx, represents a straight line passing through the origin.

3. Procedure

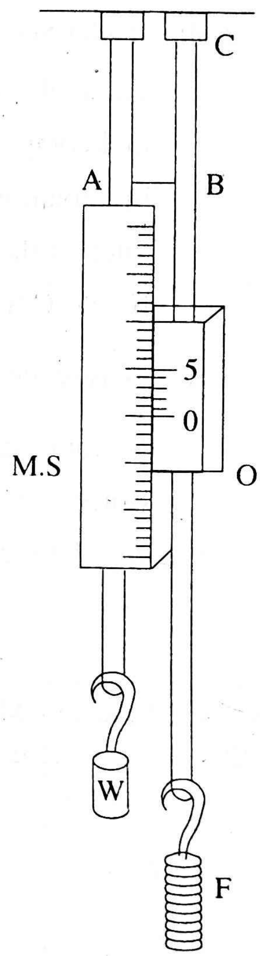


Fig. 6.1

(i) First of all, some slotted weights are suspended from each of the wires to use them as the initial load to keep the wires taut so that there may not be any kinks in them.

(ii) The original length of the experimental wire is then measured from the point of support upto the point where the slotted weights are suspended.

(iii) The diameter of the wire is measured at about 5 different points along the length of the wire, by means of a micrometer screw gauge, taking the readings in two perpendicular directions. The area of cross–section is calculated.

(iv) The nature of the material of the wire is noted. From the physical tables the breaking stress of the wire is known. Then the breaking weight for the wire is calculated. Breaking weight = Breaking stress X area of cross–section of the wire.

(v) In order to ensure that the wire is not strained beyond the elastic limit, the maximum permissible load should not exceed half the breaking weight calculated above.

(vi) This maximum permissible load is to be suspended from the experimental wire in steps of 0.5 kg. each time.

(vii) The value of each division of the main scale and vernier constant of the vernier attached are determined.

(viii) The initial reading of the vernier is noted when only the initial load is suspended.

(ix) Then the standard slotted weight of 0.5 kg, is suspended from the experimental wire. Sometime about 2–3 min is allowed for extension of the wire. The reading of the main scale and vernier scale is noted.

(x) After this, operation (ix) is repeated, increasing the weights each time in steps of 0.5 kg. until the maximum, permissible load is reached.

(xi) The above operations and the observations are repeated, this time decreasing the weights by 0.5 kg.

(xii) The vernier reading corresponding to zero load is subtracted from that corresponding to the load of 0.5 kg. Similarly the reading corresponding to the zero load is subtracted from that corresponding to that of 1 kgm. and so on.

In this way the elongation or extension for different loads is determined. These elongations are plotted against the corresponding loads in a graph paper. From this graph, elongation for 1 kgm. is read off.

(xiii) The vernier reading corresponding to the zero load is subtracted from that corresponding to a load of 1 kgm. This gives an extension for 1 kgm. Next the reading corresponding to the load of 0.5 kgm. load is subtracted from that corresponding to that of 1.5 kgm. and so on. The mean extension for a load of 1 kgm. is thus determined.

(xiv) Observations are entered in tabular form and the results calculated as shown below:

4. Observation

Original length of the experimental wire = L .... cm.

Micrometer Screw Gauge:

Value of 10 smallest divs. of the main scale = ...

In 4 complete rotations, the cir. scale moves though ... divs. of the main scale

In 1 rotation it moves through div

Pitch of the screw = ...

No. of C.S. divs. = ...

∴ Least count (L. C.) = $\dfrac{\text{pitch}}{\text{No. of C. S. divs.}}$

Instrumental error =

∴ Correction = ...

Reading: for the cross–secton of the wire:

Table No. 6.1

No. of obs.	Reading in	Main scale reading mm	Cir. scale reading mm	Total mm.	Mean Diameter mm	Mean Diameterd cm	Mean Radius r cm	Mean Cross Section πr^2
1	1st perp.							
2	2nd perp							
3								
4								
5								
6								

Vernier Apparatuss

10 divisions of the main scale = ...

∴ 1 .... = ...

10 vernier divisions coincide with ... divs. of the main scale.

∴ 1 .... = ...

∴ Vernier constant (V.C.) = (......) × value of 1 div. of the main scale.

Table No. 6.2

No. of obs	Loads in kg	Readings of the scale when						Mean Reading cm	Elongation in		Elongation for 1 kg.
		Loads increasing			Loads decreasing						
		Main scale	Vernier scale	Total	Main scale	Vernier scale	Total		cm.	m	
1	×										
2	0.5										
3	1.0										
4	1.5										
5	2.0										
6	2.5										
7	3.0										
8	3.5										
9	4.0										

Calculation

Mean elongation for 1 kg. from the above = ... (a)

Elongation for 1 kg from graph = ... (b)

$$\therefore \quad Y = \frac{\omega g L}{\pi r^2} = \ldots\ldots \text{ Nm}^{-1}$$

$$= \frac{gL}{\pi r^2} \times \frac{\omega}{x} = \frac{gL}{\pi r^2} \times \frac{1}{\text{Slope}}$$

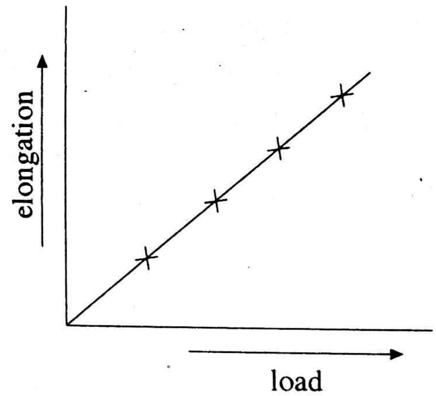


Fig. 6.2

Precautions

1. About 2 or 3 minutes should be allowed for extension or contraction after a load is added or removed before taking a reading.
2. While taking readings, care should be taken to see that the suspended system should not be twisted.
3. The constant load (Zero load) on both the wires should be sufficient to keep them taut and free from kinks.
4. While calculating elongation for various loads the difference between consecutive readings should never be taken but the difference between the 5th and the 1st, 6th and the 1st and so on. This will enable all the readings to be utilized.

Errors and Order of a Accuracy

Errors are likely to occur in (1) reading the vernier (2) load and (3) the length of the wire. The percentage error in (2) and (3) will be small but the error (1) in the extension may be large. Besides the percentage error in r^2 is very important.

Order of Accuracy

By taking log of both sides in the expression for Y, and differentiating, then max. % error in Y is

$$\frac{\delta Y}{Y} \times 100 = \left(\frac{\delta W}{W} + \frac{\delta L}{L} + = \frac{3\delta r}{r} + \frac{\delta x}{x}\right) \times 100\%.$$

From the graph of extension against load, Y can be found out as $\frac{gL}{\pi r^2} \times \frac{1}{\text{slope}}$, slope is obtd. from the graph.

The lines with greatest and least slopes agreeing with the plotted points are drawn. Then the error in Y is found from the variation is slope.

1. State the difference between plasticity and elasticity.
2. State Hooke's law of elasticity.
3. Define stress, strain, elastic limit, breaking stress. State the unit in each case.
4. What is elastic fatigue ?
5. Define Young's modulus of elasticity. State its units and dimensions.
6. Do you prefer a long wire or a short wire in this expt. on elasticity ? Give your reason.
7. Which is more elastic steel or rubber ?
8. Why is it necessary to wait for some time after loading and unloading the wire ?
9. A load of 7 kg wt. produces an extension of 0.5 mm in a wire 2.5 m log and 1 mm diameter. Calculate the Young's modulus of the wire. ($g = 9.8$ m/S^2)
10. Young's modulus for the tendon in a man's leg is 1.6 ¥ 10^8 N/m^2. If the tendon is 10 cm long and 0.45 cm in diameter. How much will it be stretched by a force of 10N ?

(b) Surface Tension

Surface tension is the property of liquid by virtue of which its free surface behaves like a stretched membrane. It is measured in terms of force of tension acting per unit length. It is defined as the amount of force acting per unit length on either side of and imaginary line drawn over the liquid surface.

Thus if F be the force acting along the length l of such a line, T is given by

$$T = \frac{F}{l} \text{ dynes cm}^{-1} \quad \text{or} \quad \text{Nm}^{-1}.$$

Experiment No. 6.2

To determine the Surface Tension of water by Capillary Tube method.

1. Apparatus Required

(i) Travelling Microscope M (ii) Beaker (iii) Cork C with a pin P

(iv) Clamps and stand (v) Capillary tube (vi) Thermometer

(vii) Mercury (viii) Watch glass.

2. Theory

For water,

$$T = \frac{rh\rho g}{2} \quad \ldots (1)$$

where r is the radius of the capillary tube, h is height of the capillary rise of water column, ρ the density of water at the lab. temp. g acceleration, due to gravity. In C. G. S unit, T is in dynes/cm. In SI units T is in N m^{-1}.

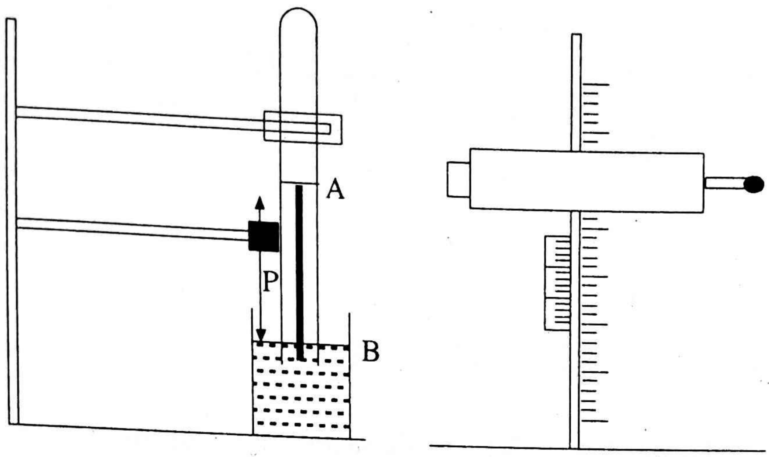


Fig. 6.3

3. Procedure

(i) The expt. should be performed near a window.

(ii) The capillary tube is first cleaned with dilute caustic soda and finally rinsed properly with distilled water.

(iii) The capillary tube A is pushed not water in a beaker so that the inside is wet. The tube is raised so that water rises up above the level of water outside.

(iv) The tube is fixed in a clamp.

(v) The pin is pushed through the cork and placed in clamp such that the tip of the pin just touches the surface of water in the beaker.

(vi) The microscope is focused on the lower meniscus which is seen inverted in the field of view. The reading of the main scale and vernier scale of the microscope is taken.

(vii) Next the microscope is adjusted to focus on the upper tip of the pin.

(viii) The difference x between the reading of the upper tip of the pin and the bottom of the meniscus. If l be the length of the needle, then the height of the meniscus is given by $h = l + x$ (+ve if the tip of the pin is below the meniscus & –ve if it is above).

(ix) The capillary tube is next removed carefully from the breaker. It is dried by means of methylated spirit. warmed a little in low flame.

(x) The diameter of the tube is determined by Travelling microscope.

(xi) The above operations are repeated for 3 tubes of different diameters.

4. Observation

(a) Temperature of water = ... °C

∴ Density of water t °C = ... cm

main scale div. of microscope = ... cm

Vernier constant = ...

Table No. 6.3(a) : Reading for the length of the pin

No. of obs	Readings of the pin.						Diff. = l cm.	Mean length cm
	Lower tip			Upper tip				
	M.S cm.	V.S.	Total cm.	M.S. cm.	V.S.	Total cm.		
1								
2								
3								

Table No. 6.3(b) : Reading for the height h

Tube obs.	Reading of upper tip of the pin			Reading of the bottom of meniscus			Diff.	$h = l \pm x$ cm
	M.S	V.S.	Total cm. A	M.S.	V.S.	Total cm. B	$x = A \sim B$	
1								
2								
3								

Table No. 6.3(b) : Reading for diameter

No. of Tube	Direction	Reading			Mean d cm.
		M.S.	V.S.	Total cm.	
1	one dir^n perp. dir^n	....	....	....	
2	one dir^n perp. dir^n	....	....	....	
3	one dir^n perp. dir^n	....	....	....	

Conclusion

The surface tension of water at .... 0 °C = ... dyne/cm = ... Nm^{-1}

Error and Order of Accuracy

The error in the capillary rise h may arise due to (i) errors in the vernier reading (ii) error in setting the cross wires on the meniscus at pin. (ii) error in setting the pin at the water surface.

Exercises

1. Define surface tension. State its units and dimensions.
2. Explain why water rises in a capillary tube.
3. What is angle of contact ?
4. Does surface tension depend on temperature ? How.
6. If you incline the capillary tube. What will happen ?
7. Distinguish between adhesive and cohesive forces.
8. Calculate the height to which water will rise in a capillary tube of diameter 0.5 min. in an expt. to determine the surface tension of water. Determine the surface tension of water.
9. What are the limitations of this method ?
10. On what factor does the surface tension of a liquid depend ?

(c) Viscosity

Viscosity is the property due to the frictional force exerted by a liquid: A small steel ball or a lead shot falls very quickly through a cylinder full of water or paraffin oil but very slowly through glycerine or some synthetic adhesive (gum). The latter is said to be more viscous.

In steady flow called laminar flow along a pipe, particles or layer of the liquid at the same distance from the axis have the same velocity. The velocity decreases from a maximum value at the centre or axis to zero at the walls of the tube so that a velocity gradient exists across each layer.

The frictional force or the viscous drag or a layer of liquid moving uniformly over another layer is directly proportional to the area of the layer and to the velocity gradient.

Terminal Velocity

When a small steel ball, lead shot or a glass lead is gently released in a tall jar of glycerine along the axis, its downward force of gravity gradually balances against the upthrust and the viscous drag and then attains a steady uniform velocity called its terminal velocity.

Experiment No. 6.3

To determine the coefficient of viscosity of water by capillary tube flow method.

1. Apparatus

(i) Constant head apparatus A	(ii) Capillary tube of about 0.4 or 0.5 mm. diameter
(iii) Two clamps and stands	(iv) Beaker B
(v) Stopwatch	(vi) Rubber tubing for connecting A to T and for the water waste,
(vii) Half meter scale	(viii) Watch glass
(ix) Some mercury	(x) Thermometer 0 – 10 °C
(xi) Spirit level	(xii) Travelling Microscope.

2. Theory

By Poiseuille's formula:

$$V = \frac{\pi p r^4}{8\eta l} = \frac{\pi(X - H)\rho g r^4}{8\eta l} \quad \dots(1)$$

where X is the height of constant water level in A and H, the height of the capillary tube T, from the level of the working table, r the radius of the tube T, η is the coeff. of viscosity and l the length of the tube, ρ is the density of water at lab temp; V is the vol. of water flowing out per sec.

3. Procedure

(i) The constant head apparatus A is placed below the water tap. The rubber tubing is connected to the waste outlet of A so that water may run away to the waste outlet of A so that water may run away to the sink. The water outlet D is connected to the capillary tube T.

(ii) Using a spirit level, the tube T is clamped horizontally H cm. above the working table.

(iii) The water supply is turned on so that water drips at slow rate from the open end of T. To prevent water from running back beneath the tube, a small spot of grease on the underside of the tube near the end is to be placed.

(iv) Water is then collected in clean, dry and weighed beaker B for about 3 to 5 minutes. The beaker along with water is weighed.

(v) Operations are repeated for different values of H, varying the rate of flow as much as possible without allowing the flow to become rapid or turbulent.

(vi) The temp of water is noted at intervals.

(vii) The capillary tube is removed and its length l is measured. The diameter of the tube is measured by Travelling microscope as in Expt. 6.2.

Diameter of the capillary tube = ... radius r =

A graph of the vol. of water per sec. (v) is plotted against H, which will be a st. line.

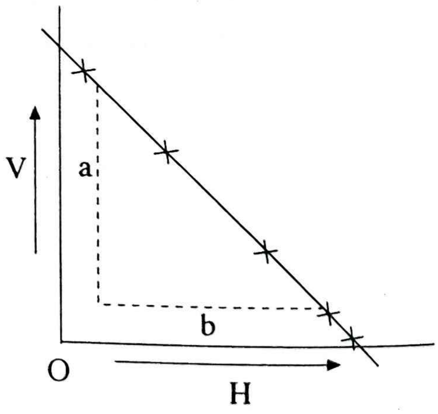


Fig. 6.4

The slope $\frac{a}{b}$ of the best line is measured for the error.

Then slope $$\frac{a}{b} = \frac{\pi \rho g r^4}{8\eta l} \quad \dots (3)$$

from which $$\eta = \frac{\pi \rho g r^4}{8 l \times \frac{a}{b}}$$

Conclusion

Thus the coeff. of viscosity of water at ...... °C = ... poise

= .... nsm^{-2}

Error and Order of Accuracy

1. The error $\delta\left(\frac{a}{b}\right)$ in the gradient of the line by drawing the line whose slope differs as much as possible from the best line is to be estimated, taking care to see that the line still passes close to a majority of the plotted points.

Experiment No. 6.4

To determine the coeff. of viscosity of liquid by Stoke's method.

1. Apparatus Required

(i) Measuring cylinder G.

(ii) Steel ball bearing or glass beads C of varying diameter.

(iii) Liquid (Glycerine or Turpentine oil)

(iv) Micrometer Screw gauge.

(v) Stop watch

(vi) Meter scale

(vii) Hydrometer

(viii) Thermometer 0 –100 °C

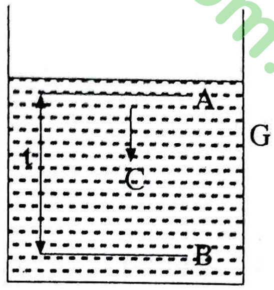


Fig. 6.5

2. Theory

When a small steel ball bearing or a glass bead is allowed to fall through a viscous liquid, after a certain time, it will attain a terminal velocity v such that the apparent weight.

i.e. $$6\pi\eta av = \frac{4\pi}{3} a^3 (\rho - \sigma)g$$

∴ $$\eta = \frac{2}{9} g(\rho - \sigma) \times \frac{a^2}{v} = \frac{2}{9} (\rho - \sigma) \times \frac{c}{d} \qquad \ldots(1)$$

where η is the coeff. of viscosity $\frac{d}{s} = \frac{a^2}{v}$

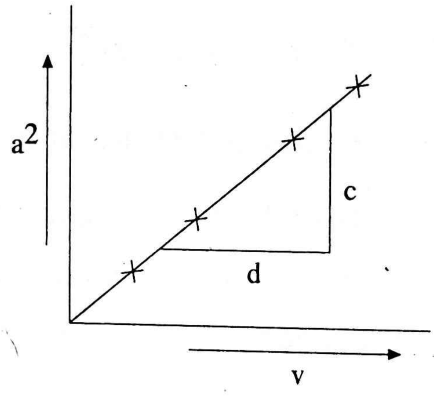


Fig. 6.6

ρ is the density of the ball.

σ is the density of the liquid

a is the density of the radius of the ball

v is the density of the terminal velocity of the ball

η is expressed in poise in C.G.S. units and Nsm^{-2} in S.I. units.

3. Procedure

(i) The measuring cylinder is filled with the experimental liquid.

(ii) An index mark A is fixed by sticking a label well below the top of the liquid so that the ball may reach a steady velocity by the time it reaches A. A second mark B is fixed near the bottom of the cylinder. The distance L cm. between A and B is carefully measured.

(iii) The diameter of a ball is measured accurately and is then allowed to fall through the liquid in the cylinder. The time of fall is noted. This is repeated for at least 7 balls.

(iv) The instrumental error of the micrometer screw gauge is noted if there by any.

(v) The density of the liquid is measured by a hydrometer and its temperature noted. The density of the ball is noted from the tables.

Observations are noted as shown below:

Table No. 6.4

Micrometer Reading mm.	Average Diameter mm.	Time of fall for AB t sec.	Terminal vel. v	a^2 mm^2

4. Observations

Instrumental error of the micrometer screw gauge .... mm

Distance AB = l ....

Density of Glycerine = ... $g\ cm^{-3}$

σ = ... $kg.\ m^{-3}$

Density of steel ρ = ... $g\ cm^{-3}$ from physical Tables.

Temp. of glycerine = ... °C

$$\therefore \quad \eta = \frac{2}{9} g (\rho - \sigma) \frac{a^2}{v} = ...$$

Errors and Order of Accuracy

From the curve a^2 against v, the slope $\frac{c}{d}$ is found, and the error in $\frac{c}{d}$ is obtd. by drawing the slope of greatest or least slope passing near a majority of plotted points. The percentage error can be estimated by finding the % error in $\frac{a^2}{v}$ which is

$$\left(2\frac{\partial a}{a} + \frac{\partial l}{l} + \frac{\partial t}{t}\right) \times 100\%$$

The maximum % of error in the measurement of viscosity is $\dfrac{\partial\left(\frac{c}{d}\right)}{\left(\frac{c}{d}\right)} \times 100\ \%$ neglecting errors in the densities.

Exercises

1. What is viscosity ?
2. Define coefficient of viscosity.
3. What do you mean by velocity gradient and pressure gradient ?
4. State Stoke's law.
5. Distinguish between stream line. and turbulent motion of a liquid.

Chapter 7
Thermometry and Thermal Expansion
Heat

7.1 Temperature is a measure of the state of heating of a body. The temperatures at which water freezes and at which it boils uner normal atmospheric pressure of 760 mm of mercury are used to furnish a scale of temperature. These temperatures are respectively called the lower and the upper fixed points of the thermometer scale.

Temperature is commonly measured in the Celsius (or Centigrade) scale and the Fahrenheit scale. For scientific purposes, the absolute Kelvin scale and the Rankine scales are used.

The Kelvin and Celsius scales use the same intervals for degrees. The Farhenheit and Rankine scales use an interval such that.

Celsius degree $\frac{180}{100} = \frac{9^\circ}{5}$ Fahrenhit . Farhenheit

A comparison of the four scales is given below:

Table 7.1

Absolute zero	Temp. water freezes	Water boils	
0	273.15	373.15	Kelvin (K)
−273	0	100	Celsius (° C)
0	492	672	Rankine (°R)
−460	32	212	Fahrenheit (°F)

Conversion Table

$$\frac{C - 0}{100} = \frac{K - 273}{100} = \frac{F - 32}{180} = \frac{R - 492}{180}$$

7.2 Thermal Expansion

$$\text{Linear expansivity } \alpha = \frac{\text{Increase in length}}{\text{Original Length} \times \text{Rise in temp.}} = \frac{\Delta l}{l \times \Delta t}$$

Experiment No. 7.1

To compare the readings of a Centigrade thermometer with those of a Fahrenheit thermometr. Hence determine the temperature at which the temperatures in the two thermometers will be the same.

1. Apparatus Required

(i) Centigrade thermometer of range 110 °C

(ii) Fahrenheit thermometer of range 212 °F

(iii) A beaker

(iv) Heating arrangement (Burner, Tripod stand, wire gause etc.)

(v) A cork with two holes for inserting the thermometers.

2. Theory

If C be the reading in a Centigrade Thermometer and F that in a Fahrenheit thermometer, they are related as

$$\frac{F - 32}{180} = \frac{C - 0}{100}$$

or $$\frac{F - 32}{9} = \frac{C}{5} \quad \cdots (1)$$

$\therefore$ $$F = \frac{9C}{5} + 32 \quad \cdots (2)$$

which represents a st. line not passing through the origin.

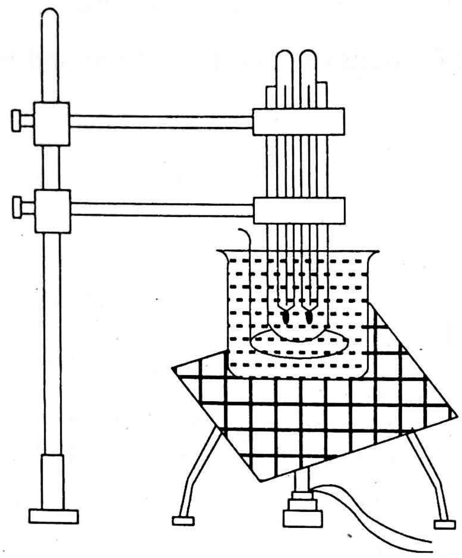


Fig. 7.1

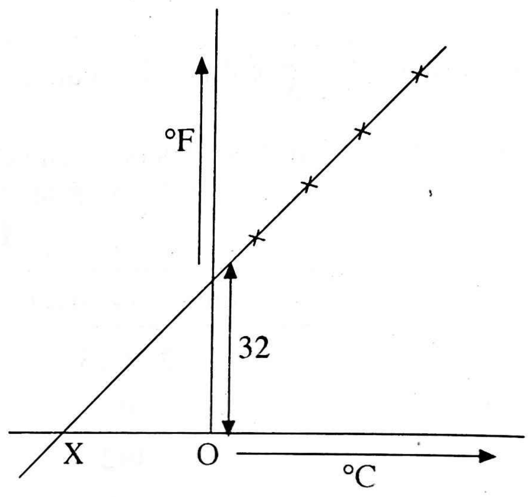


Fig. 7.2

3. Procedure

(i) A beaker nearly half full of water is placed over a wire gauge on a tripod stand as shown in the fig. 8.2.

(ii) Two given thermometers are introduced into the holes bored through the cork. They are immersed in water as shown in the fig. The readings in both the thermometers are noted accurately.

(iii) Water is then gradually heated. Readings in both the thermometers are noted at regular intervals of 5 °C rise. This is continued till water boils.

(iv) The burner is removed and readings are noted in the reversed order at the same intervals while water is cooling.

(v) Observations are noted as follows:

(vi) Graphs of (i) F readings and C readings, (ii) observed F and calculated F readings, (iii) Observed F readings and error are plotted from the C – F graph. F reading corresponding to 0 °C is extrapolated. The temperature at which both the thermometers give the same reading is also calculated.

4. Observtions

1 div. of centigrade thermometer = ... °C

1 div. Fah = ... °F

Table No. 7.2

No. of obs.	Centigrade reading °C	Fahrenheit reading while water is being		Mean F readings °F(b)	Calculated °F (a)	Error (a – b)
		Heated	Cooled			

From the graph

F reading corresponding to 0 °C = ...

Reading at which both the thermometers will be read the same = ...

Experiment No. 7.2

To determine the Fixed Points of the given Thermometer and find the correct temperature of tap water in the Laboratory.

1. Apparatus Required

(i) Hypsometer
(ii) Heating arrangement
(iii) Centigrade thermometer
(iv) Stand with a ring and clamp
(v) Beaker
(vi) Glass Funnel
(vii) Ice
(viii) Fortin's Barometer

2. Theory

The lower fixed point of a thermometer is the temperature at which pure ice melts under normal atmospheric pressure. The melting point of pure ice is 0 °C.

The upper fixed point is the temperature of the steam issuing from boiling water under normal atmospheric pressure. It is 100 °C under standard pressure.

It is found experimentally that a change of 1 cm. of atmospheric pressure produces a change of 0.37° in the temperature of steam.

Hence the True Steam point = {100 – (76 – observed atm press. cm.) × 0.37} °C

3. Procedure

(i) The given thermometer is inserted through a small hole in the small lumps of pure ice placed in the funnel as shown in the fig. 8.4. The bulb of the thermometer should be well within ice. The lowest temperature reached is noted. The reading is taken every two minutes, till 3 to 5 constant temperatures are obtained.

(ii) The thermometer is passed through a hole in the cork which is fitted tightly in the hypsometer which is a boiler provided with a double walled steam jacket. However, the boiler should first be about half filled with water.

(iii) Water is heated. It begins to boil. The highest temperature observed is noted every two minutes till 3 to 5 constant readings are obtained.

(iv) The atmospheric pressure in cms. is read from the Fortin's Barometer.

(v) A correction curve is drawn with correction against observed temperature. From the correction curve, temperature of tap water is found out.

1 smallest div. of the thermometer = ... °C

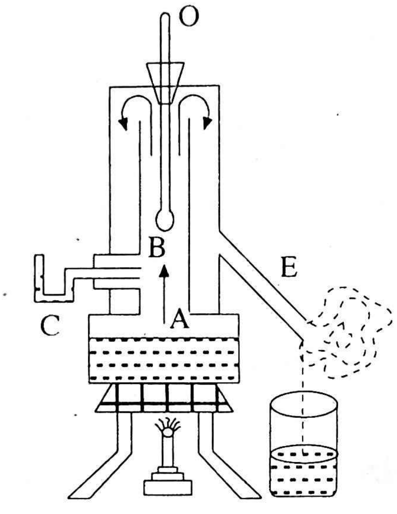


Fig. 7.3

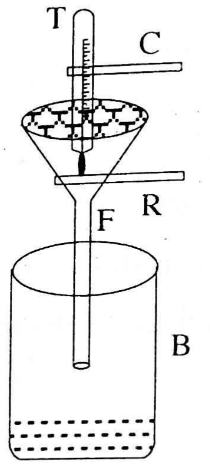


Fig. 7.4

Lower Fixed Point

Table No. 7.3

No. of obs	Thermometer	Readings every 2 mins	Lower Fixed Point		Correction
			Observed	True	
1					
2	Centigrade				
3					
4					
5					

Upper Fixed Point

Observed Atmospheric Press. = P cms.

Normal Atmospheric Press. = 76 cms.

∴ Correction of Steam point = $(76 - P) \times 0.37$

= °C = x °C = °C

∴ True Steam Point = 100 – x = ... °C

Table No. 7.4

No. of obs.	Thermometer Correction	Readings every 2 mins	Steam Point	
			Observed	True
1				
2	Centigrade			
3				
4				
5				
6				
7				

Observed temp. of tap. water = ... °C

Correction for the temp. from the correction curve = ... °C

= .... °C

Correct temp. of tap water ....

Precautions

1. Ice must be pure, for the presence of small impurity in it alters the melting point very much.
2. The thermometer must be placed in the steam, not in the boiling water, because the temperature of the steam is not exactly the same as that of boiling water.
3. Water in the boiler should not be heated violently otherwise the steam pressure may exceed the pressure outside.

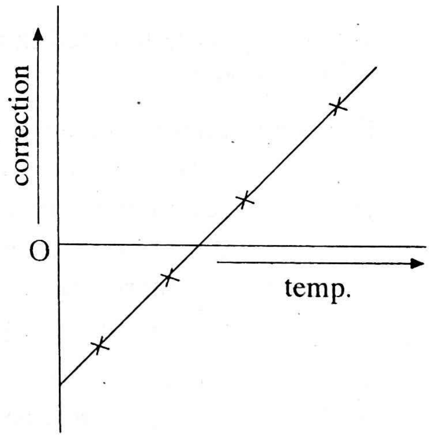


Fig. 7.5

Exercises

1. What are the fixed points of a thermometer ?
2. What is fundamental interval ?
3. Why is it that hot water boils at Kathmandu at a temperature less than 100°C ?
4. How does the pressure affect the boiling point of a liquid ?
5. What do you mean by the steam point ?
6. A faulty thermometer has its fixed point marked - 0.5° and 96°. What is the correct Celsius temperature when this thermometer reads 22° ?

Experiment No. 7.3

To determine the coefficient of linear expansion of a solid by Pullinger's apparatus.

1. Apparatus Required

(i) Pullinger's apparatus (ii) Centigrade Thermometer (iii) Boiler
(iv) Spherometer (v) Heating arrangement (vi) Meter scale

2. Theory

The coefficient of linear expansion of a solid in the form of a tube or a rod is the increase in its length per unit length per unit degree rise of temperature.

Let l_1 be the length of the tube at t_1 °C

l_2 .... t_2 °C

The increase in length for l_1 length for a rise of $t_2 - t_1 = l_2 - l_1$

∴ Increase per unit length per unit rise of temp. $= \dfrac{l_2 - l_1}{l_1 \times (l_2 - l_1)}$

∴ The coeff. of linear expansion $\alpha = \dfrac{l_2 - l_1}{l_1 \times (l_2 - l_1)} = \dfrac{\text{Increase in length}}{\text{original length} \times \text{rise of temp.}}$

3. Procedure

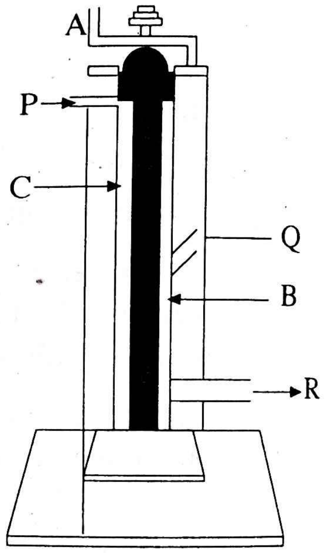


Fig. 7.6

(i) The tube (or the rod) is taken out. Its original length is measured by means of a metre scale at t_1 °C. It is then replaced in its position.

(ii) Thermometer is inserted in its position. The initial reading of the tube i.e. t_1 °C is noted.

(iii) The spherometer is taken. Its pitch and least count are determined. Then it is placed on the tube (or the rod) so that its central leg just touches the upper surface of the tube and its outer legs rest on the base plate. The initial circular scale reading of the spherometer is noted down. From this position, the central leg is raised up by 4 complete rotations in order to allow some space for the expansion of the tube (or the rod).

(iv) Water is boiled in a boiler nearby. Steam from this is passed through a rubber tubing into the tube (or the rod). Steam first condenses and the condensed water comes out of the outlet near about the base. The outlet tube is connected by a rubber tube, the thermometer end of which is dipped in a vessel containing water. When the temp. of the tube (or the rod) becomes steady for about 15 minutes indicating the uniformity of temp. throughout, steam is discontinued.

(v) The central leg of the spherometer is now lowered slowly, counting the no. of complete rotations made. When the central leg just touches the surface of the tube (or the rod), the final circular scale reading of the spherometer is noted.

(vi) The observations are noted and the results calculated as follows:

4. Observations

Material of the tube (or the rod) supplied:

Original length of the tube (or the rod) = l_1 = ... cms.

Initial temp. of the tube (or the rod) = t_1 °C = ... °C.

Value of 10 smallest divs. of the main scale of the spherometer = ... mm.

∴ Value of 1 smallest divs. of the main scale of the spherometer = ... mm.

In 4 complete rotations, the circular scale of the spherometer moves through ....divs. of the main scale.

∴ In 1 complete rotations, the circular scale of the spherometer moves through .... div.

∴ Pitch of the screw (P) = ... div = ... mm

NO. of circular scale divs. (N) = ...

∴ Least count (L.C.) = $\frac{\text{Pitch}}{\text{No. of cir. scale divs.}} = \frac{P}{N}$ = ... mm = ... cms.

Initial cir. scale reading on the upper surface = ... (a, say)

No. of complete rotations through which the circular scale is raised = 5 i.e. ...... divs. = x (say)

No. of complete rotations lowered = ... divs. = y

Final circular scale reading on the upper surface = ... (b, say)

Final steady temperature of the tube (or the rod) = t_2 °C = ...

5. Calculations

No. of additional cir. scale divs. lowered = a – b = z divs.

∴ total no. of cir. scale divs. lowered = y + z

∴ increase in length = x – (y + z) = ... divs.

= ...... × L.C. = ... cms.

Rise of temp. = $t_2 - t_1$ = ... °C.

Coeff. of linear expansion $\alpha = \frac{\text{Increase in length}}{\text{original length} \times \text{rise of temp.}}$

6. Discussion

The length should be accurately measured. The back–lash error should be avoided in the spherometer by turning the screw of the spherometer always in the same direction. However a little error is always present, because the screw is to be turned in opposite direction while raising the central leg. The temp. must be kept constant for at last 15 minutes so as to ensure uniformity of temp. throughout the tube (or the rod). The spherometer must not be displaced bodily from its position during the experiment so that the point of contact may be the same.

Exercises

1. Determine the increase in length of the given tube when heated 40 °C.
2. Determine the temperature upto which the given tube is to be heated in order that its length may increase by $\frac{1}{7}$ mm.
3. What is meant by thermal expansion ?
4. Define coeffs. of linear and cubical expansion. State their units.
5. State the relation between α, β and γ.
6. Explain the statement.

Chapter 8
(a) Calorimetry

8.1 Calorimetry is the measurement of heat. The unit of heat normally used is a calorie. It is the amount of heat required to raise the temperature of one gram of water through 1 °C. In the M.K.S. system the unit of heat is kilocalorie which is the amount of heat required to heat 1 kg. of water through 1 °C. In the S.I. units the amount of heat is measured in terms of joule (J).

Specific Heat: It is the quantity of heat required to raise the temperture of a unit mass of the substance through a unit rise of temperature.

Its unit is k cal kg^{-1} °C while in S.I. it is J kg^{-1} °C.

It is also defined as the ratio of the amount of heat required to raise the temperature of the substance through a certain range of temperature to the amount of heat required to raise the temperature of an equal mass of water through the same range of temperature.

Thermal Capacity: The thermal capacity of a body is the amount of heat required to raise its temperature by 1 °C. It is given by

$$H = ms$$

where m is its mass and s its sp. heat.

Water Equivalent W: The water equivalent of a body is the mass of water in gm (or kg.) which would require the same amount of heat to raise its temperature through 1 °C as the body when heated through the same temperature.

It is given by W= ms gm/or kg.

The Standard Thermal Equation: The amount of heat lost or gained by a body is

$$Q = ms\,\theta$$

where s is its sp. heat. θ is the fall or rise in temperature.

Principle of Calorimetry: When a hot body is mixed with a cold body, exchange of heat will take place. The hot body loses heat and the cold absorbs it. The exchange will take place till both of them attains the final common temperature.

Then, Heat lost by the hot body = Heat gained by the cold body.

Experiment No. 8.1

To determine the water equivalent of the given calorimeter and its stirrer.

1. Apparatus Required

(i) Calorimeter with stirrer

(ii) Sensitive thermometer of range 50 °C., Grad. $\frac{1}{10}$ °C.

(iii) Thermometer of range 100°, grad. 1 °C

(iv) One flat bottomed flask

(v) Heating arrangements.

2. Theory

The water equivalent of a calorimeter is defined as the amount of water in gms. which can be heated through 1 °C by the amount of heat required to raise the temp. of the calorimeter itself through the same range of temperature.

So if W be water equivalent, w its mass, s the sp. heat of its material, then W = ws gm.

Now let mass of the calorimeter and its stirrer = w gms.

mass of the calorimeter and water (filled $\frac{1}{3}$ rd) = w_1 gm.

∴ Mass of water alone = $w_1 - w = m$ gm.

Initial temp. of calorimeter and its contents = t_1 °C

Temp. of hot water to be added = t_2 °C

mass of cal., stirrer, water + hot water added = w_2 gms.

∴ Mass of hot water added = $w_2 - w_1 = M$ gms.

Temp. of the mixture = t °C

∴ Heat lost by hot water in cooling from t_2 °C to t °C = m $(t_2 - t)$ cal

Heat gained by calorimeter and its stirrer in rising from t_1 °C to t °C = W. $(t - t_1)$ cals.

Heat gained by cold water in rising from t_1 °C to t °C = $m(t - t_1)$ cals.

∴ Total heat gained by calorimeter and its contents = $W(t - t_1) + m(t - t_1)$

By the principle of calorimetry heat gained = heat lost

or $W(t - t_1 + m(t - t_1) = M(t_2 - t)$

or $$W(t - t_1) = M(t_2 - t) - m(t - t_1)$$

∴ $$W = \frac{M(t_2 - t)}{(t - t_1)} - m$$

4. Procedure

(i) The calorimeter with its stirrer is rubbed well with a piece of sand paper so as to make its inner and outer surface polished.

(ii) The calorimeter with its stirrer, is weighed carefully in a physical balance and its weight is noted.

(iii) About $\frac{1}{3}$ rd of it is filled with water at the room temperature and its weight is noted.

(iv) During this time, some water is already being heated in a flask. The temp. of hot water in the flask is noted down. (The temperature should preferably be approximately 10 to 15 °C above the room temp). Hot water is then immediately poured into the calorimeter to fill about $\frac{2}{3}$ rd. of it. The water is to be constantly stirred and the maximum temperature attained (of the calorimeter and its contents) is noted down. Observations are noted and the result calculated as below:

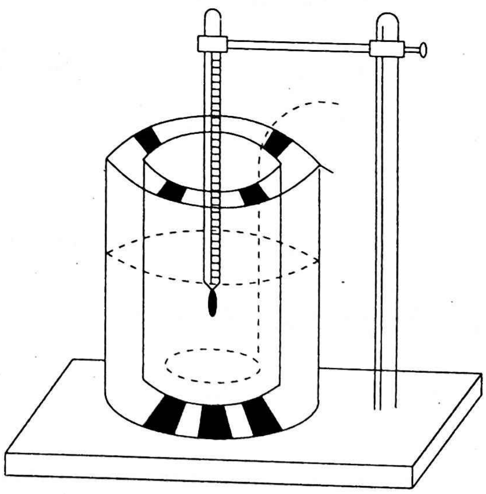


Fig. 8.1

Observations

Mass of calorimeter and its stirrer = w gm.

Mass of cal., stirrer and water (about $\frac{1}{3}$ rd) = w_1 gm.

∴ Mass of cold water = $w - w_1$ gm = m gm.

Initial temp. of calorimeter and its contents = t_1 °C.

Temp. of hot water in the flask = t_2 °C

Temp. of the mixture = t °C

Mass of cal., stirrer + hot water added = w_2 gm

∴ mass of hot water added = $w_2 - w_1$ = M gm.

Calculation

Heat lost by hot water in cooling from t_2 °C to t °C = M $(t_2 - t)$ cals.

Heat gained by cal., stirrer and cold water in rising from t °C to t_1 = $W(t - t_1) + m(t - t_1)$

By the principle of calorimetry, we have

Heat gained = Heat lost

$$W(t - t_1) + m(t - t_1) = M(t_2 - t)$$

or
$$W(t - t_1) = M(t_2 - t) - m(t - t_1)$$

∴
$$W = \frac{M(t_2 - t)}{(t - t_1)} - m$$

This is the experimental value of the water equivalent.

By actual calculation, W = ws, where s is the sp. heat of the cal.

Then % error = $\frac{C - O}{C} \times 100$ where C is calculated value and O is the experimental value obtained.

Experiment No. 8.2

To determine the specific heat of a solid by the method of mixtures.

1. Apparatus Required

(i) Regnault's apparatus (ii) Sensitive thermometer range 50 °C, Grad. $\frac{1}{10}$ °C

(iii) Ordinary thermometer range 100 °C, grad. $\frac{1^\circ}{1}$ C or $\frac{1}{2}$ °C (iv) Solid (experimental)

(v) Calorimeter with stirrer (vi) Boiler (vii) Heating arrangements (viii) Balance and weight box

2. Theory

The sp. heat of a substance is defined as the ratio of the heat required to raise the temperature of a certain mass of the substance through a certain range to the amount of heat required to raise the temp. of an equal mass of water through the same range of temperature.

Otherwise, it may also be defined as:

"The sp. heat of a substance is numerically equal to the amount of the heat required to raise the temp. of 1 gm. of the substance through 1 °C.

Let the specific heat of the solid to be determined = S (?)

Mass of the solid taken = M gms.

Mass of the calorimeter and its stirrer = W gm.

Sp. heat of the material of the calorimeter = s.

Mass of cal, stirrer + water = w_1 gm.

Mass of water taken = $w_1 - w = m$ gm.

Initial temp. of cal., and its contents = t_1 °C

Steady temp. of the solid = t_2 °C

Temp. of the mixture = t °C

Thus heat lost by the solid in cooling from t_2 °C to t °C = MS $(t_2 - t)$ cals.

Heat gained by calr., its stirrer and cold water in rising from t_1 °C to t °C = ws $(t - t_1)$ + m $(t - t_1)$

= (ws + m) $(t - t_1)$ cals.

By the principle of calorimetry, we have

Heat lost = Heat gained.

or $MS\,(t_2 - t) = (ws + m)\,(t - t_1)$

$$\therefore \quad S = \frac{(ws + m)\,(t - t_1)}{M\,(t_2 - t)}$$

3. Procedure

(i) The nature of the material of the solid is noted. The solid is weighed carefully and its weight is noted.

(ii) The solid is then placed inside a steam heater suspending it by means of a piece of thread passing through a piece of cork. A thermometer reading upto 100 °C or more is introduced through the other hole of the same cork so that the bulb of the thermometer and the solid be at about the same depth but not touching each other.

(iii) The boiler is filled sufficiently with water so that water may not run short during the experiment. Water is then heated.

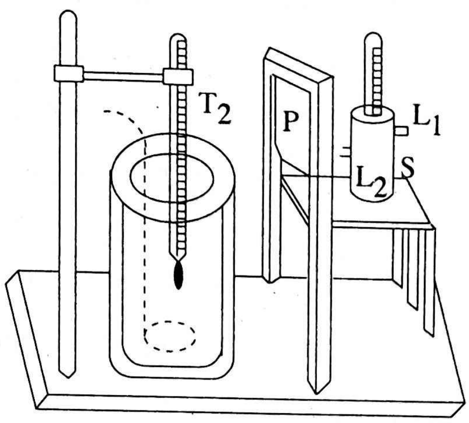


Fig. 8.2

(iv) The shutter is opened. The calorimeter is just tried whether it can slide well along the groove. It is kept just below the steam heater. It should be seen that the solid if dropped will be received by the calorimeter without breaking the thermometer. This should be tried before heating the solid.

(v) During this time steam is being prepared in a boiler. Steam is then passed to the steam jacket by means of a rubber tubing. The outlet of the steam heater is fitted with a long rubber tubing, led to a vessel at a distance so that the condensed steam may collect.

(vi) The calorimeter with its stirrer is polished by rubbing it with a piece of sand paper. It is then cleaned, dried and weighed carefully in a balance and its weight is noted.

(vii) It is filled with sufficient water so that the solid when dropped into it may be completely covered up by it. It is weighed once more carefully. The difference between this weight and the previous one will give the weight of cold water taken.

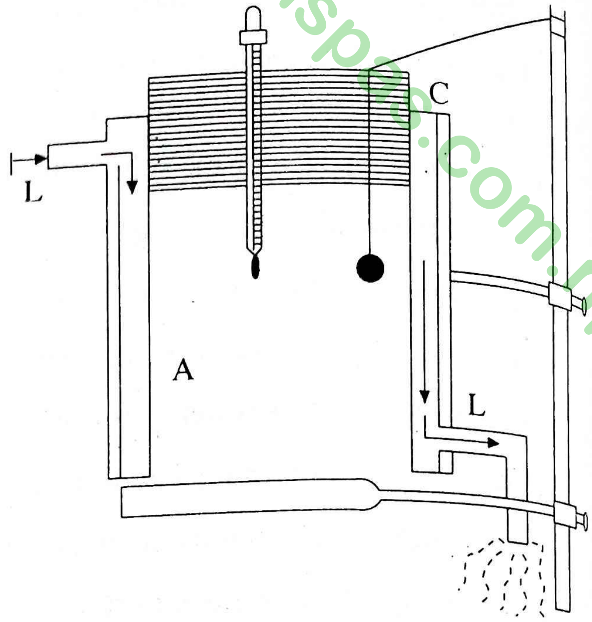


Fig. 8.3

(viii) The initial temperature of the calorimeter and its contents is noted by means of the sensitive thermometer reading upto 0.1 °C.

(ix) By this time, the solid might have been sufficiently heated. When the temp. of the solid becomes steady for at least 10 minutes, the shutter is opened and the calorimeter is slowly slided along the groove and placed just below the steam heater. The thread suspending the solid is untied and loosened and opening the shutter just below the steam heater, the solid is dropped into the calorimeter and the calorimeter is removed to a distance. The water in the calorimeter is constantly stirred and the maximum temperature attained is noted. The observations are noted and the result it calculated as shown below:

4. Observations

Material of the solid: Brass, iron, zinc, tin (or what).

Mass of the solid = M gm

Sp. heat = S (?)

Mass of the calorimeter with stirrer = w_1 gm

Sp. heat of the material of the calorimeter = s (supplied)

Mass of the cal^r. with stirrer + water = w_2

Mass of the cold water taken = $w_2 - w_1$ = m gm.

Initial temp. of the cal. and its contents = t_1 °C

Steady temp. of the solid = t_2 °C

Final common temp. of the mixture = t °C

Conclusion

Heat lost by the solid in cooling from t_2 °C to t °C = MS $(t_2 - t)$ cals.

Heat gained by the cal. stirrer and water in rising from t_1 °C to t °C = ws $(t - t_1)$ + m $(t - t_1)$

$$= (ws + m)(t - t_1)$$

By the principle of calorimetry, we have MS $(t_2 - t) = (ws + m)(t - t_1)$

$$\therefore \quad S = \frac{(ws + m)(t - t_1)}{MS(t_2 - t)}$$

Errors

In this expt., the error may arise due to (1) heat lost by the hot solid during its transfer to the calorimeter, (2) some hot water is also carried over with the metal. (3) Observations of temp. (4) weighing.

e.g. (20.5 ± 0.1 °C) and mass (69.7 ± 0.1 g)

Percentage Error

The % errors in weighing the calorimeter, solid, the mass of water noting the temp. rise of water and temp. fall of solid, are calculated separately and then added to obtain the total percentage error.

Order of Accuracy

The result of the sp. heat by log calculation should be given to two significant figures.

Note: Express your result in SI units.

Precautions

1. The maximum temp. of the solid should remain constant for at least 10 min. before it is dropped into the water.
2. Sufficient quantity of hot solid should be dropped in the cold water so as to achieve a considerable rise in temperature.
3. The solid should be transferred gently into water and no drop of it should be lost.
4. The mixture should be stirred continuously.
5. The highest temperature attained should be noted when it just begins to fall.

Experiment No. 8.3

To determine the Sp. heat of the given liquid by the method of cooling.

1. Apparatus Required:

(i) Two identical calorimeters in a double walled vessel with lid,

(ii) Two centigrade thermometers (ii) Stopwatch

(iv) Physical balance with weight box (v) Given liquid

(vi) Heating arrangement

2. Description of the Apparatus

The double walled rectangular vessel ensures the constancy of the surroundings of the calorimeters. The thermometers are passed through the rubber stoppers closing the holes in the cover of the chamber. The calorimeters are marked on the inner surface upto which the liquid is filled in, ensuring equal volumes of liquids in them.

3. Theory

When a hot body is allowed to cool, the rate of loss of heat by it depends on (i) the difference of temp. of the body and its surroundings and (ii) the nature and area of the exposed surface.

If hot liquid of mass M and sp. heat S in a calorimeter of mass w and sp. heat s is cooled from temp. θ_1 °C to θ_2 °C in t_1 sec. then rate of loss of heat by

$$\text{the liquid} = \frac{(ws + MS)(\theta_1 - \theta_2)}{t_1} \quad \ldots(1)$$

Similarly if water of mass m and of the same volume as the liquid in another similar calorimeter of mass w and sp. heat s is cooled from θ_1 °C to θ_2 °C in t_2 secs. in the same surrounding the rate of loss of heat by

$$\text{water} = \frac{(w's + mS)(\theta_1 - \theta_2)}{t_2} \quad \ldots(2)$$

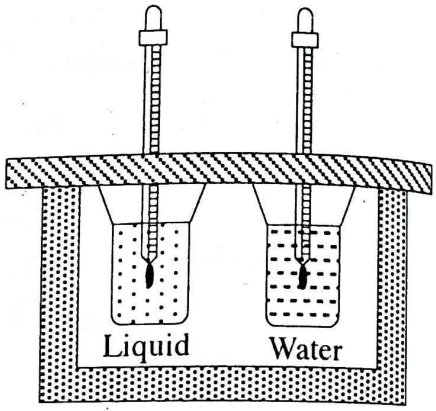


Fig. 8.4

As the rate of loss of heat should be the same in both the cases, we have,

$$= \frac{(ws + MS)(\theta_1 - \theta_2)}{t_1} = \frac{(w's + mS)(\theta_1 - \theta_2)}{t_2}$$

or $$(ws + MS) = \frac{t_1}{t_2}(w's + m)$$

or $$S = \left[\frac{1}{M}\left(\frac{t_1}{t_2}\right)(w's - m) - ws\right] \quad \ldots(3)$$

Thus S is found from eqn. (3)

4. Procedure

(i) Both the calorimeters are weighed empty. A mark made on the inner side of each at about 2 cm. from the top.

(ii) Water and the given liquid are taken in separate test tubes (or large size) placed in the same beaker containing water. They are heated to about 70 °C.

(iii) Water and the liquid are then transferred to the calorimeters. The lid is placed in position.

(iv) Temperatures of the contents in both the calorimeters are noted at intervals of 1 min. During this time, they should be constantly stirred. The recording of temperatures is continued until they are about 10 to 15 °C above the room temp. After this, the calorimeters with water and liquid are weighed again.

(v) The temperatures are plotted against time for water and the liquid in the same piece of graph paper. The times required by water and the liquid to cool from θ_1 °C to θ_2 °C are extrapolated from the curves. S is then calculated from eqn. (3) above.

(vi) Observations are noted as shown below:

5. Observation

Mass of empty calorimeter with stirrer (A) = w ...... gms.

...... + liquid = w_1 .... gms.

∴ Mass of liquid taken = $w_1 - w = M$ gms = ...

Mass of empty calorimeter with stirrer (B) = w = ... gms.

...... + water = w_1 = ... gms

∴ Mass of water taken = $w_1 - w = m$ = ... gms.

Sp. heat of calorimeter material = s .... (supplied)

1 smallest div. of the thermometer (1) = ... °C

1 smallest div. of the thermometer (2) = ... °C

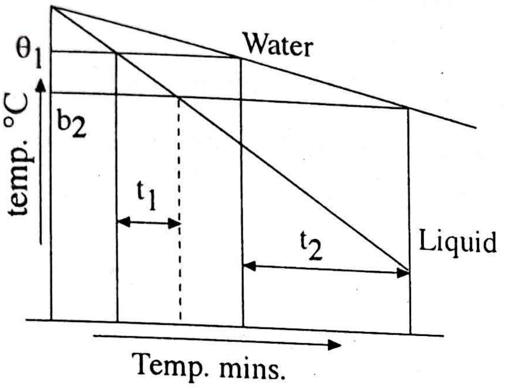


Fig. 8.5

&

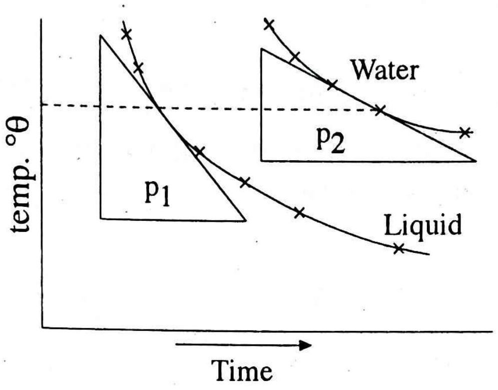


Fig. 8.6

From the cooling curve,

Time taken by liquid to cool from θ_1 to θ_2 °C = t_1 min. = ...

.... water ....= t_2 min. = ...

∴ S = ...

Alternative Calculation

Tangents are drawn to the cooling curves at a particular temperature θ and respective rates of temperature drop p_1 and p_2 are found for liquid and water respectively.

Then at θ = ... °C, {Liquid = ... °C per min}

Water = ... °C ...."

∴ We get from theory (above),

$(ws + MS)\ p_1 = (w's + m)\ p_2$

∴ S = ...

Conclusion

Sp. heat of the liquid = ...

Express it in S.I. units,

Errors and Order of Accuracy

In the expt., errors may arise due to (1) observations of volume, mass and temperature (2) difficulty of drawing a smooth cooling curve. (3) difficulty of drawing a tangent to the curve for the alternative calculation.

Order of Accuracy

From the above results for S, the difference D between average value A and the result which differs most widely from the average is found out. The percentage of the average value is calculated. This gives an approximate value of the order of accuracy $\frac{D}{A} \times 100\%$.

Precautions

1. The electric fan (if any in the Lab) should be switched off while performing the expt.
2. The calorimeter must not touch the double walled vessel.
3. The calorimeters should be covered with lids to prevent evaporation which will otherwise enhance cooling.
4. The water and the liquid should be stirred gently and uniformly before taking reading.
5. The temperature should be read quickly at proper timings specially in the beginning when the fall of temperature is very rapid.

8.(b) Change of state

8.2 Latent Heat

The heat required to change the state of a substance from solid to liquid, liquid to gas and vice–versa is called latent heat because during the change of state there is no rise or fall of temperature.

Latent heat of fusion: It is the amount of heat required to convert a unit mass of a substance from solid to liquid at its melting point is called the latent heat of fusion. If ice changes into water it is called latent heat of fusion of ice. Its value is 80 cals per gm. In SI units it is 3.4×10^5 Jkg^{-1}

Latent heat of vaporisation: It is the amount of heat required to convert a unit mass of a substance from liquid to gaseous state at its boiling point without any change of temperature. In the case of water it is called latent heat of steam and its value is 537 cals/gm. In SI unit, it is 2.3×10^6 Jkg^{-1}.

Experiment No. 8.4

To determine the latent heat of fusion of ice.

1. Apparatus Required

(i) Calorimeter with wire gauge stirrer

(ii) Sensitive thermometer grad. $\frac{1}{10}$ °C

(iii) Ice

(iv) A piece of flannel cloth

(v) Blotting paper

(vi) Balance and weight box

2. Theory

The latent heat of fusion of ice is defined as the amount of heat absorbed by one gm. of ice at °C in being converted into ice at the same temp.

Let the latent heat of fusion of ice = L (?)

Mass of the calorimeter with stirrer = w gms.

Sp. heat of the calorimeter with stirrer = s

Mass of cal. stirrer + water = w_1 gms.

∴ Mass of water taken = $w_1 - w = m$ gm.

Initial temp. of cal and its contents = t_1 °C

Temp. of ice t °C = 0 °C

Temp. of the mixtures = t °C

Mass of calr., stirrer + water after addition of ice = w_2

∴ Mass of ice added = $w_2 - w_1 = M$ gms.

Thus heat lost by cal. and water in cooling from t_1 to t °C = $(ws + m)(t_1 - t)$ cals.

Heat gained by ice in melting to water at 0 °C and

then resulting water in rising from 0 °C to t °C = $ML + M(t - 0) = ML + Mt$.

By the principle of calorimetry, we have heat gained = heat lost or $ML + Mt = (ws + m)(t_1 - t)$

or $ML = (ws + m)(t_1 - t) - Mt$

$$L = \frac{(ws + m)(t - t_1)}{M} - t$$

3. Procedure

(i) The calorimeter with its wire gauge stirrer is polished by rubbing it with a piece of sand paper. It is then cleaned, dried and weighed carefully in a balance and its weight is noted.

(ii) It is nearly half filled with water and weighed again. Its weight is noted. The difference between this weight and the previous one gives the weight of water taken.

(iii) The initial temp. of the calorimeter and its contents is noted with the help of a sensitive thermometer.

(iv) A block of ice is taken and washed with water and placing it in a piece of flannel cloth pounded into small pieces. These pieces of ice and soaked in a piece of blotting paper so that water may not adhere into them.

(v) Pieces of ice are dropped into the calorimeter and kept immersed by means of the wire gauge stirrer. Water is gradually stirred. Ice is added and water stirred until the mixture, when all ice melts, falls to a temp. Some 5 to 10 °C below the initial temp. of water. The final temp. of the mixture is noted carefully.

(vi) The calorimeter along with its contents is weighed once more. The difference between this weight and the second weight gives the weight of ice added.

(vii) Observations are noted and the results calculated as shown below.

4. Observation

Latent heat of fusion of ice = L (?)

Mass of the calorimeter with stirrer = w gms.

Sp. heat .... = s (to be supplied)

∴ Mass of the cal., stirrer + water (nearly half) = w_1 gms.

Initial temp. of cal. and its contents = t_1 °C

Temp. of ice = 0 °C

Temp. of the mixture = t °C

Mass of cal., stirrer + water after the addition and melting of ice = w_2 gms.

Mass of ice added = $w_2 - w_1 = M$ gms.

Calculation

Heat gained by ice in melting to water at 0 °C and then by the resulting water in rising from 0 °C and then by the resulting water in rising from 0 °C to t °C = ML + M (t – 0) = ML + Mt

Heat lost by calr., stirrer and water in cooling from t_1 to t °C = $(ws + m)(t_1 - t)$

By the principle of the calorimetry, we have

Heat gained = Heat lost

or $ML + Mt = (ws + m)(t_1 - t)$

or $ML = (ws + m)(t_1 - t) - Mt$

$$\therefore \quad L = \left[\frac{(ws + m)(t_1 - t)}{M}\right] - t$$

Conclusion

The latent of fusion of ice = ... cals./gm.

Express in SI units.

Errors

The errors may arise due to the following reasons:

(i) The ice may not be perfectly dry, thus leading to error in the mass of ice.

Order of Accuracy

Since $L = \frac{Q}{M}$ where $Q = (ws + m)(t_1 - t) - Mt$ the percentage error in L is the sum of percentage in Q and M. The percentage in M has a great effect of L, since (a) M is small and (b) a significant mass of water may be carried over along with ice if it is not perfectly dry.

Experiment No. 8.5

To determine the Latent Heat of Vaporisation of water or Latent Heat of Steam.

1. Apparatus Required

(i) Calorimeter with stirrer and condenser

(ii) Steam trap with connecting tubes

(iii) Sensitive thermometer, range 50 °C grad

(iv) Ordinary thermometer range 100 °C

(v) Boiler

(vi) Heating arrangements

(vii) Balance and weight box

2. Theory

The latent heat of vaporisation of water or the latent heat of steam is defined as the amount of heat liberated by one gm of steam at the steam point in condensing to water at its boiling point. Otherwise it may also be defined as the amount of heat absorbed by one gm. of water at its boiling point in being converted to steam at the same temp. It is expressed in calories per gm or Jkg^{-1}.

Let the latent heat of vaporisation of water = L (?)

Mass of calorimeter, stirrer and condenser = w. gm.

Sp. heat .... = s

Mass of calr., stirrer, condenser and water nearly half filled = w_1 gm.

$\therefore$ Mass of water taken = $w_1 - w = m$ gm

Initial temp. of cal. and its contents = t_1 °C

Steady temp. of steam = t_2 °C, temp. of mixture = t °C

Mass of cal^r, stirrer, condenser + water after condensation of steam = w_2 gm.

∴ Mass of steam codensed = $w_2 - w_1 = M$ gm.

∴ Heat lost by steam in condensing to water at $t_2°$ and then by the resulting water in cooling from t_2 to $t = ML + M(t_2 - t)$ cals.

Heat gained by cal and its contents in rising from t_1 to $t = (ws + m)(t - t_1)$

(By the principle of calorimetry, we have heat lost = heat gained

or $ML + M(t_2 - t) = (ws + m)(t - t_1)$

or $$ML = (ws + m)(t - t_1) - M(t_2 - t)$$

∴ $$L = \left[\frac{(ws + m)(t - t_1)}{M} - (t_2 - t)\right] \text{ cal/gm}$$

3. Procedure

(i) The calorimeter with its stirrer and condenser is polished by rubbing it with a piece of sand paper. It is then cleaned, dried and weighed carefully in a balance and its weight is noted.

(ii) It is nearly half filled with water and weighed again.

(iii) The initial temp. of the cal. and its contents is noted by means of a sensitive thermometer.

(iv) During this time, steam is being generated in a boiler. The temp. of steam is noted. Steam is then communicated through the connecting tube and steam trap into the calorimeter, by way of the condenser.

(v) During the passing of steam into the calorimeter, water in the carl. is constantly stirred. Steam is allowed to pass until the mixture attains a temp some 5 to 10 °C above the initial temp. When this happens, stem is disconnected and the final common temp. of the mixture is noted very carefully.

(vi) The calr. along with its contents is now once more weighed carefully, the difference between this weight and the second weight gives the weight of steam condensed.

(vii) The observations are noted and the result calculated as shown below.

4. Observations

Latent heat of vaporisation of water = L (?)

Mass of the calorimeter, stirrer and condenser = w gm.

Sp. heat .... = s (to be supplied)

Mass of the cal., stirrer, condenser and water (nearly half filled) = w_1 gm.

∴ Mass of water taken = $w_1 - w = m$ gm.

Initial temp. of the cal. and its contents = t_1 °C

Temp. of steam = t_2 °C

Final common temp. of the mixture = t °C

Mass of calr. stirrer, condenser + water after the condensation of steam = w_2 gm.

∴ Mass of steam condensed = $w_2 - w_1 = M$ gms.

Calculation

Heat lost by steam in condensing to water at t_2 °C and then by the resulting water in cooling from t_2 °C to t °C = ML + M $(t_2 - t)$ cals.

Heat gained by calr. and its contents in rising from

t_1 to t = (ws + m) $(t - t_1)$,

By the principle of calorimetry, we have

Heat lost = Heat gained.

or $ML + M(t_2 - t) = (ws + m)(t - t_1)$

or $ML = (ws + m)(t - t_1) - M(t_2 - t)$

$\therefore \quad L = \left[\dfrac{(ws + m)(t_2 - t)}{M}\right]$ cals/gm

Then express it in S.I. units.

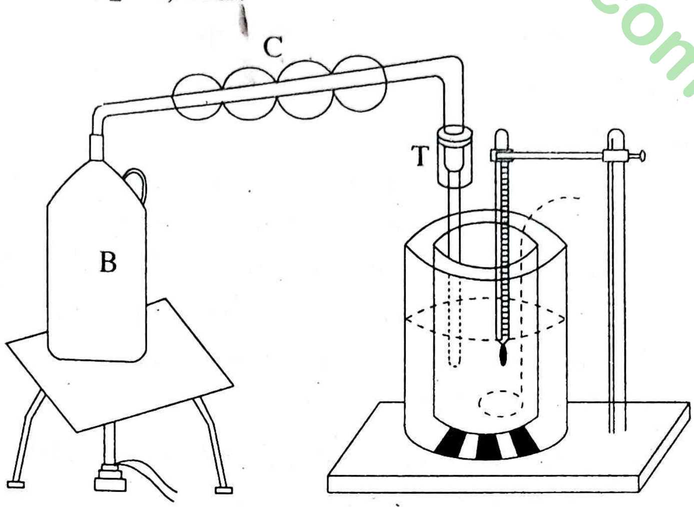


Fig. 8.7

Errors

Here the errors may arise due to (i) Condensation of steam before passing into the water. (ii) Errors in weighing and in recording temperatures. (iii) A cooling correction is needed. This can be avoided by cooling the water with ice about 5 to 10 °C below the temperature of the surroundings. Note that the error due to condensation of steam tends to give a low result.

Order of Accuracy

Since $L = \dfrac{Q}{M} = (ws + m)(t - t_1) - M(t_2 - t)$. The percentage error in L is the sum of the percentage error in Q and M. The mass of steam must therefore be very carefully measured. Since it is a small difference between two measured weights.

Experiment No. 8.6

To determine the melting point of the given solid by cooling curve method

1. Apparatus Required

(i) Hard glass test tube containing wax

(ii) Centigrade thermometer

(iii) Stop watch or clock

(iv) Heating arrangement

(v) Solid supplied – wax

2. Theory

When a solid substance is heated, its temperature will gradually rise. A time will come when it will just begin to melt. The temp. at which the solid just begins to melt is called the melting point of the solid. This temp. remains constant until all the solid changes into liquid after which it rises again. Conversely, the substance in the liquid state begins to solidify. The temp. at which the solidification starts is the same as the temp. at which the solid begins to melt. This temp. remains constant during the process of solidification.

3. Procedure

(i) The hard glass test tube containing the solid is placed in beaker containing water. Water is heated. As water gets heated, the temp. of solid will also rise. When all the solid melts, a centigrade thermometer is inserted into it through a well fitting cork.

(ii) The test tube is placed on a stand. The temperature is noted and simultaneously the stop watch or the clock is started.

(iii) The liquid wax begins to fall in temperature. The temperature is noted at the intervals of 1 min. After some time, the temp. remains constant or almost constant for a no. of readings. After the temperature becomes constant, some 8 or 10 observations are noted.

(iv) A graph is drawn with time along the x–axis and temperature along the y–axis. The graph will be as shown in the fig. 9.8.

(v) From the horizontal portion of the curve, a straight line is drawn parallel to the x–axis, cutting the temp. axis at a point which gives the melting point of the solid.

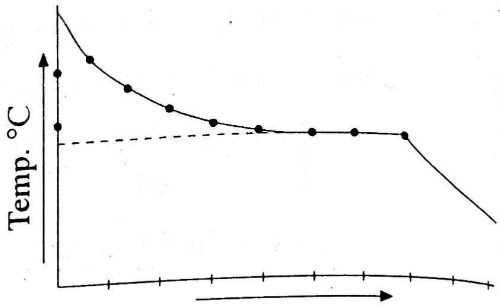


Fig. 8.8

4. Observations

10 divs. of the thermometer supplied = °C

∴ 1 divs. of the thermometer supplied = °C.

10 divs. of the stop watch (or clock) = ... secs.

∴ 1 ....= .... sec.

Conclusion: From the curve, the melting point = x °C

= .... °C

Table No. 8.1

Time in min	Temp. in °C
1	
2	
3	
4	
5	
6	
7	
8	

Experiment No. 8.7

To determine the melting point of the given solid. Capillary tube method.

1. Apparatus Required

(i) Beaker with water

(ii) Centigrade thermometer

(iii) Capillary tube

(iv) Given solid (say paraffin wax or Napthalene or ......)

2. Theory

Same as in the previous expt.

3. Procedure

(i) A capillary tube about 2 to 3" long is prepared. It is dipped into the melted substance kept in a basin. It is sealed at both ends. The substance solidifies on cooling.

(ii) The capillary tube if fastened to the thermometer so that the bulb and the experimental substance are close to each other.

(iii) The thermometer with tube is dipped inside water in a beaker which is gradually heated. The water gets heated. The temperature at which the solid melts is recorded. The flame is removed. The water is allowed to cool. The temperature at which the substance solidifies is noted. This is repeated for at least 4 or 5 observations. The mean melting point is calculated. The readings are recorded as shown below:

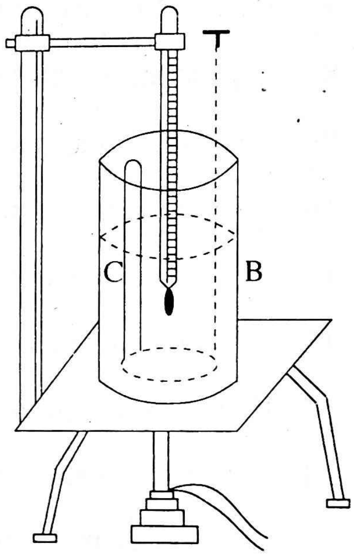


Fig. 8.9

Observations

1 Smallest div. of the thermometer = ... °C

Table No. 8.2

No. of obs	Temp. at which the substance		M.P. $= \frac{t_1 + t_2}{2}$	Mean M.P.
	Begins to melt t_1 °C	Begin to solidify t_2 °C		
1				
2				
3				
4				
5				

Exercise 8

Calorimetry and Changes of State

1. State the difference between heat and temperature.
2. Define specific heat capacity. What is its unit ?
3. Define thermal capacity and water equivalent. What is the difference between them.
4. Explain why the temperature remains constant during the change of state of a substance. Define latent heat of fusion of ice and latent heat of steam.
5. Which is more severe, burn due to steam or boiling water at 100°C ?
6. What is a calorie ?
7. What is the use of drying ice with a blotting paper before adding it to water in a calorimeter ?
8. Explain the use of steam trap and condenser while finding the latent heat of steam.
9. Why is it that steam burn is more severe than burn due to boiling water ?
10. What is the use of polishing the calorimeter ?
11. Why do you use a stirrer in a calorimeter ?
12. Why do you use a wire gauge stirrer in an expt. on latent heat of ice ?
13. How does the specific heat of water vary with temperature ?
14. Does a gas possess one or two sp. heats ? Why ?
15. Which of them is greater and why ?
16. 150 gm of iron of sp. heat 0.112 at 95° C is dropped into a calorimeter containing 200 gm of oil of sp. heat 0.8. The final temperature of the mixture is 65°C and water equivalent of the calorimeter is 10 gm. Calculate the initial temperature of the oil.
17. The temperature of 500 gm of a certain metal is raised to 100°C and is then placed in 200 gm of water at 15°C. If the final steady temp. rises to 21°C, calculate the sp. heat capacity of the metal.
18. Calculate the quantity of heat required to convert 2 kg. of ice at - 12°C to steam at 100°C.
19. 500 c.c. of water and an equal volume of a liquid of density 0.8 gm/cc are poured successively into the same calorimeter and they are cooled from 60°C to 55°C in 2.5 min and 1.5 min. respectively. Find the sp. heat of the liquid water equivalent of the calorimeter is 20 gm.

Exercise

Melting point of solid

1. Define melting point and freezing point.
2. Why does the temperature remains constant during change of state ?

Experiment No. 8.8

To determine the thermal conductivity of a good conductor by Searle's method.

1. Apparatus Required

(i) Searle's apparatus

(ii) Four thermometers $\theta_1, \theta_2, \theta_3$ and θ_4

(iii) Constant Head apparatus H

(iv) Measuring cylinder C

(v) Stop watch

(vi) Boiler

2. Theory

When a steady state is attained, the heat flowing along the bar of a good conductor per sec. is equal to the heat gained per sec. by the water flowing in the spiral S.

$$Q = \frac{KA\,(\theta_1 - \theta_2)t}{x} = mC_w\,(\theta_4 - \theta_3)$$

or

$$K\,\frac{\pi d^2}{4}\,\frac{(\theta_1 - \theta_2)}{x} = \frac{m}{t}\,C_w\,(\theta_4 - \theta_3) \qquad \ldots (1)$$

From which K may be found out.

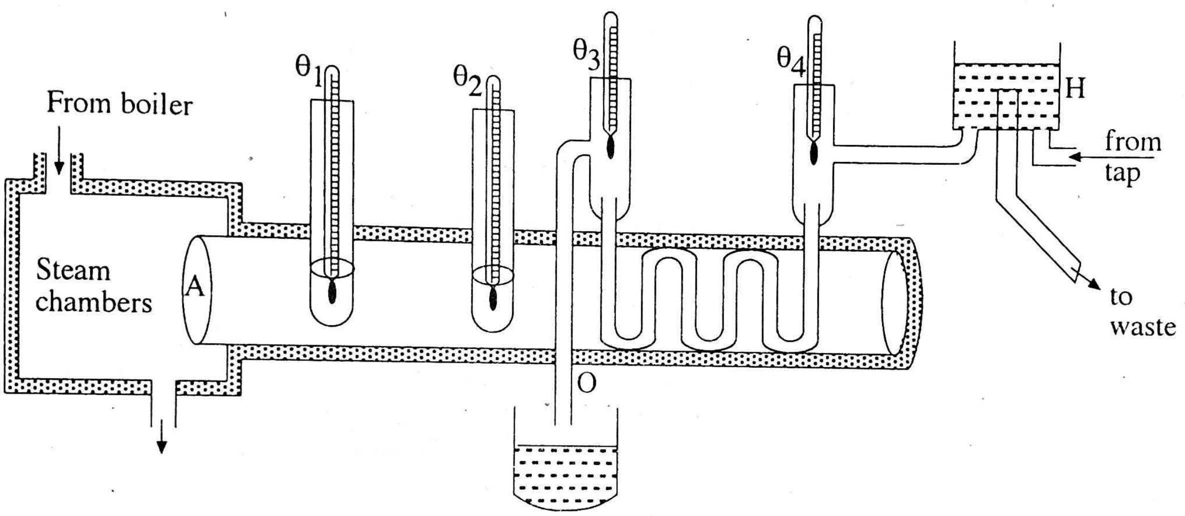


Fig. 8.10

where C_w is the sp. heat of water, K is the thermal conductivity of the good conductor, m = the mass of water collected in t secs, d = the diameter of the bar θ_1, θ_2, θ_3 and θ_4 are the temperatures recorded by the four thermometers in the steady state.

3. Procedure

(i) The diameter of the bar is measured by a vernier callipers. The distance x along the bar is also measured.

(ii) The four thermometers are inserted (as shown in the fig.) in the holes drilled in the bar with a little mercury or glycerine to ensure good thermal contact between the bar and the thermometer bulbs.

(iii) The inlet tube of the bar is connected to the constant – head apparatus H. The positions of the outlet tube O and H are adjusted such that a steady flow of a few c.c. of water per sec. is obtained.

(iv) The bar if supplied with a steam chamber S at the other end which is connected to a boiler to maintain a steady flow of steam.

(v) θ_1 and θ_2 are read every 3 min. When they are nearly steady, the height of H is adjusted so that the rate of flow is increased or decreased until the difference between θ_3 and θ_4 is about 5 or 6 °C.

(vi) The thermometers are allowed to reach their steady values. Then θ_1, θ_2, θ_3 and θ_4 are noted.

(vii) The out flow of water from O is collected for a known interval say t secs. in a measuring cylinder C. The mass. of water collected is recorded.

(viii) Operations 5, 6, 7 are repeated when the steady state is again reached say twice or thrice (according to time available) by slightly increasing or decreasing the rate of flow.

(ix) Observations are noted as follows.

4. Observations

Distance x = ... cm.

Diameter d of the bar = ... cm.

Table No. 8.3

Obs.	θ_1 °C	θ_2 °C	θ_3 °C	θ_4 °C	Mass of water gm.	Time t sec.

Errors

1. The error in $(\theta_1 - \theta_2)$ and $(\theta_4 - \theta_3)$ is the sum of the errors in reading two temperatures. Loss of heat from the bar may affect $\theta_1, \theta_2, \theta_3$ and θ_4 more or less equally, thus will not affect their difference to any great extent.

2. Errors in measuring the mass m of the water and time t can be minimised by collecting water over as long a period as possible.

Order of Accuracy

The maximum % error in K is given by $\frac{\delta K}{K} \times 100$

$$= \left[\frac{\delta(\theta_1 - \theta_2)}{(\theta_1 - \theta_2)} + \frac{\delta(\theta_4 - \theta_3)}{(\theta_4 - \theta_3)} + \frac{\delta m}{m} + \frac{\delta t}{t} + \frac{\delta x}{x} + \frac{2\delta d}{d}\right] \times 100\ \%$$

The errors in $(\theta_1 - \theta_2)$ and $(\theta_4 - \theta_3)$ are likely to be much more significant than those in m, t, x and d because of these small size of the temperature differences.

Experiment No. 8.9

To determine the thermal conductivity of a Rubber Tubing

1. Apparatus Required

(i) Rubber Tubing R. (ii) Drilled wooden cover w. (iii) Calorimeter C (iv) Boiler

(v) Thermometer $\left(\frac{1}{10}\ ^\circ C\right)$ (vi) Travelling microscope (vii) Accurate balance & weight box.

2. Theory

Steam is passing through rubber tubing immersed in water in a calorimeter. So the heat passing per sec. through the walls of the tubing by conduction = the heat gained per sec. by the calorimeter and water at room temp.

or $$\frac{KA\,(\theta_2 - \theta_1)}{x} = (ws + m)\,\frac{a}{b} \qquad \ldots(1)$$

where k is the thermal conductivity of rubber, A is the surface area of the walls of the tubing,

x = wall thickness

θ_2 = temp. of steam.

θ_1 = room temp.

m = mass of water

w = mass of caorimeter

S = sp. heat of calorimeter.

$\frac{a}{b}$ = gradient of the curve of temp. & time at room temp.

$$\therefore \quad K\ 2\pi r.l\,\frac{(\theta_2 - \theta_1)}{x} = (ws + m)\,\frac{a}{b} \qquad \ldots(2)$$

r is the average radius of the tubing, l is the length of the tubing immersed.

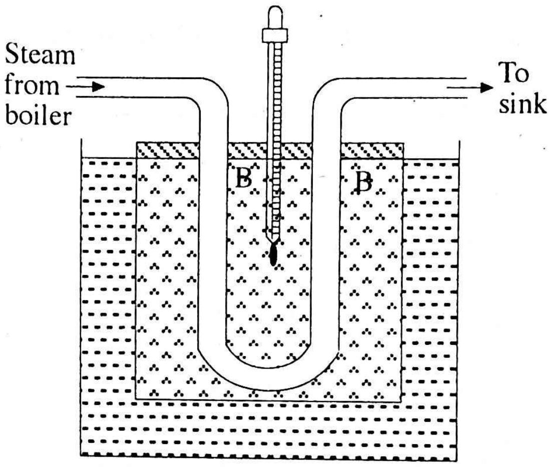


Fig. 8.11

3. Procedure

(i) The rubber tubing R is passed through the holes in the wooden cover W so as to form a U – shape inside the calorimeter C.

(ii) The calorimeter is weighed empty.

(iii) Sufficient ice is added to cool water some 10 °C after all ice has melted. The calorimeter is reweighed, not allowing the temp. to rise more than 5 °C.

(iv) Next steam from the boiler is allowed to pass through the rubber tube immersed in water in the calorimeter.

(v) The temp. of water is noted every 15 sec. stirring well, until it is about 10 °C above the room temp. The room temp. is finally noted.

(vi) The length of the rubber tubing immersed in water (between the marks BB upto water levels in R is measured.

(vii) The rubber tubing is removed. The inner and outer diameters of the tubing are measured by means of a travelling microscope.

4. Observations

Mass of calorimeter = w .... g

Sp. Heat .... = S

Mass of cal. + water = w_1

∴ Mass of water = $w_1 - w = m = g$

Room temp. θ = ... °C

Inner diameter d_1 = ... cm

Outer diameter d_2 = ... cm.

Table No. 8.4

Time in sec.									
Temp./°C									

Temperature is plotted against time. A tangent is drawn to the curve at the room temp. θ. Next the gradient $\frac{a}{b}$ of the curve at this temp. is measured.

Inner radius of tubing = r_1 = ... cm

Outer .... = r_2 = ... cm

Average radius r $= \frac{1}{2}(r_1 + r_2)$ = ... cm.

Thickness of wall of the tubing = $r_2 - r_1$ = ... cm.

Then from eq. (2) above $K \times 2\pi r l \frac{(\theta_2 - \theta_1)}{x} = (ws + m)\frac{a}{b}$.

From which K can be calculated.

Conclusion

∴ The thermal conductivity is found to be ....

Errors

May occur in the measurement of : (i) gradient $\frac{a}{b}$ of the curve at θ, (ii) weights (iii) length (iv) thickness x (v) average radius (vi) room temp θ.

The error $\delta\left(\frac{a}{b}\right)$ in the gradient may be estimated by drawing lines that are not just tangential to the curve at temp. θ and the slope is measured. The % error in the total water eg. of water plus the calorimeter should be small since the weights involved are fairly large.

Order of Accuracy

Maximum % error in K is $\frac{\delta K}{K} \times 100\% = \left[\frac{\delta\left(\frac{a}{b}\right)}{\left(\frac{a}{b}\right)} + \frac{\delta x}{x} + \frac{\delta l}{l} + \frac{dr}{r} + \frac{\delta(\theta_2 - \theta_1)}{(\theta_2 - \theta_1)}\right] \times 100\%$

Experiment No. 8.10

To determine the Relative Humidity of Air in the Laboratory.

1. Apparatus Required

(i) Daniell's Hygrometer (ii) Ether (iii) Small pipette.

2. Description

Daniell's Hygrometer has two bulbs A and B connected by a glass tube. A has a golden or silvery surface around it and B connected by a glass tube. A has a brightly polished surface around it. It contains ether. The bulb B is wrapped up with a piece of muslin cloth. There are two thermometers–one 't' inside the bulb A and the other T on the stand.

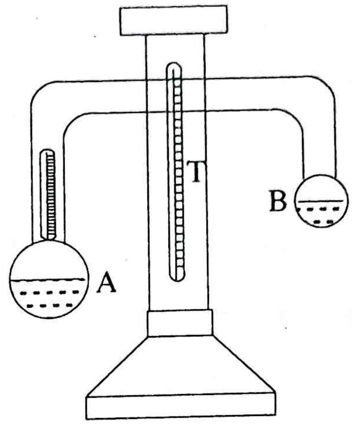


Fig. 8.12

3. Theory

The dampness of the air depends not on the quantity of water vapour present but on the nearness of that vapour to saturation. The dampness is expressed by the relative humidity.

The relative humidity of air at any time

$$= \frac{\text{mass of water vapour actually present in a given volume of air}}{\text{mass of water vapour reqd. to saturate the same vol. at the same temp}} \times 100$$

$$= \frac{\text{S.V.P. at dew point}}{\text{S.V.P. at lab temp.}} \times 100$$

4. Procedure

(i) Ether is poured drop by drop on the muslin cloth by means of pipette or a dropper. Ether evaporates and B is cooled. The temp. inside the bulb A is gradually lowered to such an extent that dew is formed outside B. Just at this instant, the temp. of the thermometer t is noted carefully.

(ii) The pouring of ether is stopped. The temp. rises. The temp. t is again noted as soon as the dew disappears.

(iii) Operations (i) and (ii) are repeated at least 5 times.

(iv) The temp. of the air outside is noted from T.

(v) The saturation vapour pressure at the dew point temperature and the temp. of the atmosphere is found out from the physical tables and the humidity is calculated.

5. Observations

Table No. 8.5

No. of obs.	Temp. at which dew		Mean dew. point	Remarks
	appears t_1	disappears t_2	$t\ °C = \frac{t_1 + t_2}{2}$	

From the physical tables:

S.V.P. at dew point (t) = f

S.V.P. at temp. T = F ......

$\therefore$ Rel. Humidity (R.H.) $= \frac{f}{F} \times 100$

Errors and Order of Accuracy

(i) These arise due to errors in reading the thermometer including zero error.

(ii) Error in locating the dew point temperature. This however will not be larger than the difference between the temperatures at which the dew forms on cooling and diappears on warning.

The variation δf and δF in the value of the S.V.P. at the dew point (t °C) and the room temp. T °C caused by error δt and δT respectively in the temperature $= \frac{\delta RH}{RH} \times 100 = \left(\frac{\delta f}{f} + \frac{\delta F}{F}\right) \times 100\%$.

Exercise

1. Define dew point.
2. What do you understand by saturated and unsaturated vapour ?
3. What is relative humidity ?
4. What is absolute humidity ?
5. What is a dew point hygrometer ?
6. Why do wet clothes dry slower in rainy season than in summer, even though the temperature be the same ?
7. What is the importance of the knowledge of hygrometry in every day life ?
8. On a particular day, the dew point was observed to be 12.5 °C, when the temperature of air was 18.7 °C. Calculate the relative humidity on the day.

Chapter 9
Optics
9.(a) Reflection at Plane Surfaces
Light

9.1 Laws of Reflection

The angle of incidence is the angle between the incident ray and the normal to the reflecting surface at the point of incidence. The angle of reflection is the angle between the reflected ray and the normal to the surface at the point of incidence. In regular reflection.

(i) The incident ray, the reflected ray and the normal to the reflecting surface at the point of incidence lie in the same plane.

(ii) The angle of incidence is equal to the angle of reflection.

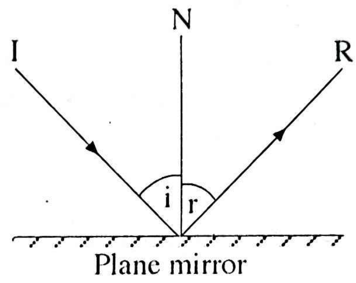


Fig. 9.1

9.2 Law of Rotation

It states that if the mirror is rotated through an angle θ, the reflected ray is rotated through 2θ. Plane mirrors form images that are erect, virtual and of the same size as the object, and are as far behind the mirror as the object is in front of it.

Experiment No. 9(a).1

To verify the Laws of Reflection of Light

1. Apparatus Required

(i) Plane mirror mounted on wooden block (ii) Protractor (iii) Scale
(iv) A sheet of paper (v) Drawing board (vi) Fixing pins (vii) Hair pins.

2. Theory

The laws of reflection state that (i) The angle of incidence is equal to the angle of reflection. (ii) The incident ray, the normal at the point of incidence and the reflected ray all lie in the same plane.

3. Procedure

(i) A sheet of paper is fixed on the drawing board with the help of 4 fixing pins.

(ii) A st. line NM' is drawn through the middle of the paper. A point O is marked in front of the line at a distance more than 10 cms. From O, line OA_1, OA_2,OA_3,OA_4,OA_5 are drawn so that they make angles of 30°, 40°, 50°, 60°, 70° respectively with the normal drawn at A_1, A_2, A_3, A_4 and A_5.

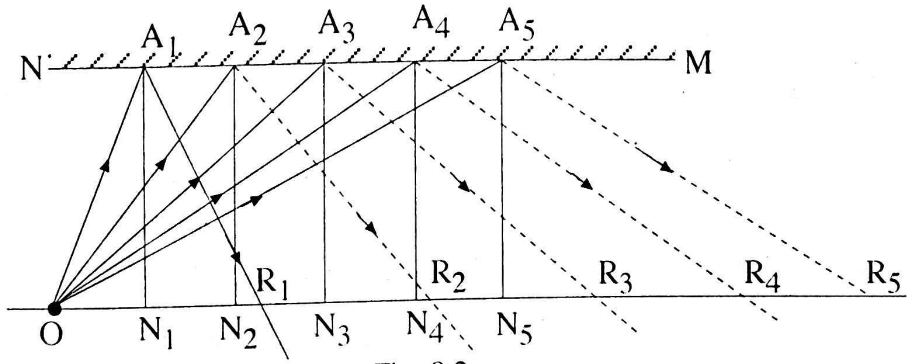


Fig. 9.2

(iii) The plane mirror is now placed vertically so that its reflecting surface may coincide with the line NM. For a thick mirror, the actual reflecting surface will be at a distance of about two–thirds of the thickness of glass from the first surface.

(iv) Two pins are fixed on OA_1 at a distance of more than 10 cms. The images of these pins are looked for along A_1R_1. Placing the eye in such a way that the reflected images of the previous two pins appear to be only one, a third p in is fixed to cover the third point. Now these two pins and the reflected images of the first two pins should appear to be in the same st. line. It should be remembered that the two pins should be at a distance not less than 10 cms. Pin pricks are marked (1,1).

(v) Operation (iv) is repeated for other incident rays OA_2, OA_3 etc. Pin pricks along reflected ray are marked (2,2), (3, 3) etc.

(vi) The pins and the mirrors are now removed. Pin pricks (1,1), (2,2) etc. are joined by drawing st. line through them. The lines are produced to meet the line NM'. Normals are drawn at A_1, A_2, A_3 etc. Through O, a st. line is drawn parallel to NM and meeting the normals and reflected rays at N_1R_1, N_2R_2 etc.

(vii) The first law is then verified by any of the two ways shown below.

4. Observations

Verification of the 1st Law.

Table No. 9(a).1

I. Using a Protractor

No. of obs.	Angle of incidence i($\angle OA_1N_1$)	Angle of reflection r($\angle N_1A_1R_1$)	Remarks	Conclusion
1				
2				
3				
4				
5				

Table No. 9(a).2

II. Without using a protractor

No. of obs.	Distance (ON_1)	Distance (N_1R_1)	Remarks	Conclusion
1				
2				
3				
4				
5				

Verification of the 2nd Law

This is a case of normal reflection. The incident ray and the reflected ray pass through pin–pricks lying on the plane of the paper. The normal drawn perpendicular to the plane of the mirror also lies on the plane of the paper. Hence the incident ray, the normal and the reflected ray all in the same plane.

Errors and Precautions

1. The mirror should be of good glass, thin properly silvered. It should be mounted vertically.
2. The back surface of the mirror (silvered surface) should coincide with the line NM.
3. The linear deviation will be more for a given angular deviation if the distance between the pins is large. Hence small angular deviations can be detected if the pins are fixed wide apart about 10 cm. or more.
4. The pin positions on the board are marked clearly by drawing small circles around the pin point with a pointed pencil.
5. The direction of the rays should be marked by arrow heads.
6. The eye should be placed about 25 cm. from the pins while making observations.

Experiment No. 9(a).2

To verify the Law of Rotation of Light

1. Apparatus Required

(i) A plane mirror mounted on wooden blocks (ii) Protractor (iii) Scale
(iv) A sheet of paper (v) Drawing board (vi) Fixing pins (vii) Hair pins

2. Theory

The law of rotation states:

"When a mirror rotates through an angle θ, the reflected ray rotates through 2θ."

3. Procedure

(i) A sheet of paper is fixed on the drawing board by four fixing pins.

(ii) A st. line MM' is drawn through the middle of the paper.

(iii) Five st. lines OM_1, OM_2, OM_3 etc. are drawn at O making angles of 10°, 20°, 30° etc. with MM'.

(iv) An incident ray IO is drawn so that ∠IOM is 40° two pins about 10 cms. apart fixed on IO.

(v) The plane mirror is placed vertically such that its reflecting surface coincides with MM'.

(vi) Looking along OR, two other pins are fixed along OR so that reflected images of the first two pins appear to be in the same st. line as the third and fourth pins. The distance between pins should always be more than 10 cm.

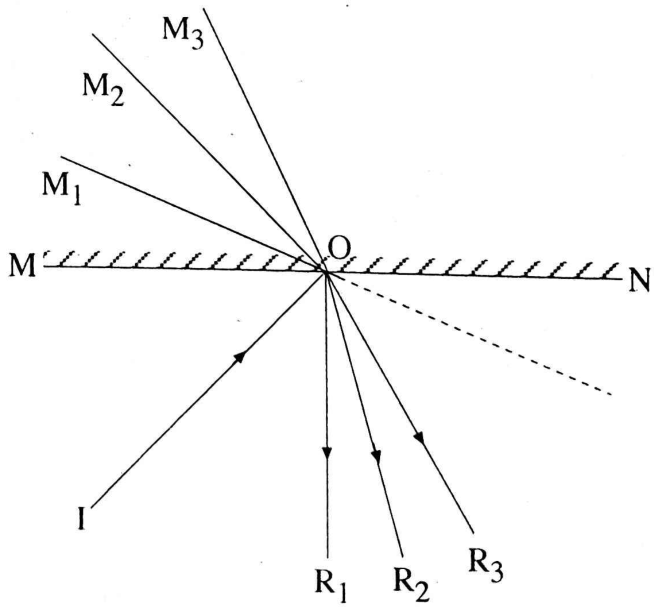


Fig. 9.3

(vii) Then the mirror is placed in positions OM_1, OM_2, OM_3 etc. are obtained.

(viii) The angles between OR and OR_1, OR and OR_2 etc. are measured and entered in a tabular form as follows.

4. Observations

Table No. 9(a).3

No. of obs.	Angle of rotation of the mirror i.e. ∠MOM_1 etc. θ	Angle of rotation of the reflected ray i.e. ∠ROR_1 etc. 2θ	Inference ROR_1
1	10°		
2	20°		
3	30°		
4	40°		
5	50°		

5. Conclusion

This it is seen that the reflected ray is rotated through 2θ when the mirror is rotated through θ.

Errors and Precautions

Same as in the previous expt.

Chapter 9
(b) Reflection at Spherical Surface

9(b).1 Spherical Mirrors

A spherical mirror is the part of a hollow sphere, the inside or outside surface of which is reflecting. The former is called a concave mirror and the latter a convex mirror.

Centre of Curvature

It is the centre of the sphere of which the mirror is a part.

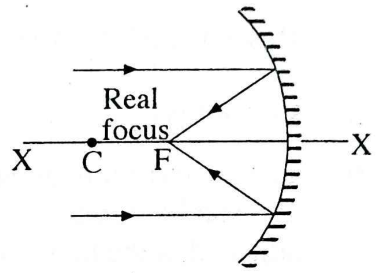


Fig. 9(b).1

Pole

It is the centre of the circular boundary of the reflecting surface.

Principal Axis

It is the line joining the center of curvature and the pole of the mirror.

Radius of curvature: It is the distance between the pole and center of curvature of the mirror.

9(b).2 Principal Focus and Focal Length

When parallel beam of light is incident on a spherical mirror, after reflection it actually passes or appear to pass through a fixed point called the principal focus F of the mirror. The distance of this point from the pole of the mirror is called its focal length. It is equal to half the radius of curvature.

Concave mirrors form real and inverted images of objects located beyond the principal focus. They form virtual, erect and enlarged image when the object is between the focus and the pole of the mirror. Convex mirrors produce only virtual, erect and diminished images if objects are if placed in front of them.

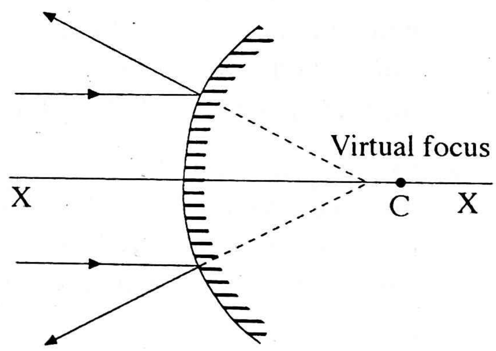


Fig. 9(b).2

Experiment No. 9(b).3

To determine the focal length of a concave mirror by

(i) *Single pin method Parallax method*

(ii) *Double pin method*

(i) Single Pin Method: By Parallax (i) Using an Optical Bench.

1. Apparatus Required

(i) Optical bench with adjustable pin and mirror holders

(ii) Concave mirror

(iii) One screen.

2. Theory

A beam of light proceeding from O, the top of the object at the centre of curvature C, in a direction parallel to the principal axis of a concave mirror will after reflection, pass through the principal focus F. Any ray starting from O and passing through F, falls on the mirror at A' and after reflection pass along AI meeting the previous reflected ray at I.

Then I is the position of the real and inverted image of O i.e. IC is the real and inverted image of OC formed at the centre of curvature itself. Then the distance PC is the radius of curvature of the mirror.

Hence focal length $f = \frac{1}{2} r$.

3. Procedure

(i) The concave mirror M and the object pin O are mounted on suitable and adjustable stands on the optical bench. The height of the pin is to be adjusted at the height of the pole of the mirror.

(ii) The rough focal length of the mirror is found out by focusing a distant object on a screen placed in front of the mirror. When the distinct image is seen on the screen, the distance between the pin and the screen which gives the rough focal length is measured.

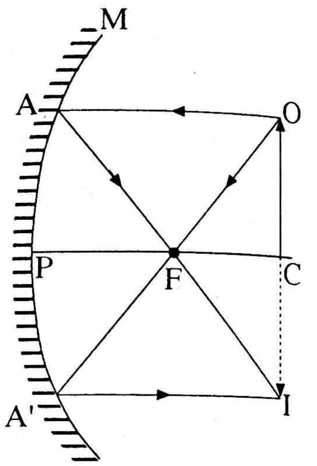


Fig. 9(b).3

(iii) The pin mounted on the adjustable stand is placed at a distance equal to twice the rough focal length. Then viewing from the front, it is seen whether the pin and its inverted image as seen through the mirror just touch each other or not. If not the height of the pin or the inclination of the mirror is adjusted as required.

(iv) In this condition, the eye of the observer is moved sideways. If there is parallax, the object and the inverted image will have relative displacement. In case the inverted image moves ahead of the object point, the pin is moved away from the mirror i.e. the distance is increased. If the erect pin moves ahead, the distance of the pin is decreased. This adjustment is done till parallax is completely eliminated.

(v) The positions of the mirror and the object pin are noted from the optical bench. The difference between these two readings gives the observed radius of curvature.

(vi) The above operations are repeated 5 times.

(vii) Index rod correction is then applied. To do this the length of the rod is measured. It is held by allowing one end touching the pole of the mirror, the other end touching the tip of the object pin. Let this distance (length of the rod) be x. In this condition, the positions of the pin stand and the mirror stand are read from the optical bench. Let it be y. If x = y, no error, there is no need of any correction. If x > y, x - y = correction to be added to the observed distance, if x < y, x - y = correction to be subtracted from the observed distance.

4. Observation

Length of the index rod = x =......cm.

Observed distance =y =......cm.

Index correction =x ~ y = ...cm.

Table No. 9(b).4

No. of obs.	Position of the		Observed Distance cm.	Mean obs. Distance cm.	Index rod correction cm.	True Distance r cm.	$f = \frac{1}{2}$ r cm.
	Concave mirror cm.	Object pin cm					
1							
2							
3							
4							
5							

Hence the focal length = ...cm.

Error and Order of Accuracy

Errors

(i) May arise due to difficulty in setting the zero of the rule at the pole of the mirror.

(ii) In reading the position on the pin.

(iii) In setting the no- parallax position, which may be estimated from the variations in the result obtained.

The total error in r is the sum of these errors. Hence the error in f and the order of accuracy are found out.

(i) Single Pin Method: By Parallax

(ii) Without using an Optical Bench

1. Theory

Same as given above.

2. Procedure

(i) The height of the pin is adjusted at about that of the pole of the mirror. The rough focal length of the mirror is determined by focussing a distant object on a screen held in front of the mirror.

(ii) The pin is then held in front of the mirror at distance equal to twice its rough focal length. It is seen whether the pin and the tip of its inverted image just touch each other or not. If not, the height is again properly adjusted. Then moving the eye right or left, parallax is completely removed as explained in the above expt. The distance between the

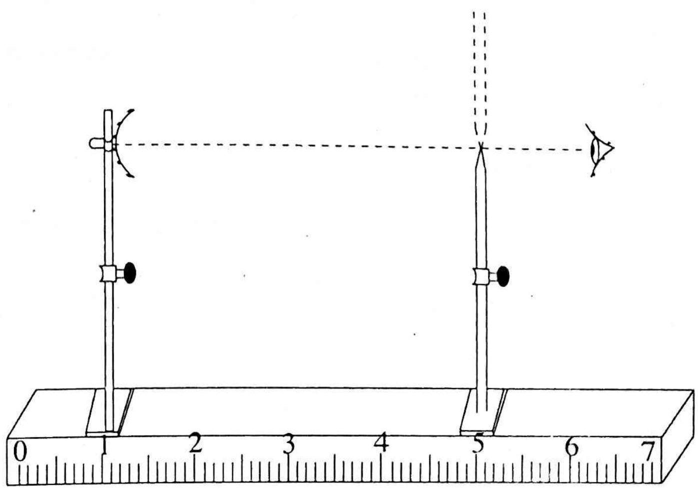


Fig. 9(b).4

pole of the mirror and tip of the pin is directly measured by means of a metre scale. To make the measurement convenient, a pin is attached at one end of the scale, with one cm. of the pin projecting outwards. This makes it possible to place the scale at the pole of the mirror.

(iii) The observations are repeated 5 times and the mean of which gives the radius of curvature of the mirror, half of which is its focal length.

3. Observation

Table No. 9(b).5

No. of obs.	Dist. between the pole of the mirror and the pin head = r cm.	mean r cm.	$f = \frac{1}{2}$ r cm.
1			
2			
3			
4			
5			

$\therefore$ f = ...cm.

(ii) Double Pin Method: u - v Method using an optical bench.

1. Apparatus Required

Optical bench with adjustable stands for object and image pins. (2) Concave mirror also on an adjustable stand.

2. Theory

In a concave spherical mirror, we have

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

where u denotes the object distance i.e. distance between the object and the pole of the mirror.

v denotes the image distance i.e. the distance between the image pin and the hole of the mirror, f is the focal length of the mirror.

3. Procedure

(i) The rough focal length of the mirror is found by focussing a distant object on a screen placed in front of the mirror. When well defined distinct image is formed on the screen, the distance between the pin and the screen which gives the rough focal length is measured.

(ii) The object pin and the image pin are marked red and black respectively. They are mounted on adjustable stands at the same heights as the pole of the mirror.

(iii) First the object pin is placed at a distance equal to twice the focal length of the mirror. The inverted image is made to just touch the tip of the object pin. Then parallax is removed as described in operation (4) in the single pin method. The position of the object pin, and the mirror are read from the optical bench.

(iv) The object pin is then placed nearer the mirror by about 2 or 3 cms. The image of this pin is received by the other pin placed beyond $2f$ and parallax is eliminated as in the previous operation. This observation is repeated at 4 object distances within f and $2f$ and adjusting the image pin, each time noting the position o the object pin, image pin and the mirror.

(v) After this, the object pin is placed beyond $2f$, its image being received by a pin placed within $2f$, the parallax being eliminated as before. This operation is also repeated at 4 distances of the object beyond $2f$.

(vi) Index correction is applied with the help of an index rod of known length. If the actual length of the index rod say x is equal to the observed distance y between the object and the pole as read from the optical bench, there is no error and hence no correction. If however x > y, x - y = correction is to be added to the observed distance.

4. Observation

Length of the index rod = x =......cm.

observed dist. between object and the pole = y =......cm

∴ Correction for U = x ~ y = ...cm

Similarly, observed distance between image

pin and the pole = y = ...cm.

∴ Correction for V = x ~ y = ...cm.

Rrough Focal length of the mirror.

Table No. 9(b).6

No. of obs.	obs	Position of mirror a	Position of object pin b	Position of Image pin c	Apparent u	Apparent v	Corrected u	Corrected v	$\frac{1}{u}$	$\frac{1}{v}$	$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$	f	Mean f	$m=\frac{v}{u}$
1	at	cm	cm	cm										
2	$2f$													
3														
4														
5														
6														
7														
8														
9														

Note: The following graphs are drawn and the focal length is determined from each of them:

(i) u and v (ii) $\frac{1}{u}$ and $\frac{1}{v}$

(iii) u and m (magnification) (iv) v and m(magnification)

Conclusion from Graphs

(ii) Double Pin Method: u - v Method without using an optical bench.

1. Apparatus

(i) Concave mirror, object and image pins on adjustable stands.

(ii) One meter scale with a pin attached at one end, one cm. of it being projected outwards.

2. Theory

Same as above.

3. Procedure

(i) Same as in the single pin method. This time the expt. is performed in the free table. The object and the image distance are measured by a scale.

(ii) Observations are taken in this way: One at $2f$, 4 or 5 of the previous expt. (ii) are repeated in this case also. Observations are tabulated as shown below and results calculated.

4. Observations

Rough focal length of the mirror = ...cms.

Table No. 9(b).7

No. of obs.	obs at	Obj. Dist. u cms.	Image v cms.	$\frac{1}{u}$	$\frac{1}{v}$	$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$	f cm.	Mean cm.	$m=\frac{v}{u}$
1	$2f$								
2	beyond								
3	within $2f$								
4									
5									
6									
7									
8									
9									

N.B: The following graphs are drawn and the focal length is determined from each of them:

(i) u and v

(ii) $\frac{1}{u}$ and $\frac{1}{v}$

(iii) u and m

(iv) v and m

Conclusion from graphs

Experiment No. 9(b).4

To determine the focal length of a convex mirror by

(i) Convex lens method *(ii) Plane mirror method*

(i) Convex Lens Method

1. Apparatus Required

(i) Optical bench

(ii) Object pin and image pin in adjustable pin holders

(iii) Convex mirror

(iv) Convex lens.

2. Theory

Let O be an object in front of a convex lens L and I be the position of its real and inverted image, determined by Parallax method.

Let the convex mirror M be placed at some distance from L and viewed from the front side. The position of M is adjusted till the inverted image of the pin is concident with the object itself. This will happen only when the ray of light will retrace the path, with the object itself. This will happen only when the ray of light will retrace the path, which is possible only if the rays have fallen on the convex mirror normally. If that be so, the extension of these rays behind the mirror M must meet at its centre of curvature.

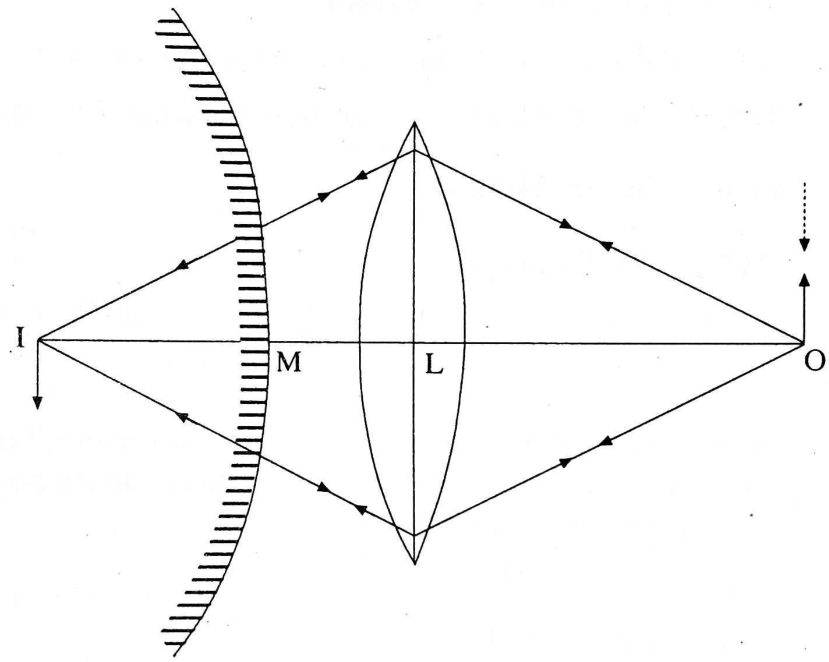


Fig. 9(b).5

Hence I should be the centre of curvature of the mirror M. Then the radius of curvature is

$$r = MI = LI - LM.$$

$$\therefore \quad f = \frac{1}{2} r$$

3. Procedure

(i) An object pin O is held in front of a convex lens beyond its focal length. Its real and inverted image is obtained without parallax at I. The positions of the lens L and image I are noted.

(ii) Then the convex mirror M is interposed between L and I and adjusted so that when viewed from the front side the inverted image coincides with the object itself. The position of the mirror M is then noted.

(iii) Operations (i) and (ii) are repeated at least 5 times by slightly changing the distance of the object and also the mirror and hence adjusting as in (ii), the observations are tabulated as shown below:

Table No. 9(b).8

No. of obs.	Position of				Distance		Radius $r = LI - LM$	Mean r cm	$f = \frac{1}{2} r$
	Object O	Lens L	Mirror M	Image I	LI	LM			
1									
2									
3									
4									
5									

Error and Order of Accuracy

Errors may occur in M and I for sharpest forms and hence in measuring LI and LM.

From the different values of r, the greatest difference is obtained from the average value.

(ii) Plane Mirror Method

1. Apparatus Required

(i) Convex Mirror (ii) Plane Mirror (iii) Pin holder

2. Theory

A plane mirror strip is held between the convex mirror P and the object pin. The pin O is adjusted so that the reflected images seen through the convex and the plane mirror lie along the same line without parallax. Then for the convex mirror.

Object distance u = PO

Image distance v = - PI

= - (MI - PM)

= - (MO - PM)

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

3. Procedure

(i) The plane mirror strip is held in front of the convex mirror such that the top of the plane mirror lies on the principal axis of the convex mirror. It is placed say about 4 or 5 cm infront the convex mirror. They are placed along a meter scale.

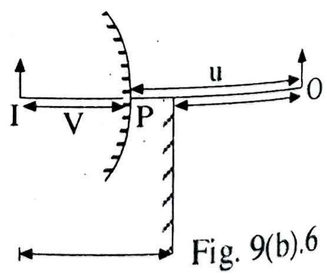


Fig. 9(b).6

(ii) An object pin is held in front of both the mirrors. Its position is adjusted so that there is no parallax between the two images of the object seen through the two mirrors. The positions of the object pin, the plane mirror and the convex mirror are noted.

(iii) The above operations are repeated five times by changing the distance between the two mirrors by 1 cm each time. Observations are entered and results calculated as shown below:

4. Observations

Table No. 9(b).9

No. of obs.	Position of			PM cm.	MO cm.	MO - PM = V cm.	Po = u cm.	$\frac{1}{u}$	$\frac{1}{v}$	$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$	f	Mean f
	Convex mirror P cm.	Plane mirror M cm.	Object pin O c.									
1												
2												
3												
4												
5												

Conclusion

Thus the focal length of the convex mirror is ...cm.

Error and Order of Accuracy

Errors may occur in measuring MO and MI. The uncertainty in the image distance can be obtained by finding the distance. M can be moved before the images just show parallax. From the different values of f, the greatest difference from the average value is noted.

Light
Reflection at Plane and Spherical Surfaces

Exercises

1. What is Reflection ?
2. What do you mean by Regular and Diffused Reflection ?
3. State the laws of Reflection light.
4. Use a diagram to define and angle of incidence and angle of reflection.
5. What is the difference between an image and a shadow ?
7. How can a real image be distinguished form a virtual image ? Can each type be projected on a screen, Why ?
8. What is the relation between the objected distance and the image distance in a plane mirror.
9. What is lateral Inversion ?

10. State the Law of Rotation of light.

11. What do you mean by the deviation of a ray of light in a plane mirror ?

12. Define principal focus, pole, center of curvature, radius of curvature, focal length of a spherical mirror.

13. What type of image do you see in this experiment on a concave mirror ? Is it real or virtual ?

14. Does a concave mirror form a real image ? If not, when does it form a virtual image ?

15. State some of the uses of (i) a concave mirror (ii) a convex mirror.

16. Does a convex mirror form an inverted image ? Illustrate by ray diagrams.

17. What type of graph do you expect between

    (i) U and V
    (ii) U and m } of a concave mirror
    (iii) V and m

18. Sketch and calculate the image formed by an object placed 2 cm. in front of (i) concave mirror (ii) a convex mirror of focal length 15 cm. What is the magnification in this case ?

19. An observer walks towards a plane mirror in a speed of 3 m/s. With what speed does he approach his image ?

20. In what position in front of a spherical concave mirror should an object be placed to produce a real image magnified 3 times if its radius of curvature is 18 cm.

21. Show in a diagram the image formed by placing an object 30 cm in front of a convex mirror of focal length 10 cm. Calculate its magnification.

Chapter 10
Refraction at Plane Surfaces

Refraction

When a beam of light travels from one medium (say air) to another medium (say water) the beam of light is bent towards the normal. This bending of light is known as refraction. If it passes from the denser medium (water) to the rarer medium (air), it is bent away from the normal. The refraction of light takes place according to the following two laws:

1. For a ray passing from a rarer to a denser medium, the sine of the angle of incidence (I) bears to the sine of the angle of refraction a constant ratio (η), whose value depends on the nature of the two media and the colour of light. This law is known as Snell's law. The constant is called the refractive index of the medium. Thus,

$$\eta = \frac{\sin i}{\sin r} = \frac{\text{speed of light in air}}{\text{speed of light in medium}}$$

2. The incident ray, the refracted ray and the normal to the surface at the point of incidence are in the same plane.

Speed of light in air = 3×10^8 m/s

Refractive Index and Lateral Shift.

QXYZ is the outline of a glass slab. Let a ray IA be incident at A. MN is the normal at A. Then the ray will undergo refraction and is bent towards the normal and will proceed along AR. At R, the ray will bend away from the normal and will proceed along RE. IP is the incident ray produced.

Thus IA is the incident ray.

AR .... refracted ray.

RE .... emergent ray

∠IAN is the angle of incidence (i)

∠MAR .... refraction (r)

∠N'RE is the angle of emergence.

∠RAP .... deviation (i – r)

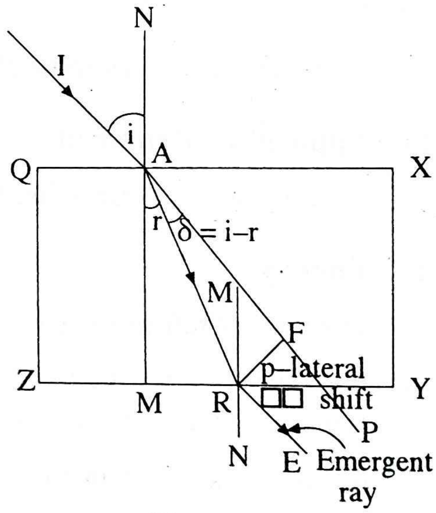


Fig. 10.1

RF is the perpendicular distance between the incident ray and the emergent ray. It is called the lateral shift or lateral displacement and denoted by p.

$$\eta = \frac{\sin i}{\sin r}$$

The lateral shift (p) is related to the angle of incidence according to the relation.

$$p = \frac{t \sin (i - r)}{\cos r}$$

Critical Angle

When light passes from denser medium to rarer medium in which its speed is greater, i.e. from water to air, the ray bends away from the normal.

Thus the angle between the ray and the normal in air is always greater than that in water. The angle in water for which the angle in air is 90° is the critical angle for water. When the ray in water makes an angle which exceeds the critical angle light is totally reflected at the surface of separation, back in to water.

$$\eta = \frac{\sin i}{\sin r} = \frac{\sin 90°}{\sin C} = \frac{1}{\sin i_c}$$

$$\therefore \quad \sin C = \frac{1}{\eta}$$

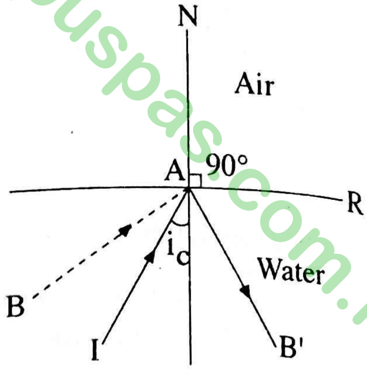


Fig. 10.2

Refraction Through a Prism

The refractive index η of the material of a prism can be determined from the relation.

$$\eta = \frac{\sin \frac{Dm + A}{2}}{\sin \frac{A}{2}}$$

where A = refracting angle of the prism.

D_m the angle of minimum deviation.

Experiment No. 10.1

To verify the laws of refraction and Determine the Refractive index of a glass slab.

1. Apparatus Required

(i) Glass slab (ii) Drawing Board (iii) Paper (iv) Fixing pins, Hair pins (v) Instrument box.

2. Theory

The laws of refraction are:

(i) For a ray proceeding from the rarer to a denser medium, the sine of the angle of incidence bears to the sine of the angle of refraction a constant ratio η given by $\eta = \frac{\sin i}{\text{sing } r}$. This is known as Snell's law.

(ii) The incident ray, the refracted ray and the normal to the surface at the point of incidence are in the same plane.

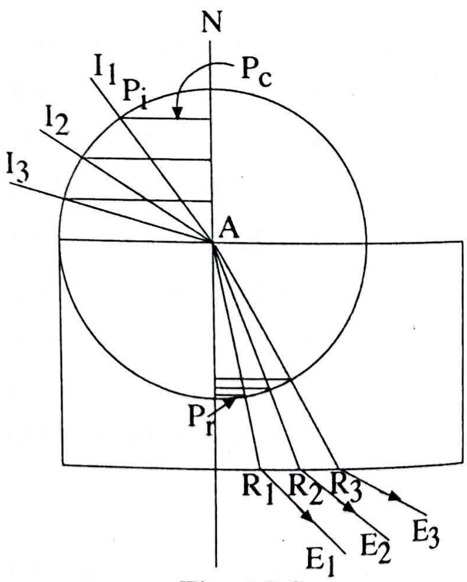


Fig. 10.3

Construction

With a as the centre, a circle is drawn such that its lower portion cuts the refracted rays within the outline of the glass slab. From the points of intersection of the circle and the incident and the refracted rays, perpendiculars Pi and Pr etc. are drawn on thermal MN.

$$\eta = \frac{\text{Sin } i}{\text{Sin } r} = \frac{\frac{P_1}{\text{hypotenuse}}}{\frac{P_r}{\text{hypotenuse}}} = \frac{P_i}{P_r}$$

3. Procedure

(i) A sheet of paper is fixed on the drawing board. The glass slab is placed at about the middle of the paper. Its outline, a normal NAM is drawn. Incident rays, like I_1A, I_2A etc. are drawn so that angles of incidence are 10°, 20°, 30° etc.

(ii) Two pins are fixed at least 10 cms. apart on the first incident ray I_1A. The glass slab is placed on the outline. Looking from the opposite side through the slab, two other pins are fixed 10 cms apart so that these tow points and the refracted images of the first two pons lie in the same straight line.

(iii) Operation (ii) is repeated for all the seven incident rays.

(iv) The glass slab is removed. The corresponding pin pricks e.g. R_1E_1, R_2E_2, R_3E_3 etc. are joined. AR_1, AR_2, AR_3 etc. are also joined.

(v) Then the circle is drawn as explained under the construction above.

(vi) Angles of refraction are measured with a protractor.

(vii) Perpendiculars Pi, Pr are drawn for the corresponding rays.

(viii) Observations are entered and results calculated as shown below.

4. Observations and Results

Table No. 10.1: (a) With a protractor

No. of obs	Angle of incidence $\angle i = \angle IAN$	Angle of refraction $\angle r = \angle MAR$	Deviation $\delta = i - r$	sin i	sin r	$\eta = \frac{\sin i}{\sin r}$	Mean η
1	10°						
2	20°						
3	30°						
4	40°						
5	50°						
6	60°						
7	70°						

Table No. 10.2: (b) Without a Protractor

No. of obs	Perpendicular P_i cm	Perpendicular in glass P_r cm	$\eta = \frac{P_i}{P_r}$	Mean η
1	10°			
2	20°			
3	30°			
4	40°			
5	50°			
6	60°			
7	70°			

A graph of angle of incidence I and deviation δ is drawn.

5. Conclusion

The constant value of η as obtained above verifies the first law.

Since the incident ray and refracted ray lie in the plane of the paper along with the normal MN, they are all coplanar. This verifies the second law.

Refractive index of glass with respect to air η = ...

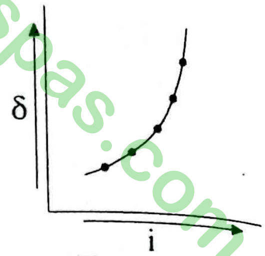


Fig. 10.4

6. Discussion

(i) Pin pricks must be at least 10 cms apart.

(ii) Angle of incidence should be large so as to make Pi and Pr large, which therefore minimises the error.

(iii) The pins must be observed from a distance of about 25 cm.

Experiment No. 10.2

To study the variation of the lateral shift of the given glass slab with the angle of incidence and hence find the thickness of the slab.

1. Apparatus Required

Same as the previous expt.

2. Theory

The lateral shift or displacement is related to the angle of incidence and the thickness of the glass slab by the relation.

$$P = \frac{t \sin (i - r)}{\cos r}$$

where P is the lateral shift i.e., the perp. distance between the emergent ray and the incident ray produced.

t is the thickness of the slab.

i and r the angles of incidence and refraction respectively.

$$P = \frac{t \sin (90° - r)}{\cos r} = \frac{t \cos r}{\cos r} = t$$

Thus the lateral shift corresponding to the 90°, angle of incidence is equal to the thickness of the given glass of the given glass slab.

3. Procedure

(1) Operation (1) to (5) of the previous expt. are performed. (7) Between the incident ray produced and the corresponding emergent ray, perpendiculars (lateral shift) are drawn at three different points and measured. This is done for each corresponding pair. Observations are entered as shown below. (8) A graph of lateral shift ρ is drawn against the angle of incidence. The value of ρ corresponding to t = 90° is extrapolated which gives the thickness of the slab.

4. Observations

Table No. 10.3

No. of obs.	Angles of Incidence	Lateral Shift P cms
1	10°	{ ....
		{ ....
		{ ....
2	20°	{ ....
		{ ....
		{ ....
3	30°	{ ....
		{ ....
		{ ....
4	40°	{ ....
5	50°	{ ....
		{ ....

∴ For i = 90°, Lateral Shift = ...

∴ Thickness of the slab = ...

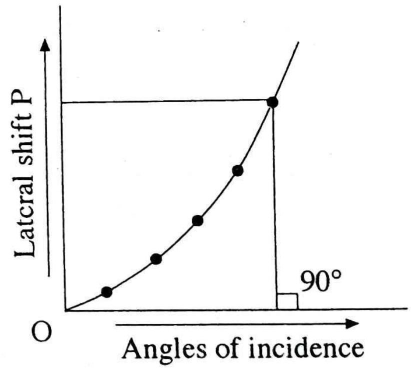


Fig. 10.5

Precautions

Same as in the previous expt.

Experiment No. 10.3

To determine the Refractive index of the glass slab and the given liquid using Travelling microscope.

1. Apparatus Required

(i) Travelling Microscope (ii) Glass slab (iii) Beaker

(iv) Given liquid (water) (v) Lycopodium power

2. Description of the Apparatus

Refer to any Text Book.

3. Theory

The refractive index

$$\eta = \frac{\text{Real depth}}{\text{Apparent depth}}$$

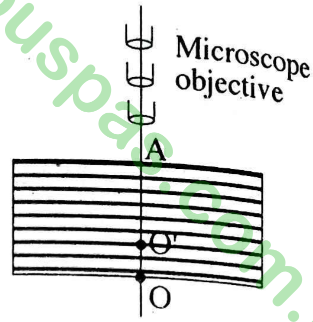


Fig. 10.6

If O be the real position, O' the apparent position of a mark at the bottom, A the position of Lycopodium powder on the upper surface of a slab, as focused by the microscope, then

$$\eta = \frac{\text{Real Depth}}{\text{App. Depth}} = \frac{3^{rd}\text{ reading} - 1^{st}\text{ reading}}{3^{rd}\text{ reading} - 2^{nd}\text{ reading}}$$

4. Procedure

(i) Value of the smallest division of the vertical scale of the microscope is noted. The vernier constant is determined.

(ii) A small piece of paper is pasted on the stage of the microscope just below its objective. A cross mark is drawn on it.

(iii) After properly levelling the base of the microscope, the microscope tube is adjusted vertical and the eye–piece is focused so as to see the cross wires distinctly. Raising or lowering the microscope as required it is focused on the cross mark avoiding parallax. The main scale and vernier readings are noted. It is slightly disturbed by defocusing on the mark. Three such readings are taken. The mean of these gives the 1^{st} reading, x_1.

(iv) The glass slab is then placed above the mark. The microscope is slightly raised and again focused on the cross mark. Three readins ae taken as before. The mean of these gives the 2^{nd} reading, x_2.

(v) A small quantity of line Lycopodium powder is taken and sprinkled on the upper surface of the glass slab. The microscope is raised and focused on the Lycopodium powder. Three reading ae taken as before. The mean of these gives the 3^{rd} reading, x_3.

(vi) In the case of the liquid, the cross mark is covered by a beaker instead of by a slab. For the 2^{nd} reading, some liquid is poured into the beaker to a certain depth, and operation (iv) is repeated. For the third reading Lycopodium powder is sprinkled on the surface of the liquid and operation (v) is repeated. This is repeated for 3 different depths of the liquid.

(vii) Observations are noted in a tabular form as shown below.

5. Observations

20 divs. of the main scale = ... cm

∴ 1 div. of the main scale = ... cm

50 vernier divs. coincide with x div. of the main scale.

∴ 1 vernier div. coincide with $\frac{x}{50}$ div. of the main scale

∴ V.C. = $\left(1 - \frac{x}{50}\right)$ × value of 1 smallest div. of the main scale = ...

Table No. 10.4

No. of obs.	Reading on the									$\eta = \frac{R.D.}{A.D.} = \frac{X_3 - X_1}{X_3 - X_2}$	Mean η
	bottom O without slab or liquid			apparent position O1 with slab or liq.			Upper surface A				
	M.S.	V.S.	Total x_1 cm	M.S.	V.S.	Total x_2 cm	M.S.	V.S.	Total x_3 cm		
Solid											
1											
2											
3											
Liquid											
1											
2											
3											

Conclusion

Thus the refractive index of the glass block = ...

and that of liquid (water) = ...

Error and Order of Accuracy

The errors in focusing the microscope may be investigated by observing the distance travelled by the microscope when moved from a position just out of focus too close to the object, to one just too far from it.

If δx be the error in a reading, then, maximum % error.

$$\frac{\delta\eta}{\eta} X = \left[\frac{\delta(x_3 - x_1)}{x_3 - x_1} + \frac{\delta(x_3 - x_2)}{x_3 - x_2}\right] \times 100$$

$$= \left(\frac{2\partial x}{t} + \frac{2\partial x}{a}\right) \times 100$$

Experiment No. 10.4

To determine the Refractive Index of Liquid by the Method of Total Internal Reflection

1. **Apparatus Required**

(i) An air cell

(ii) A cubical glass vessel

(iii) Arrangement to mount the cell, with graduated circular scale having a pointer.

2. Description of the Apparatus

An air cell is prepared by enclosing a very thin film of air between two thin parallel glass plates G and G', which are kept separated along the edges slightly by a small piece of paper, and scaled all around a vertical axis. The angle of rotation can be measured in a circular scale at the top of the rod by means of a pointer attached t the axis of rotation of the cell. Two slits are cut on the opposite side walls of the box. A source of light placed before one of the slits is visible to an eye placed behind the other slit.

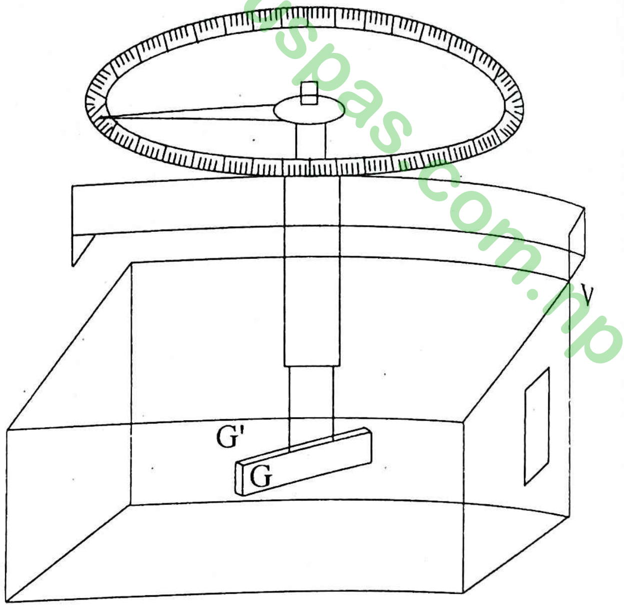


Fig. 10.7

Theory

The refractive index η of a liquid may be determined by measuring its critical angle C, using the relation

$$\eta = \frac{1}{\sin C}.$$

4. Procedure

(i) The cell is immersed in the experimental liquid contained in a cubical glass vessel V. Light from an electric bulb B rendered parallel by a convex lens is allowed to pass through the slit and fall on the air cell placed normal to the beam. The image of the slit can be seen through the opposite slit.

(ii) The air is gradually turned to one side. The image will be gradually fainter until it just disappears when the angle of incidence from liquid t air is equal t the critical angle for the liquid. A slight rotation from this position will cause total internal reflection when the image just disappears. the pointer reading is noted.

(iii) The cell is now rotated in the opposite direction until the imâge just disappears again. The angle between the two positions of the cell gives twice the critical angle C for the liquid and air. The observation are entered as shown below:

(iv) Operations (ii) and (iii) are repeated at least five times.

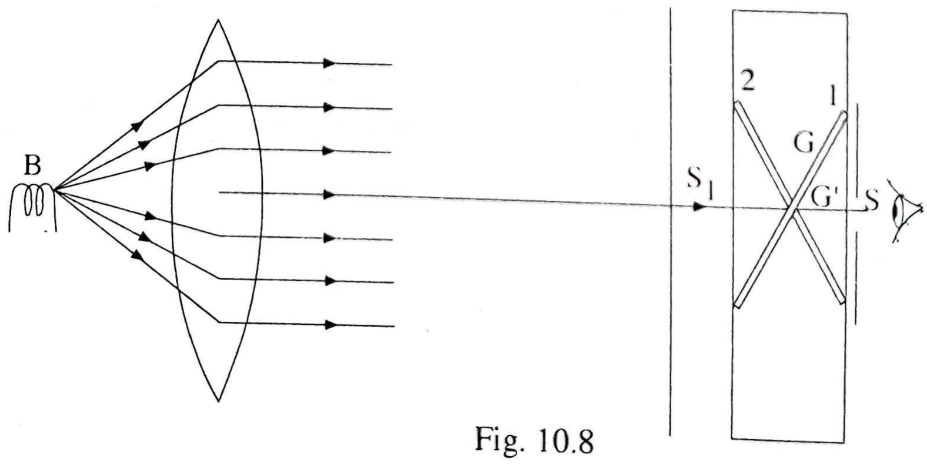


Fig. 10.8

5. Observations

Table No. 10.5

No. of obs.	Position of pointer for Disappearance of the image		Diff. = $R_1 - R_2 = 2C$	C	Mean C	$\frac{1}{\sin C}$
	Clockwise rotation R_1	Anticlockwise rotation R_2				
1						
2						
3						
4						
5						

Errors and Order of Accuracy

The errors in setting and noting the angle may be investigated by (a) repeating each setting of the air cell several times (b) measuring how far the cell has to be rotated near the cut off point to change from maximum to minimum brightness.

The error in the critical angle is equal to the error in reading R. The error in η is equal to the change in $\eta = \frac{1}{\sin C}$ produced by a change equal to the error in C which may be found by inspection of sine and reciprocal tables.

For example if the estimated error in C = 0.5° with C = 42°.

$$\frac{1}{\sin 42} = 1.495$$

$$\frac{1}{\sin 42.5} = 1.480$$

Difference = 0.015

$\therefore$ error in η = 0.015 = 0.02 approx.

$\therefore$ $\eta = 1.480 \pm 0.02$

Experiment No. 10.5

To Determine the Refractive Index of a small quantity of a liquid using a convex lens and a plane mirror.

1. Apparatus Required

(i) Convex lens (ii) Plane mirror MM' (iii) Clamp and Stand (iv) Liquid (v) S pherometer.

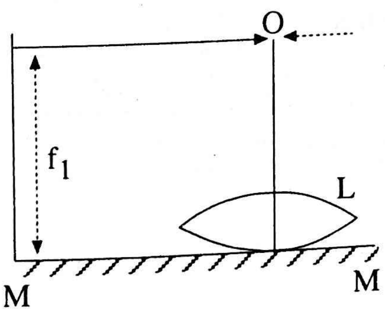


Fig. 10.9

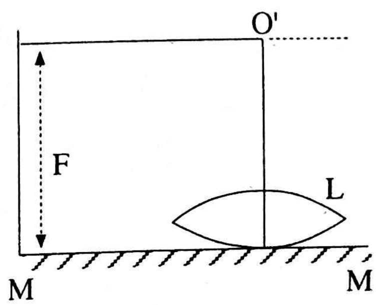


Fig. 10.10

2. Theory

If the space (curved) between the convex lens and the plane mirror (on which it is placed) be filled with the experimental liquid, the combination forms a combined lens of focal length F given by,

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

$$\frac{1}{f_2} = (\eta - 1)\frac{1}{R}$$

where f_1 is the focal length of the convex lens and f_2 that of the liquid lens which is planoconcave.

$$\frac{1}{f_2} = \frac{1}{F} - \frac{1}{f_1} \quad \ldots(2)$$

The radius of curvature of the upper surface of the liquid lens is

$$R = \frac{a^2}{6h} + \frac{h}{2} \quad \ldots(3)$$

where h is the screw displacement, a = distance between legs of the spherometers. Next

$$\frac{1}{f_2} = (\eta - 1)\frac{1}{R}$$

(since the lower surface of the liquid lens in plane). From the above η of the liquid can be determined.

3. Procedure

(i) The convex lens is placed on the horizontal surface of the plane mirror.

(ii) The pin O is clamped horizontally so that its tip is vertically above the center of the lens L.

(iii) Placing the eye at least 25 cm. above the pin, it is adjusted until at O, it has no parallax with its own inverted image. This is repeated thrice and the distance f_1 from O to L is measured each time. This gives the focal length f_1 of the convex lens.

(iv) The plane mirror is next moistened with a little experimental liquid so as to fill the space between L and M. The pin is adjusted for the new position O' of no parallax. This is repeated thrice and the distance F from O' to M is measured in each case. This gives the focal length of the combination lens.

(v) The radius of curvature of the lower face of the lens is measured with a sphereometer.

4. Observations

Table No. 10.6

No. of obs.	Focal length		Mean		f_2 cm.
	f_1 of convex lens cm.	f of the combination lens	f_1 cm.	F cm.	

Radius of curvature of the lower face:

Depth h of the lower face = ...cm.

Distance between legs of spherometer a =......cm.

$\therefore \quad R = \frac{a^2}{6h} + \frac{h}{2}$ = ...cm.

Next $\frac{1}{f_2} = (\eta - 1)\frac{1}{R}$

$\therefore \quad \eta = 1 + \frac{R}{f_2}$ =......

Conclusion

Thus the refractive index of the liquid is found to be......

Error

(1) Due to error in eliminating parallax.

(2) Error in measuring f_1 and F.

(3) Error in measuring R.

Order of Accuracy

The maximum % error $\eta - 1$ is given by

$$\frac{\delta(\eta - 1)}{(\eta - 1)} \times 100\% = \left[\frac{\delta r}{r} + \frac{\delta f_1}{f_1} + \frac{\delta F}{F} + \frac{\delta f_1 + \delta F}{F - f_1}\right] \times 100$$

The error $\delta(\eta - 1)$ is found out which is equal to the error $\delta\eta$ is η.

Experiment No. 10.7

To determine optically the angle of the given prism and the angle of minimum deviation by Symmetry method. Hence calculate its refractive index.

1. Apparatus Required

(i) Glass prism (ii) Drawing board

(iii) Sheet of paper (iv) Fixing pins, protractor, scale etc.

2. Theory

(1) If two rays I_1P_1 and I_2P_2 be incident on the two adjacent faces of a prism, P_1R_1 and P_2R_2 be their corresponding reflected rays, it may be shown that the angle between the reflected rays produced backwards is twice the angle of the prism

i.e. $$\angle R_1 OR_2 = 2A$$

$\therefore$ $$A = \frac{1}{2} \angle R_1 OR_2$$

(2) If the outline of the prism be cut symmetrically at Q_1, Q'_1 and Q_2 Q'_2, Q_3 and Q'_3 any ray is incident at Q_1 and emerge from Q^1, the incident ray and the emergent rays when produced inwards will meet at a point where the angle between the rays gives δm, the angle of minimum deviation.

$$\eta = \frac{\sin\frac{\delta m + A}{2}}{\sin\frac{A}{2}}$$

3. Procedure

(i) The outline of the prism is drawn at two different position on a sheet of paper. Two parallel lines are drawn on one of each of the faces AB and AC as in fig. 10.11.

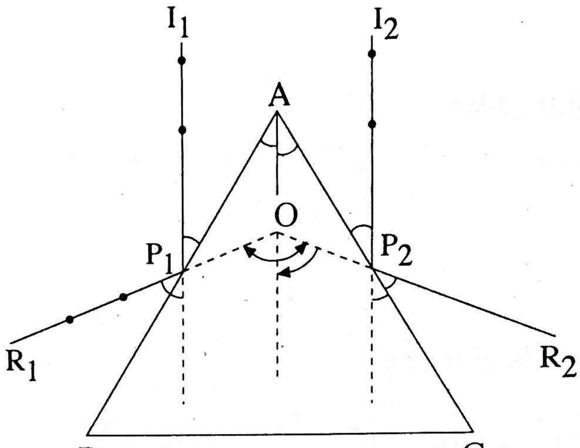


Fig. 10.11

(ii) Placing the prism is its outline, two pins are fixed at least 10 cms. apart on the line I_1P_1 fig 10.11. The reflected images of these pins are viewed from the same face aB of the reflected images of the previous two pins appear to be in the same st. line. These pin-pricks are joined and produced inwards. This operation is repeated for the other ray along I_1P_2 on the other face AC. The angle between the two reflected rays is measured, which gives an angle equal to twice the angle of the prism. This repeated for the other outline also.

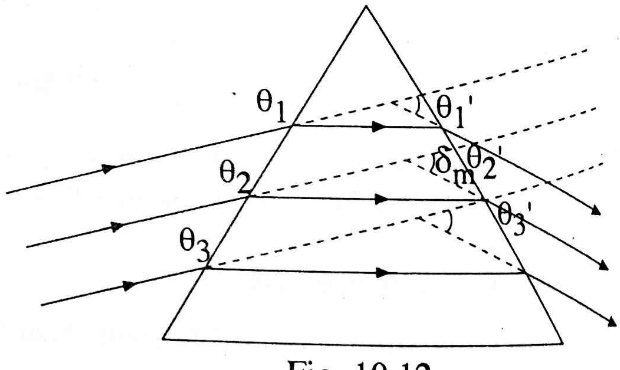


Fig. 10.12

(iii) Another sheet of paper is fixed on the drawing board. The outline of the prism is drawn. The outline is cut symmetry at positions Q_1, Q_2 and Q_3 and Q'_1, Q'_2, Q'_3 as shown in fig. 10.12 by means of a compass.

(iv) Two points are fixed at Q_1. The prism is placed on its outline. Looking from the face AC of the prism, the third pin is fixed about 10 cm, from Q'_1 such that it lies in the same st. line with the pin at Q'_1 and the refracted image of the pin at Q_1.

(v) Next looking from the face AB of the prism, the fourth pin is fixed about 10 cms. from Q_1 such that it lies in the same line with the pin at Q_1 and the refracted images of two other pins.

(vi) Pin pricks are joined. Two lines are produced to meet at a point. The actual angle between them is measured. This is the angle of minimum deviation.

(vii) Operations (4), (5) and (6) are repeated for positions Q_2 A'_2, Q_3 A'_3.

4. Observations

Table No. 10.8

No. of obs.	$\angle R_1 OR_2$ $\angle R_1 OR_2 = 2A$	Mean 2A	$\angle$A of the prism
1.			
2.			
3.			

For angle δm:

Table No. 10.9

No. of obs	δ_m	Mean δ_m
1.		
2.		
3.		

$$\eta = \frac{\sin\frac{\delta m + A}{2}}{\sin\frac{A}{2}}$$

where A is the refracting angle of the prism, δm is the angle of minimum deviation.

Experiment No. 10.8

To draw the I - D curve for the given prism and determine its refractive index.

1. Apparatus Required

(i) Glass prism

(ii) Drawing board

(iii) Sheet of paper

(iv) Fixing pins protractor, scale etc.

2. Theory

The refractive indes η of the material of a given prism for light of some particular colour is given by

$$\eta = \frac{\sin\frac{\delta m + A}{2}}{\sin\frac{A}{2}}$$

where A is the refracting angle of the prism. δ_m is the angle of minimum deviation.

3. Method of Procedure

(i) A line PQ is drawn nearly at the middle and alongside the length of a sheet of paper fixed on the drawing board.

(ii) The outline of the prism is drawn at seven different positions as shown in the fig. so that one edge is lying along the line PQ.

(iii) Each outline is given a dot mark C_1, C_2 etc. near about its middle. Using a protractor, a st. line I_1C_1 is drawn at C_1 at an angle of 60° with the line PQ so that the angle of incidence is 30°. Similarly st. lines are drawn at, C_2, C_3 etc. at angles of incidence 35°, 40°, 45° etc. respectively. Lines are drawn for 7 observations.

(iv) Two pins are fixed at least 10 cms. apart on I_1 C_1. The prism is placed on its outline. Looking from the other face, the eye of the observer is placed so as to be able to see the refracted images of the above two pins in the same st. line keeping the eye in this position, two other pins are fixed 10 cms. apart so that these pins and the two refracted images appear to be in the same st. line as along R_1 E_1. This operation is repeated for all other posiitons also.

(v) The incident ray is produced. The pin-pricks. R_1 and E1 are joined and produced to meet the incident ray I_1C_1 at D_1, then the angle between incident and the emergent ray is measured by means of a protractor. This gives the angle of deviation. This operation is also repeated for other positions also.

(vi) The observations are entered in a table shown below. A graph of anlge of incidence (I) and the angle of deviation (δ) is drawn. The curve will be as shown in the diagram. From the minimum position of the curve, a tangent is drawn parallel to the X-axis. The position where this tangent cuts the Y-axis gives the angle of minimum deviation.

(vii) The angle of the prism A measured is directly in the outline itself by the protractor. Then using the formula given above, η is calculated.

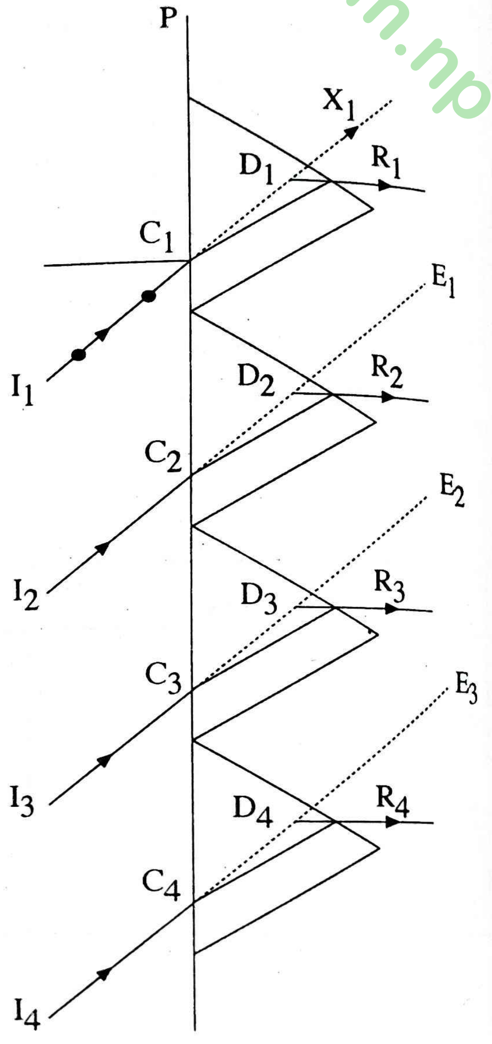


Fig. 10.13

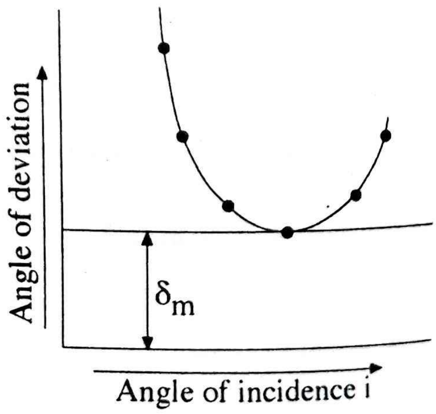


Fig. 10.14

4. **Observation**

Table No. 10.16

No. of obs.	Angle of incidence i	Angle of deviation δ	Angle of minimum deviation from graph δm	Angle of the prism A	$\eta = \dfrac{\sin\dfrac{\delta m + A}{2}}{\sin\dfrac{A}{2}}$
1	30°				
2	35°				
3	40°				
4	45°				
5	50°				
6	55°				
7	60°				

Precaution

1. The pins should be vertical.
2. Small circle should always be drawn round the pin pricks.
3. There should be no parallax between the points constituting the incident ray and the emergent rays.
4. Arrows should be drawn so as to indicate the directions of the rays.
5. The incident rays should be drawn in such a way that they meet the middle of the prism face.

Refraction at Plane Surfaces

Exercises

1. What is Refraction ?
2. State the laws of refraction. Explain why a beam of light is refracted when it enters a new medium at an angle of incidence.
3. Does light travel faster in air or in water ?
4. Define refractive index. Account for the difference in the index of refraction of glass for red light and for violet light.
5. What is lateral shift ? How does it vary with angle of incidence ?
6. In your diagram for verifying the laws of refraction, show the incident ray, refracted ray and emergent ray line the same plane.
7. What is Total reflection ? Under what conditions does it occur ? What is critical angle ?
8. Why does a swimming pool appear shallower than its actual depth ?
9. What do you mean by real depth and apparent depth ? State the relation between them.

10. What is deviation of ray of light ?

11. What is meant by the minimum deviation of a ray by a prism ? For what position of a prism is the deviation minimum ?

12. What do you mean by the principle of reversibility of light ?

13. A ray of light strikes a water surface at an angle of incidence of 40°. What is the angle of refraction in water ? $_a\eta_\omega = 1.33$

14. When a ray of light is incident on the surface of a certain liquid at an angle of incidence of 48°, the angle of refraction within the liquid is 35°. What is the index of refraction of the liquid ?

15. The velocity of light in a liquid is 0.80 as fast as it is in air. What is the index of refraction of the liquid ?

16. The water in a swimming pool is 6m deep. How deep does it appear to a diver looking straight down into it ? $_a\eta_\omega = 1.33$

17. At what angle of incidence should a ray of light approach the surface of diamond ($\eta = 2.42$) from within, in order that the emerging ray shall just graze the surface ?

18. A hollow prism having a 60° apex angle is made with parallel glass plates and filled with carbon disulfide which has an index of refraction. Reflection at spherical surface 1.643. Find the angle of minimum deviation for this prism.

Chapter 11
Refraction at Lenses

11.1 A convex lens or positive lens is thicker at the center than at the rim. It will converge a beam of parallel light to a real focus. The principal focus of a thin convex lens is the point F where rays parallel to and near the principal axis XX are brought to a focus which is real. It forms a real and inverted images of objects which are located beyond the principal focus. Where the object is between the principal focus and the lens, the image is virtual erect and enlarged.

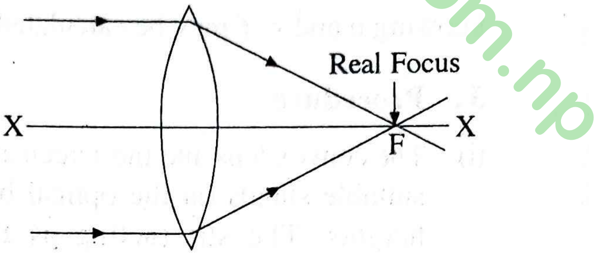


Fig. 11.1(a)

11.2 A diverging or negative lens is thinner at the center than at the rim and will diverge a beam of parallel light from a virtual focus. The principal focus for a diverging lens is virtual.

The focal relation length of the lens is the distance of the principal focus from the optical centre of the lens. Diverging lenses produce only virtual erect and diminished images of real objects.

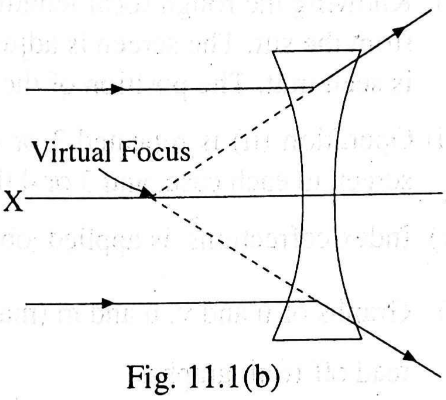


Fig. 11.1(b)

11.3 Object- Image relation for converging and diverging lens:

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

where u is the object distance.

v is the image relation distance, and f is the focal length of the lens. f is + ve for a convex lens and - ve for a concave lens.

11.4 Lens Marker's Formula

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

where η is the refractive index of the lens material, r_1 and r_2 are the radii of curvature of the two lens surfaces. This equation holds for convex and concave lenses. The radii of curvature of convex lenses are to be considered positive and negative for concave lenses. If a lens with refractive index of η_1 is immersed in a material with index η_2 then η in the Lens' maker's formula is to be the replaced by $\frac{\eta_1}{\eta_2}$.

Experiment No. 11.1

To determine the focal length of a convex lens by

(a) u -v method (Optical Bench)

(b) Displacement Method

(c) Plane Mirror Method

(a) u - v method (Optical Bench)

1. Apparatus

(i) A convex lens (ii) An optical bench (iii) Lens holder (iv) Screen holder.

2. Theory

If u be the object distance and v be the image distance for a convex lens, we have $\left(\frac{1}{u} + \frac{1}{v} = \frac{1}{f}\right)$ knowing u and v, f may be calculated.

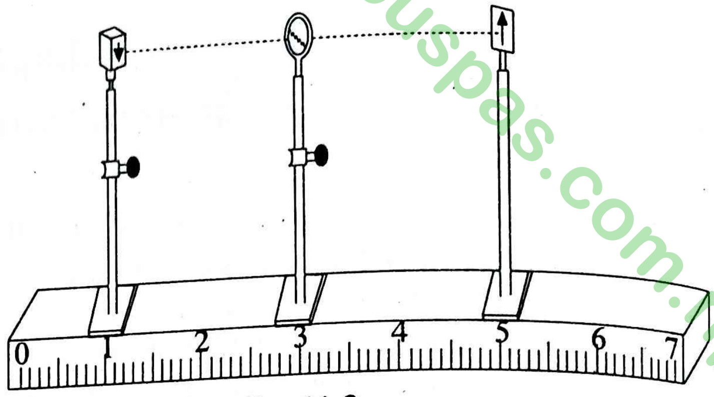


Fig. 11.2

3. Procedure

(i) The convex lens and the screen are mounted on suitable stands on the optical bench at equal heights. The slit (acting as the object) is placed at one end of the optical bench and the screen at the other.

(ii) Knowing the rough focal length of the lens already, it is placed at a distance of twice the focal length from the slit. The screen is adjusted on the other side of the lens till a real inverted and distinct image is seen in it. The position of the lens and the screen are noted.

(iii) Operation (ii) is repeated 3 or 4 times, increasing the object distance beyond $2f$ and adjusting the screen in each case, and 3 or 4 times decreasing the object distance below $2f$ (within f and $2f$).

(iv) Index corrections is applied obtain to the corrected values of u and v.

(v) Graphs of u and v, u and m (magnification), v and m, $\frac{1}{u}$ and $\frac{1}{v}$ may be drawn. Focal length may be read off from graphs.

(vi) Observations are noted as shown below:

4. Observation

Length of the index rod = x cm = ...

Observed distance bet. the slit and the lens = y cm= ...

∴ Index error = (x - y) = z.

If z is positive, z is to be added to the obj. distance to obtain corrected u.

If z is negative, z is to be subtracted from the obj. distance to obtain corrected u.

Observed distance bet. the lens and the screen = v.

∴ Index error

N.B.: Correction to be added if z is positive and to be subtracted if z -v is negative.

Table No. 11.1

No.of obs.	Position of the			u cm. =LO	v cm. = OI	Corrected u	Corrected v	$m = \frac{v}{u}$	$\frac{1}{u}$	$\frac{1}{v}$	$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$	f	Mean f
	Slit O	Lens L	Image I										
1													
2													
3													
4													
5													

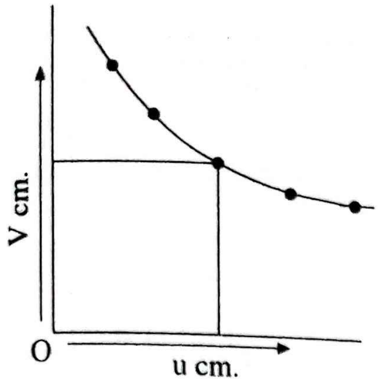


Fig. 11.3(a)

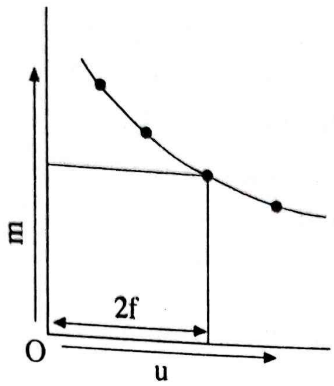


Fig. 11.3(b)

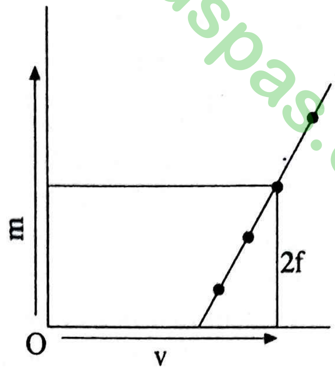


Fig. 11.3(c)

Conclusion thus the focal length = ...cm.

(i) Graph of u and v - Draw a line at 45° with x - axis. At the point of intersection with the curve, find u and V, each of which = $2f$. Hence find f.

(ii) Graph of m against u:- a rectangular hyperbola. Extrapolate the value of (u = $2f$) corresponding to m = 1.

(iii) Graph of m against v -a st. line as shown. Extrapolate V (= $2f$) at m = 1. Hence find f.

Errors

There may be errors in measuring u and hence in m.

Order of Accuracy

From the st. line graph, the slopes of lines with greater and lesser slopes than the best st. line agreeing with the majority of the points plotted are measured. The variation thus produced in the value of f is found out. The maximum error in f is noted.

(b) Displacement Method

1. Apparatus

(i) A convex lens (ii) An optical bench.

2. Theory

Let O be the position of the object in front of a convex lens L and I be its image, keeping the object and the image (position of the screen) fixed, if the lens L_1 is shifted to another position L_2 through a distance of x so that the image is again formed in the same screen, then, the focal length f of the lens is given by

$$f = \frac{D^2 - x^2}{4D}$$

where D is the distance between the object and the image, x is the displacement of lens.

3. Procedure

(i) The rough focal length of the lens is determined by focussing a distant. object on a screen. The distance between the focused image and the screen is the rough focal length of the lens.

(ii) The convex lens, the slit and the screen are mounted on suitable stands at the same heights. The slit and the screen are placed at a distance more than 4 times the rough focal length of the lens. The position of the object (slit) and the screen are noted.

(iii) The lens is placed nea the object (slit) and adjusted properly till a sharp well defined image is obtained on the screen. Then, the position of the lens is noted.

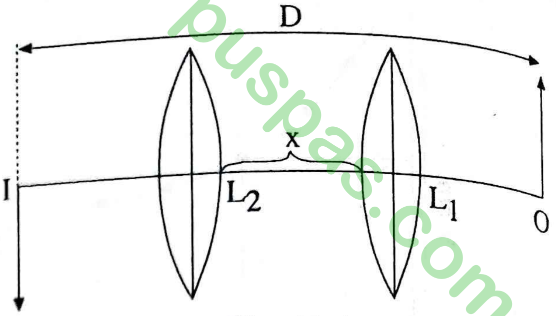


Fig. 11.4

(iv) The lens is now shifted to a second position near the screen so as to give a real, inverted and well defined image of the slit obtained as before on the screen. However the size of the image in this case will be smaller than that before because the object distance is now increased. The position of the lens is again noted.

(v) Keeping the slit fixed, the screen is shifted by about 5 cms. towards the slit and its position and that of the slit are noted.

(vi) Operation (iii), (iv) and (v) are repeated 5 to 7 times. Then if is calculated by using the formula given above.

4. Observation

Rough focal length of the lens = ……cm.

Table No. 11.2

No of. obs.	Position of				dist. D a ~ b	Displacement $= L_1 L_2 = x$	$f = \frac{D^2 - x^2}{4D}$	Mean f	$D^2 - x^2$
	Slit a	Screen	L_1	L_2					
1									
2									
3									
4									
5									
6									
7									

Errors

Here the errors are due to

(i) Zero error and reading error in D.

(ii) Errors in reading the positions of the mark on the lens holder.

(iii) Errors in setting the image at its sharpest focus.

Graph

A graph of $D^2 - x^2$ is plotted against D. This will be a st. line passing through the origin.

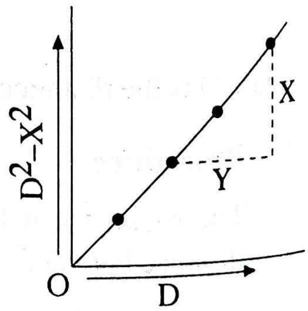


Fig. 11.5

From the graph, the gradient of the line $= \frac{X}{Y} = 4$

$\therefore \quad f = $ ………cm.

Order of Accuracy

The lines of greater and lesser slope through the origin, which just fail to agree with a majority of the plotted points are drawn. The variation in the values of f obtained from their slopes is found out. Hence the order of accuracy is found out.

(c) Plane Mirror Method

1. Apparatus Required

(i) Plane mirror strip (ii) Convex lens (iii) Lens holder

(iv) Mirror holder (v) Adjustable Pin with stand

2. Theory

If a beam of light diverges from the principal focus O of a convex lens L and passes through L, the emergent beam will be parallel to the principal axis. If this beam be incident on plane mirror normally, it will retrace its original path and hence the inverted image will coincide with the object itself. Then the focal length of the lens = LO.

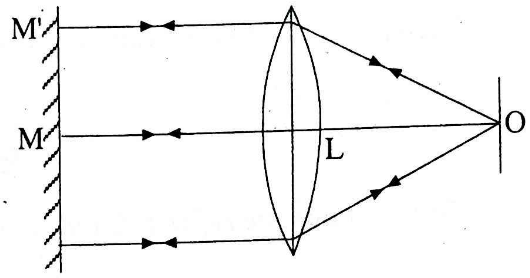


Fig. 11.6

3. Procedure

(i) The object pin O, the convex lens L and the plane mirror strip M mare mounted on their stands at suitable heights. The plane mirror strip is placed vertically just behind the convex lens.

(2) The position the object pin is adjusted so that the inverted image of the pin is obtained on the object itself. This condition will be obtained when the pin lies exactly at the principal focus of the lens. Thus the beam proceeding from the principal focus of the lens fall the lens and emerge out of it parallel to the principal axis. This emergent beam will fall on the mirror normally and hence will retrace its path and the inverted image coincides with the object itself.

(iii) The positions of the pin and lens are noted. Then the distance of the pin from the lens is calculated, which gives the focal length of the lens.

(iv) The position of the pin is disturbed and operations (ii) and (iii) are repeated at least 5 times. Then the mean f is found out.

4. Observation

Table No. 11.3

No of obs.	Position of			$f = 1 \sim 2$ cms.	Mean f
	Mirror	Lens (1)	Pin (2)		
1					
2					
3					
4					
5					
6					

Conclusion

Thus the focal length = ... cm.

Errors may Arise due to

(i) Setting the zero of the scale at the centre of the lens.

(ii) Reading the position of O.

(iii) Locating the position of no parallax. The size of this error may by estimated from the variation in the measurement of f.

Order of Accuracy

The error f in δf is the sum of the above errors. Thus the order of accuracy can be obtained.

Experiment No. 11.2

To determine the refractive index of the given convex lens.

1. Apparatus Required

(i) Convex lens

(ii) Spherometer and base plate.

2. Theory

The refractive index η of a lens is given by

$$\frac{1}{f} = (\eta - 1)\left(\frac{1}{r_1 + r_2}\right) \quad ...(1)$$

where f is the focal length of the lens.

r_1 and r_2 are its radii of curvature of its two surfaces.

The radius of curvature of a spherical surface (here the convex surface of the lens) is given by

$$r = \frac{a^2}{6h} + \frac{h}{2} \quad ...(2)$$

where 'a' is the distance between any two outer legs of a spherometer. h is the depth or distance through which the central leg of the spherometer is lowered from the convex surfaces to the plane of the base plate.

3. Procedure

(i) The focal length (f) of the given convex lens is determined by any of the methods given in the preceding experiments.

(ii) With the help of the spherometer supplied the radii of curvature of both the surfaces of the lens are determined. Then using eqn.(1), η can be calculated.

(iii) Observation are entered as in Expt. 3.3 (ii).

Experiment No. 11.3

To determine the Focal length of a Concave lens by

(i) Combination method (ii) Auxiliary lens method

1. Combination Method

(i) Optical bench (ii) one slit (to act as a source) (iii) Concave lens

(iv) Convex lens of suitable focal length (v) Index rod

(vi) Lens holder (vii) Screen

(a) Dark room method

2. Theory

If f_1 is the focal length of the convex lens and F that of the combination (of the concave and the convex lens), the focal length f_2 of the concave lens is given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

from which knowing f_1 and F, f_2 may be calculated.

3. Procedure

(i) A convex lens of suitable focal length is chosen. To do this, the given concave lens is combined with a convex lens. The combination is held in the hand and is used to view a distant object. If the image is inverted, the combinations is all right, if erect, the convex lens should be changed. The combination is expected to act as a convex lens.

(ii) The focal length of the convex lens is first of all determined as in previous experiment.

(iii) the concave lens is next combined with this convex lens and the combination is used as a single convex lens. The focal of the combination is determined as before.

(iv) The focal length of the concave lens is then calculated.

(v) Observations and table are the same as in Expt. No. 11.1.

(b) Parallax method

Theory

Same as above

Procedure

Proceed as in expt. above once with the single convex lens and then with the combination.

(ii) Auxiliary lens method

1. Apparatus Supplied

(i) Optical bench

(ii) Object pin and image pin in adjustable pin holders.

(a) Dark Room method

2. Theory

Let O be an object in front of a convex lens L_1 and I_1 be its real and inverted image. Next let the experimental concave lens L_2 be interposed at some distance from L_1. The image will no more be seen at I_1. The linediverges the beam of light and allow it to converge and form real and inverted image at I_2, further away from I_1.

Thus I_1 is now acting as the virtual object for L_2 and I_2 the real image. Then for L_2. Virtual object distance $u = - L_2I_1$.

Real image distance $v = L_2I_2$

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} = \frac{1}{L_2I_2} - \frac{1}{L_2I_1}$$

3. Procedure

(i) The convex lens and the concave lens are mounted at suitable heights as the slit object. The convex lens L_1 is placed at a distance greater than its focal length, from the object. Its real and inverted image is received on the screen placed at I_1 (see fig. above). Its position is noted.

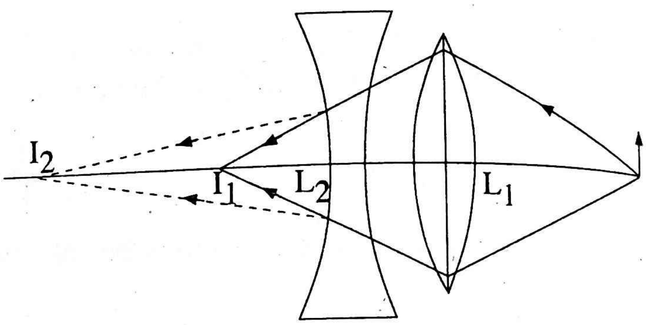


Fig. 11.7

(ii) The concave lens L_2 is then interposed between L_1 and I_1. The image is no more seen at I_1. The screen is gradually shifted further till a well defined real and inverted image is again obtained at I_2. The positions of L_2 and I_2 are noted.

(iii) The position of the convex lens L_1 is changed and operation(2) is repeated. Seven observation are taken changing the position of L_1 and adjusting the position of the screen accordingly.

4. Observations

Table No.11.4

No. of obs.	Position of 1st image I_1	Position of Concave Lens L_2	Position of 2nd image I_2	Obj. distance $u = - L_2I_1$ cms I_1	Image distance $v = L_2I_2$ cms	$\frac{1}{u}$	$\frac{1}{v}$	$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$	Mean $\frac{1}{f}$	f cms
1										
2										
3										
4										
5										
6										
7										

(b) Parallax Method

Theory

Same as above.

Procedure

Same as for the single convex lens.

The first position of I_1 due to the lens L_1 is found out without parallax. After interposing the lens L_2, the second position I_2 is also determined similarly. Proceed exactly as in the convex lens. Table of observations as above.

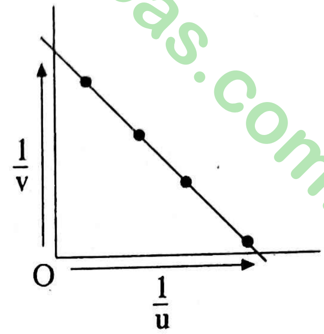


Fig. 11.8

Graph

Draw $\frac{1}{v}$ against $\frac{1}{u}$ plotting from the zero on each axis. Draw the best straight line through the points and measure the intercepts x and y on the respective axes. From $\frac{1}{u}$ and $\frac{1}{v}$ f is found out. Then the average value of f is obtained.

Conclusion

Thus the focal length of the concave lens is ……cms.

Errors and Order of Accuracy

Errors may arise due to

(i) Error in setting the zero of the scale at the required point.

(ii) Error in reading the scale.

The maximum difference between the average value of f and the individual values of f is a fair measure of the order of accuracy.

Refraction Through Lenses

1. How would you distinguish between a convex lens and a concave lens ?
2. Define Optical center, Principal focus, Secondary focus, Focal length, Focal plane, Principal axis of a lens.
3. What is the difference between a real image and a virtual image ?
4. Does a convex lens always from a real image ? If not, when does it from a virtual image.
5. What is Parallax ?
6. Using a sketch, explain why light is bent towards the thickest part of the lens.
7. Trace the course of the rays through a double convex lens to show the formation of a virtual image.
8. What is meant by the power of a lens ? In what units can it be expressed ?
9. Is the observed focal length of a lens in water longer or shorter than in air. Explain.
10. What two factors determine whether a lens is converging or diverging ?
11. In determining the focal length of a convex lens by displacement method, what should be the minimum distance between the object and the screen ? Give reasons for your answer.
12. A straight filament lamp is placed 5.0 cm in front of a convex lens of focal length 2.0 cm. How far from the lens will an image of the filament be formed ?
13. A double convex lens, both surfaces of which have radii of 20 cm., is made of glass whose index of refraction is 1.50. Find the focal length of the lens.

Chapter 12
Photometry

Luminous Intensity I of a source of light

It is a measure of the intensity as seen by the eye. A source of any colour composition is said to have a luminous intensity I of 1 candela (1 cd) if its visual brightness is the same as that of a certain standard source maintained at a white hot temperature of 2046° k. Another unit for I is the candle or candle power.

$$1 \text{ candle} = 1 \text{ candle power} = 0.981 \text{ cd}$$

The illuminating power of a source is expressed in candle (c.p.). The amount of light energy radiated out per sec. by a course of 1 c.p. through a unit solid angle is defined as a Lumen (lm). The total luminous flux radiated out from a source of candle power P is given by

$$F = 4\pi P \ (l_1 m).$$

The intensity of illumination of a source is the luminous flux per unit area of the surface. As such, it may be expressed in lm/m^2. The intensity of illumination I of a surface due to a point source is given by

$$I = \frac{P}{d^2}.$$

It is expressed in units of metre-candles or ft. candles. If the light is incident on the surface at an angle with the normal to the surface, the intensity I is given by: $I = I_0 . \cos\theta$ where I_0 is the value for normal incidence.

If P_1 and P_2 be the illuminating powers of two sources of light at distances d_1 and d_2 respectively from a surfaces on which each of these produces equal illumination, then.

$$I = \frac{P_1}{d_1^2} = \frac{P_2}{d_2^2} \text{...................}$$

This is the Principle of Photometry.

Experiment No. 12.1

To Compare the Illuminating Powers of two Sources of light by

(a) Bunsen's Photometer

(a) By Bunsen's Photometer.

1. Apparatus Required

(i) Bunsen's Photometer

(ii) An optical bench

(iii) Two electric lamps of different powers

2. Description of the Apparatus

The Bunsen's Photometer consists of an unglazed white paper having a circular grease spot at the middle. The grease-spot is translucent.

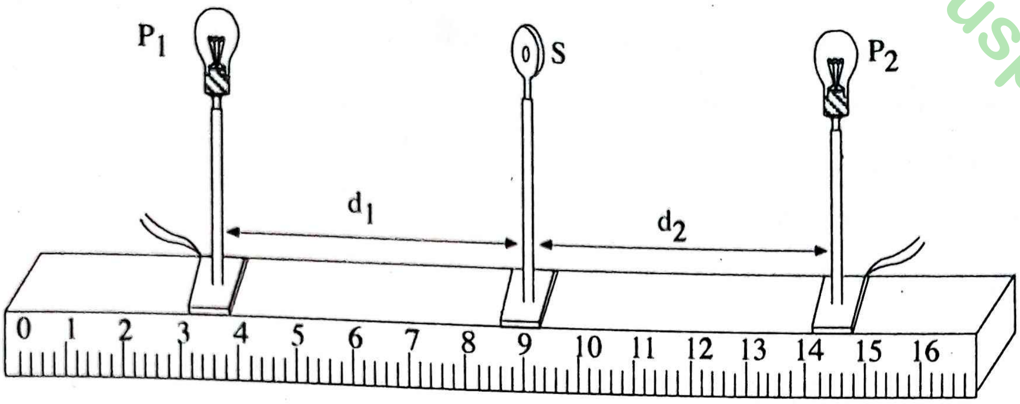


Fig. 12.1

3. Theory

When two sources of light having illuminating powers P_1 and P_2 are placed on the opposite sides of the grease-spot screen S and adjusted so that both sides of the screen look exactly alike, the intensity of illumination I_1 on the screen S due to P_1 is equal to I_2 on the screen S due to P_2.

or $I = \frac{P_1}{d_1^2} = \frac{P_2}{d_2^2}$

where d_1 and d_2 denote the distances of the 1st and 2nd source from the screen.

or $\frac{P_1}{P_2} = \frac{d_1^2}{d_2^2} = k$ (Constant)

or $d_1^2 = Kd_2^2$

Thus the graph of d_1 and d_2 is a straight line passing through the origin.

4. Procedure

(i) The given sources are mounted on suitable uprights and placed on the opposite sides of the optical bench. The grease-spot screen is mounted on the middle upright. Its height is adjusted.

(ii) The index error x_1 between the lamp P_1 and the screen and also x_2 between P_2 and the screen are determined with the help of an index rod.

(iii) The lamps P_1 and P_2 are placed at a fixed distance and their positions are noted on the optical bench.

(iv) The photometer screen is adjusted between P_1 and P_2 until the grease-spot and the rest of the paper are equally bright. The position of the two lamps and the screen are noted from the scale of the optical.

(v) Decreasing the distance between P_1 and P_2 by 5 cm each time, the above operations (iii) and (iv) are repeated five times.

(vi) The lamps are interchanged i.e. the right one is placed on the left end vice-versa. Operations (iii), (iv) and (5) are repeated five times.

Observations are entered as shown below:

(vii) A graph of d_1 and d_2 is drawn which will be a straight line passing through the origin.

5. Observations

Length of the Index rod = x = ...cm.

Observation distance of the index mark on the left = y = ...cm.

∴ Index error on the left $= x - y = ...$

(- to be subtracted, + to be added)

Observed distance on the right $= y = ...$ cm.

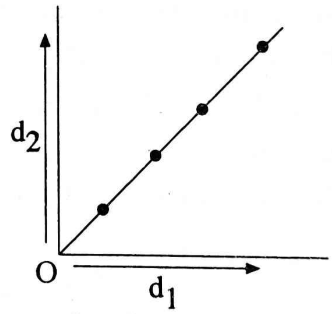
∴ Index error on the right $= x - y' = ...$cm.

Observation

No. of obs	Position of Source P_1 cm.	Position of Source P_2 cm.	Grease-spot screen left	Grease-spot screen right	Grease-spot screen mean	obs. distance d_1 cm.	corrected d dist d_1 cm	obs. distance d_2 cm.	corrected distance d_2	$\frac{P_1}{P_2} = \frac{d_1^2}{d_1^2}$	Mean $\frac{P_1}{P_2}$
1											
2											
3											
4											
5											

On interchanging the lamps

1											
2											
3											
4											
5											



Graph of d_1 and d_2

Fig. 12.2

From graph: $I = \frac{d_1^2}{d_2^2} = \frac{P_1}{P_2}$...........

Chapter 13
Sound

13.1 Vibration of Strings and Air Columns

1. Sound is produced by the vibratory motion of the particles of a medium. Hence sound travels in solids, liquids and gases but not in vacuum.
2. It travels in the from of waves. Waves are of two kinds: Longitudinal and transverse. The former consists of compression and rarefaction so that the displacement is along the direction of propagation, one compression and one rarefaction forms one wave length.
3. Transverse waves consist of crests and troughs and the particles vibrate perpendicular to the direction of propagation of wave motion. Such waves are formed only in solids and liquids not in gases.
4. Time period T is the time taken by a vibrating body to complete one vibration.
5. Frequency n is the no. of complete vibrations made in one second.

   $\therefore \quad n = \frac{1}{T}$ Hz

6. Wavelength λ is the distance travelled by a wave is one complete vibration.
7. Velocity of sound is the distance travelled by the sound waves in one second. If λ is the wavelength of sound waves n the frequency of the wave is given by $V = n\lambda$.

Experiment No. 13.1

To determine the velocity of Sound in the laboratory by Resonance Air Column method. Hence calculate the velocity of Sound in dry air at N.T.P.

1. Apparatus Required

(i) Resonance Apparatus (ii) Tuning fork (iii) Rubber pad

2. Theory

A vibrating tuning fork held slightly above the free end of the Resonance tube as in the fig. forces the air column in it to vibrate and sets up stationary waves in it. While adjusting the length of the air column, a position will be obtained when the intensity of sound will be maximum. This will occur when the frequency of the vibrating air column will be the same as that of the tuning fork. There will be an antinode at the open end and a node at the closed end. In this position for the 1st resonance.

$$V = 4n\,(l_1 + x) \qquad \ldots(1)$$

where V = velocity of sound

n = frequency of the tuning fork

l_1 = length of the 1st resonance air column

x = end correction ≑ 0. 3d, d is the internal diameter of the tube

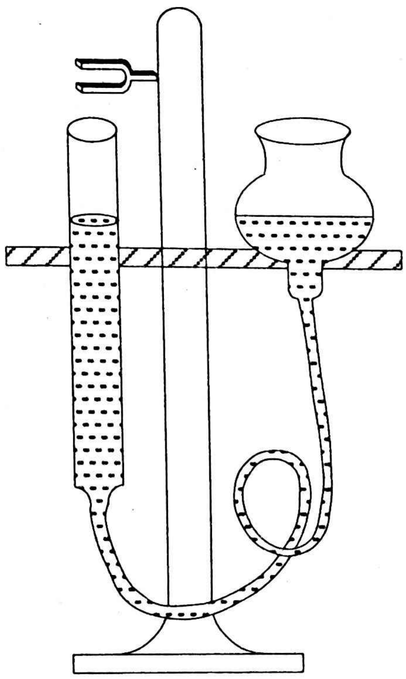


Fig. 13.1

For the 2nd resonance

$$V = \frac{4n(l_2 + x)}{3} \quad \ldots(2)$$

or

$$3V = 4n\ (l_2 + x) \quad \ldots(3)$$

where l_2 = length of the 2nd resonance

From (1) and (3) by subtraction,

$$V = 2n\ (l_2 - l_1)$$

This gives the velocity of sound in the lab. temp. and pressure. To convert it into vel. in dry air at N.T.P. we have

$$V_0 = V\sqrt{\frac{P - 0.375f}{P}\left(1 - \frac{1}{2}\propto t\right)}$$

where P = atmospheric pressure in cm. in the lab.

f = aqueous tension at the lab. temp.

α = coeff. of cubical expansion of air, t = lab. temp.

3. Procedure

(i) The tuning fork is struck against a rubber pad and is held slightly above free end of the tube. The water level is adjusted till an approximate resonance is obtained with the smallest length of the air column.

(ii) The length of the air column is adjusted properly by raising or lowering the water level till maximum resonance is obtained. This is adjusted once by gradually increasing the length of air column and next decreasing it.

(iii) These operations are repeated at least thrice. The mean is taken as the 1st resonance air column.

(iv) The length of the air column is gradually increased till the second resonance is heard. The mean length is taken as in (iii). Then the velocity of sound is calculated by using the above formula.

(v) The Barometer reading P is taken. The lab. temp is noted. The aqueous tension at lab. temp. is found out from the Physical Tables. Then V is calculated.

4. Observations

Barometer reading = ... cm.

Laboratory temperature = ...°C

Aqueous tension from tables = ...mm = ...cm

Table No. 13.1

Positions	No. of obs.	Length of the air Column l cm.		Mean length l cm.	Frequency of the fork	Velocity $V = 2n\ (l_2 - l_1)$
		Increasing	decreasing			
1st Resonance l_1	1					
	2					
	3					
2nd Resonance l_2	1					
	2					
	3					

Calculation

$$V_0 = V\sqrt{\frac{P - 0.375f}{P} \times \left(1 - \frac{1}{2} \propto t\right)} = \ldots\ldots\ldots$$

Conclusion

The velocity of sound in air at 0°C = ...m/sec

Errors and Order of Accuracy

Considering the correctness of the frequency of the fork, the most important error is that in locating the resonance positions. The distance through which the level has to be moved to just after the intensity of the resonance note. There is also error in measuring the distance l.

The maximum % error in V is given by

$$\frac{\partial V}{V} \times 100 = \left(\frac{\delta l_1 + \delta l_2}{l_1 - l_2}\right) \times 100\%$$

Velocity of Sound -Resonance Air Column Method

Exercises

1. What is Forced Vibration ?
2. What is Resonance ?
3. Define wave length, frequency, amplitude of vibration.
4. Why is it necessary to apply end correction in Resonance tube ? What is end correction ?
5. Distinguish between (i) Harmonics and overtones (ii) Nodes and antinodes.
6. What is N.T.P. ?
7. Will your value of the velocity of sound in the lab. be greater than or less than that at N.T.P. Give reasons for your answer.
8. What is aqueous tension ? How does moisture affect the velocity of sound in air ?
9. How does temperature effect the velocity of sound in air ?
10. What is closed and open organ pipe ?
11. At what position do you expect second resonance to take place in a closed organ pipe ?
12. The velocity of sound in air at N.T.P. is 332 m/s. Calculate the temperature at which the velocity of sound is 540 m/s.
13. Find the length of a closed end organ pipe which produces a fundamental frequency 480 cycles/s. Velocity of sound in air is 360 m/s.
14. The velocity of sound in air at 16°C is 341 m/s. Calculate the vel. at 60° C.
15. In a Resonance Air Column apparatus the first and the second resonance positions w`ere observed at 14.8 cm. and 48 cm. Calculate the velocity of sound in air and the end correction.

Vibration of Strings

When a stretched string is set into vibration, the frequency n of the fundamental note produced by it is given by the relation.

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}} = \frac{1}{\lambda}\sqrt{\frac{T}{m}}$$

where l is the length of the vibrating segment, T the tension in the string, m is the mass per unit length of the string and λ is the wave length.

When the string is plucked at the middle, it vibrates as a whole in one segment or loop. The amplitude of vibration is maximum at the mid point, called the antinode and is minimum at the fixed points called the nodes. This is the simplest mode of vibration of a string and the note so produced is called the fundamental note. The string can however be made to vibrate in a number of node and it produces notes of different frequencies. The mode next to the fundamental is the one is which the string vibration in two segments as shown in fig. 13.2(a), 13.2(b). The frequency in this case is twice that of the fundamental note and is called the first overtone and so on.

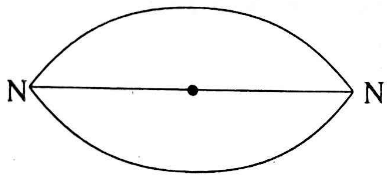


Fig. 13.2(a)

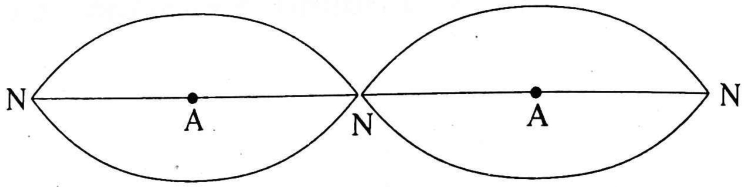


Fig. 13.2(b)

Experiment No. 13.2

To Determine the frequency of a tuning fork with the help of a sonometer.

1. Apparatus Required:

(i) A sonometer (ii) Tuning fork, (iii) Kilogram weight

(iv) Rubber pad (v) Balance and weight box.

2. Description of the Apparatus

A sonometer consists of a hollow wooden box having a wire stretched on it across wooden bridges as shown in fig. 13.3. The wire is fixed to a peg at one end and its other end pass over a pulley and is attached to a pan or a hanger in which weights are placed. The extreme bridge are fixed on the box. The movable bride is used to adjust the length of the vibrating segment of the wire.

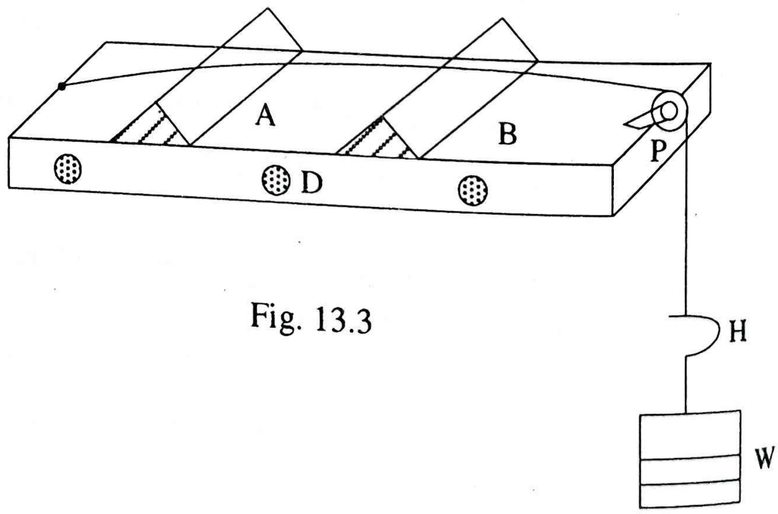


Fig. 13.3

3. Theory

The fundamental frequency η of vibration of a stretched string is given by

$$\eta = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

where l is the length of the vibrating segment. T is the tension and m is the mass per unit length of the string.

4. Procedure

(i) The string is fixed on the sonometer and two bridges are kept under the wire.

(ii) 2 or 3 kg wts. are placed on the pan or the hanger so that the wire sets properly on the bridge.

(iii) Place a paper rider at the middle of the wire between the bridges.

(iv) The bridges are brought nearer. The given tuning fork is struck on a rubber pad and kept pressed on the board of the sonometer. Keeping one of the bridges fixed, the position of the second is adjusted properly such that the paper rider begins flutter. The tuning fork is struck again and the distance between the bridges adjusted properly such that the paper flies off the wire. Then the length of the wire is vibrating with the same frequency as that of tuning fork. The wire is said to be in resonant vibration. The distance between the bridges is noted. It is repeated twice for the same load.

(v) Operation (iv) is repeated at last 3 or 5 times by changing the tension (weights in the hanger) within elastic limit.

(vi) About 80 cm. of the wire sample is taken and is weighted in a balance and its mass per unit length m is calculated.

5. Observation

$$m = \text{mass per unit length} = \frac{\pi d^2}{4} \times l \times \rho$$

where d is the diameter of the wire to be measured by a screw gauge and ρ is the density of the material of the wire.

Table No. 13.2

No. of obs.	Load in kg.w	Tension T = wg N	Resonant length between bridges l			$n = \frac{1}{2}\sqrt{\frac{T}{m}}$	n Hz.
			Increasing	Decreasing	mean cm.		
1							
2							
3							
4							
5							

Precautions

1. There should not be any kinds of the wire. It should rest well on the bridges.
2. The tuning fork should be pressed gently on the board.
3. The tuning fork should be struck only on the rubber pad and not on the table.

Experiment No. 13.3

To study the variation of frequency of a stretched string with length and tension.

1. Apparatus Required

(i) Sonometer (ii) Set of weights (iii) Tuning fork of different frequencies.

2. Theory

We have the fundamental frequency of vibration is $n = \frac{1}{2l}\sqrt{\frac{T}{m}}$

(i) or $n_1 = \frac{1}{2l_1}\sqrt{\frac{T}{m}} = k$ and $n_2 = \frac{1}{2l_2}\sqrt{\frac{T}{m}}$

where T and m are constant

or $n_1 l_1 = n_2 l_2 = \ldots\ldots\ldots$etc.

$\therefore \frac{n_1}{n_2} = \frac{l_2}{l_1}$ or $n_1 l_1 = n_2 l_2$ etc.

(ii) $\frac{n_1}{n_2} = \sqrt{\frac{T_1}{T_2}}$ but $\frac{n_1}{n_2} = \frac{l_2}{l_1}$

or $\frac{l_2}{l_1} = \sqrt{\frac{T_1}{T_2}}$

or $l_1\sqrt{T_1} = l_2\sqrt{T_2} = k$

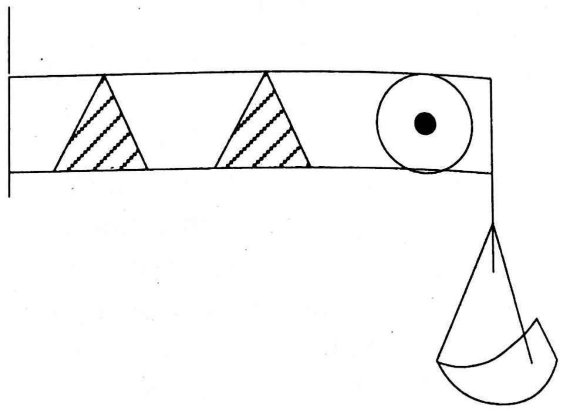


Fig. 13.4

3. Procedure

(i) n - 1 (1) A sonometer is set up.

(ii) A load of about 3 to 4 kg. is suspended from the end of the wire so that it may emit a musical sound.

(iii) Tuning forks of different frequencies n_1, n_2, n_3 etc. are taken. For each, the vibrating length of the wire is determined when it is in unison with the tuning fork, keeping the load constant.

(iv) A graph of n and $\frac{1}{l}$ is drawn, which will be a st. line passing through the origin.

4. Observation

Tension applied = 3 kg.

Table No. 13.3(a)

No. of obs.	Freq. of the fork n Hz.	Vibrating length l cm	nl	$\frac{1}{l}$	Remarks
1					
2					
3					
4					
5					

Conclusion

(i) *Thus nl remains constant i.e. no varies inversely as the length. The graph of n and $\frac{1}{l}$ is st. line passing through the origin.*

Errors

Here the errors are likely to occur in the measurement of l. Besides there is an uncertainly in setting the bridge in the final tuning. This may be found out by measuring the distance through which the bridge can be shifted before the note from the wire goes perceptibly out of tune with the fork. The resonance point may not be exact. The tuning fork should be struck gently on a rubber pad or cork. The frequency of the fork may differ slightly from the value marked on in it.

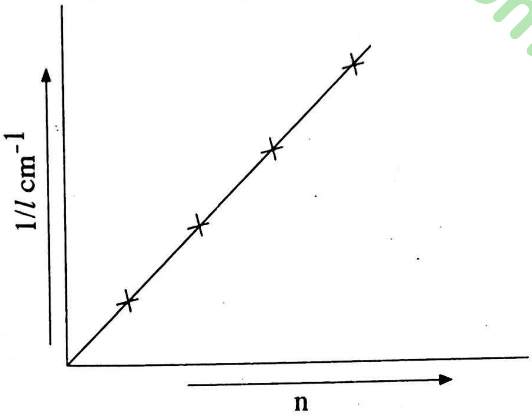


Fig. 13.5

(ii) *Variation of frequency of a steretched wire*

Procedure

(i) One comparison on wire B is stretched along side the experimented wire A which is loaded with a suitable load T kg. (about 2 kg. to start).

(ii) The comparison wire is loaded with a fixed load of about 3 to 4 kg.

(iii) The distance between the bridges below the wire A is adjusted to make sound emitted by it in unision with that emitted by B when the bridge beneath B are well separated apart say about two thirds of the total length of B. This distance is noted and also the tension in wire A.

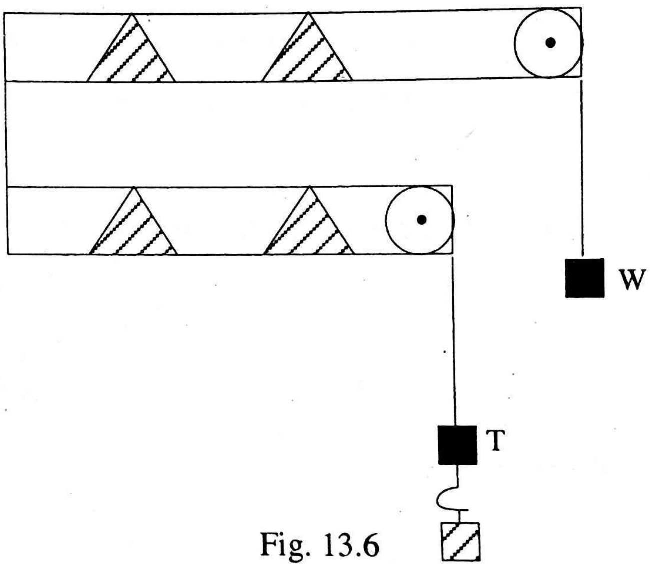


Fig. 13.6

(iv) Next the tension in A is altered about 0.5 kg at a time. Keeping the length in A constant the distance between the bridges in the wire B is altered so as to make the sound emitted by it in unision with that emitted by the fixed length of A.

(v) Operation (iv) is repeated at least 5 times and observations are entered as follows.

(vi) A graphs of $\sqrt{T}$ and l is drawn which will be a rectangular hyperbola.

Observation

Table 13.3(b)

No. of obs.	Tension in the experimental wire T	Length in the		$\sqrt{T}$	$l\sqrt{T}$
		Expt. wire A cm.	Aux. wire Bl cm		
1					
2					
3					
4					
5					

Conclusion

Thus $l/\sqrt{T}$ = const. which means $\eta \propto \sqrt{T}$

Errors

Same as in the previous part.

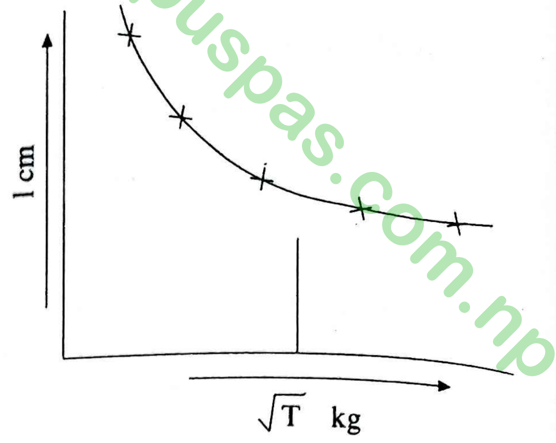


Fig. 13.7

Experiment No. 13.4

To determine the frequency of A.C. Mains using a Sonometer.

1. Apparatus Required

(i) Sonometer (ii) Horse shoe magnet, M (iii) kg. weight (iv) Rheostat

(v) Step down Transformer (220V → 6V), (vi) Spring Balance (vii) Physical Balance.

2. Theory

When the wire resonates the frequency f of the mains = the frequency of vibration of the spring, then

$$f = \frac{1}{2l}\sqrt{\frac{T}{2l}} = \frac{1}{2l}\sqrt{\frac{wg}{m}} = \text{.........Hz}$$

where w is in kg., m in kg. m^{-1} and $g = 9.8\ ms^{-2}$.

3. Procedure

(i) The sonometer wire is cleaned near its point of contact over the metal pulley and at the far end where it is attached to the sonometer.

(ii) Taking one lead front the end of the wire and the other from the pulley, the wire is connected in series with the rheostat R and 6V secondary of the step down transformer. The wire should pass between the poles of the magnet.

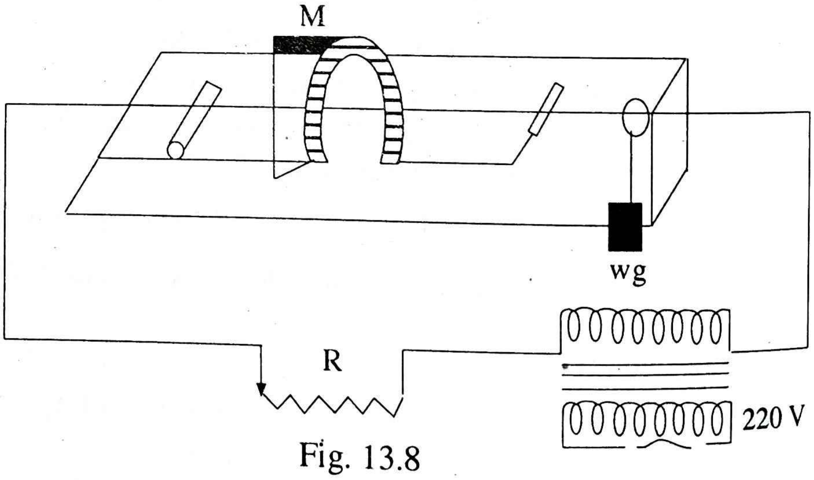


Fig. 13.8

(iii) The current is adjusted until the wire can be felt to vibrate slightly without being appreciably heated.

(iv) The scale pan or hanger is weighted in a spring balance. A load of about 200 gm. is placed on the scale pan. The bridges A and B are adjusted until the wire between them resonates in its fundamental mode, the horse shoe magnet being at the center of AB. The length of the wire l between A and B is measured in meters. The combined weight w of the load and the pan is rerouted.

(v) The load is increased by another 200 gm. and operation (iv) is repeated. This is continued for at least 5 times each time increasing the load by 200 gm.

(vi) Measuring the diameter of the wire and knowing its density, its mass per unit length is calculated.

4. Observation

Table No. 13.4

No. of obs.	Wts. on the scale pan kg.	Total load in kg. w	Resonating length l	fHz.	Mean f Hz.
1					
2					
3					
4					

Diameter of the wire = ... meter

Density......... = ρ = ... kg/m^3

$\therefore$ m = mass per meter = $\frac{\pi d^2}{4} \times 1\rho$ = ... kg/m

$$f = \frac{1}{2l}\sqrt{\frac{wg}{m}} = \text{.........Hz}$$

Hence the frequency of the A.C. mains = ...Hz

Errors and Order of Accuracy

1. Due to friction at the pulley, the tension in the wire is likely to lower than wg.
2. The resonant condition is difficult to be detected.
3. Error in measuring l and m the maximum percentage error in f is

$$\frac{\delta f}{f} \times 100\% = \left[\frac{\delta_1}{1} + \frac{1}{2} + \frac{\delta w}{w} + \frac{1}{2}\frac{\delta m}{m}\right] \times 100$$

Vibration of String

Exercises

1. What type of waves are produced in the stretched string ?
2. What do you mean by nodes and antinodes ?
3. What is amplitude of vibration ?
4. Why is tension needed to make a wire vibrate ?
5. In the formula n = $\frac{1}{2l} = \sqrt{\frac{T}{m}}$, what are m and n ?
6. What do you mean by the fundamental mode of vibration ?

7. State the laws of vibration of string ?

8. What is resonant vibration ?

9. What do you mean by resonating length ?

10. What are overtones ?

11. What are stationary waves ?

Frequency of A.C. Mains

12. Using A.C. mains in a sonometer why does a wire vibrate without plucking it ?

13. What is meant by A.C. ? How does it differ from D.C. ?

14. Why do you need a step-down transformer in this expt. ?

15. A string 2.0 m long has a mass 1.20×10^{-4} kg. and is stretched by a force of 100 N. What is the frequency of the fundamental vibration ?

16. Calculate the tension in a stretched string for which the frequency of the fundamental vibration equals the frequency of the second overtone when the tension is 4.96×10^5 dyne.

17. A sonometer wire of length 0.75 m is maintained under a tension of 4 kg wt. and an A.C. is passed through the wire. A horse shoe magnet is placed with its poles above and below the wire at its midpoint, and the resonating forces set the wire in resonant vibration. If the density of the material of the wire is 8800 kgm^{-3} and the diameter of the wire in 1 m, what is the frequency of the A.C. Mains ?

Chapter 14
Magnetism

14.1 Properties of Magnet

(1) **Attractive Property** - It has the peculiar property of attracting magnetic substances e.g. Iron, Cobalt, Nickel etc.

(2) **Directive Property** - When freely suspended, it always takes up the position North and South.

Poles and axis of a magnet - The two regions near about the two ends of a magnet where the attractive forces are the greatest and from where these forces seem to originate are called the poles of the magnet.

The line joining the two poles of a magnet is called its magnetic axis.

Equivalent length: The shortest distance between the poles of the magnet is called its magnetic length or equivalent length. In a standard magnet, the ratio:

$$\frac{\text{Magnetic Length}}{\text{Real length of the magnet}} = 0.85 \text{ approx.}$$

Real length is the distance between the ends of the magnet

14.2 Magnetic Meridian

It is the imaginary vertical plane drawn through the magnetic axis of a freely suspended or freely pivoted magnetic needle at a place 14.3 Laws of magnetic action.

(i) Like poles repel and unlike poles attract

(ii) The force F of action between two magnetic poles of strength m_1 and m_2 held d meter apart is given by

$$F \propto m_1 m_2$$

$$F \alpha \frac{1}{d^2}$$

or $$F \alpha \frac{m_1 m_2}{d^2} \text{ (Newton)}$$

$\therefore$ $$F = K \frac{m_1 m_2}{d^2} \text{ N}$$

where m_1 and m_2 are the pole strength in ampere meter, and k proportionality constant is

$$K = 10^{-7} \frac{\text{Newton}}{(\text{Amp})^2} = \frac{N}{A^2}$$

Unit pole: It is that pole which when placed at a unit distance from another pole of equal and similar strengths in vacuum is repelled with a force or 1 dyne of 10^{-5} N.

14.4 Magnetic Induction B

It is quite common practice to refer to the strength or the intensity of the magnetic field as the magnetic induction B.

The magnetic induction B at any point in space may be defined as the force per a unit N pole placed at that point.

$$B = \frac{F}{m} = \frac{kmm^1}{d^2\ m} = k\frac{m^1}{d^2}$$

$$= \frac{N}{A^2} \times \frac{N}{Am} = \text{Tesla.}$$

$$k = 10^{-7}\frac{N}{A^2} = 10^{-7}\frac{kgm}{S^2A^2}$$

in fundamental unit sand = $10^{-7}\frac{Tm}{A}$

14.5 A line of force is a continuous curve in a magnetic field such that a tangent drawn at any point of it gives the resultant magnetic field at that point. Lines of force cannot cross each other.

Neutral point: It is a point in a magnetic field where the resultant magnetic intensity is zero. Thus a small magnetic needle placed at that point will tend to remain in the same direction in which it is placed.

At the neutral point the resultant intensity due to the magnet is counter balanced by the horizontal component of the earth's field at that point.

Experiment No. 14.1

To locate the poles of the given bar magnet and determine the ratio of its effective length to its real length.

1. Apparatus Required

(i) A bar magnet (ii) Small compass needle (iii) Drawing board

(iv) Paper fixing pins, scale, a long thread (v) Two tall hair pins.

2. Theory

The poles of a bar magnet are defined as the two points near its ends where the attractive force is strongest.

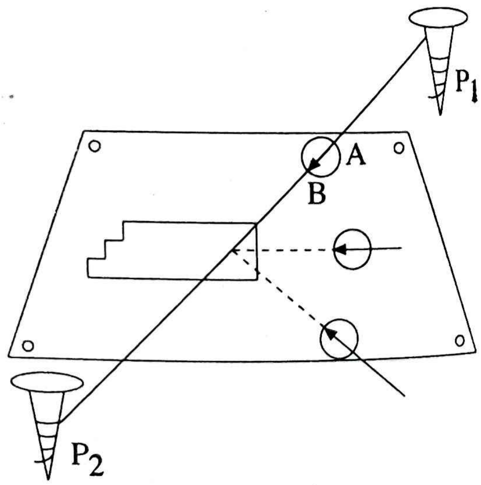


Fig. 14.1

3. Procedure

(i) Removing all the magnets and magnetic substances from the working table, a sheet of paper is fixed on the drawing board.

(ii) The bar magnet is placed in the middle of the paper, and its outline drawn.

(iii) The bar magnet is removed. A small compass needle is placed on the outline. The paper is rotated so that the outline is parallel to the needle. A long thread attached to two pins, P_1 P_2 is then stretched along the outline. Now the thread, the outline and the needle are all parallel. A chalk mark is drawn around the table so that the board, if disturbed somehow during the expt. may be kept again in its original position i.e. in the magnetic meridian. The magnetic meridian at this place is the vertical plane passing through this thread.

(iv) The bar magnet is then placed in its outline. The compass needle is placed near one end of the magnet. The paper is slowly rotated so as to set the needle parallel to the thread. This will keep it parallel to the magnetic meridian. Two dot marks A and B are put corresponding to the end of the needle. The line joining them should pass through the pole of the magnet at this end.

(v) The compass needle is then placed in the second and third position and the above operation is repeated.

(vi) Operations (iv) and (v) are repeated for the pole at the other end.

(vii) The magnet and compass needle are removed. Each pair of dot marks is joined by a st. line. Three st. lines at each end meet at a point which defines the pole at that end. Similarly the other pole is obtained.

(viii) The real length of the magnet, i.e., the distance between the ends of the magnet is measured. The distance between the poles is also measured.

4. Observations

Equivalent or magnetic length = $2l$ = ...cms. = ...m.

Real length or actual length of the magnet =........ cms. = ...m.

$$\text{Ratio} = \frac{\text{Equivalent Length}}{\text{Real Length}} = \text{........}$$

Experiment No. 14.2

To determine the magnetic moment of a bar magnet by neutral point method.

1. Apparatus Required

(i) A bar magnet

(ii) A small compass needle

(iii) A sheet paper

(iv) Drawing board, drawing pins, a long thread.

2. Theory

A line of force is a continuous curve the tangent at any point of which represents the resultant magnetic field at that point.

The neutral point is a point where the magnetic field intensity F is exactly balanced by the horizontal component H of the earth's field. Its position as also the value of F however depends on the placing of the magnet relative to the magnetic meridian.

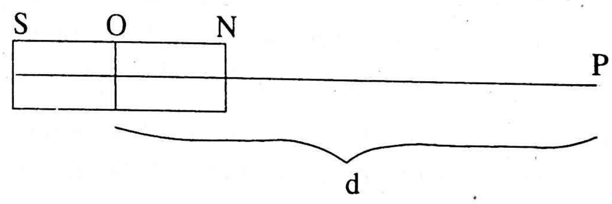


Fig. 14.2

(a) When the magnet is placed along the magnetic meridian with its north pole pointing south, the neural points are obtained on the axis produced.

At the neutral points,

$$F = H$$

or

$$\frac{2Md}{(d^2 - l^2)^2} = H$$

where d is the distance of the neutral point from the centre of the magnet, l is the semi magnetic length.

$$\therefore \quad M = \frac{H(d^2 - l^2)^2}{2d} \qquad \text{...(1)}$$

3. Procedure

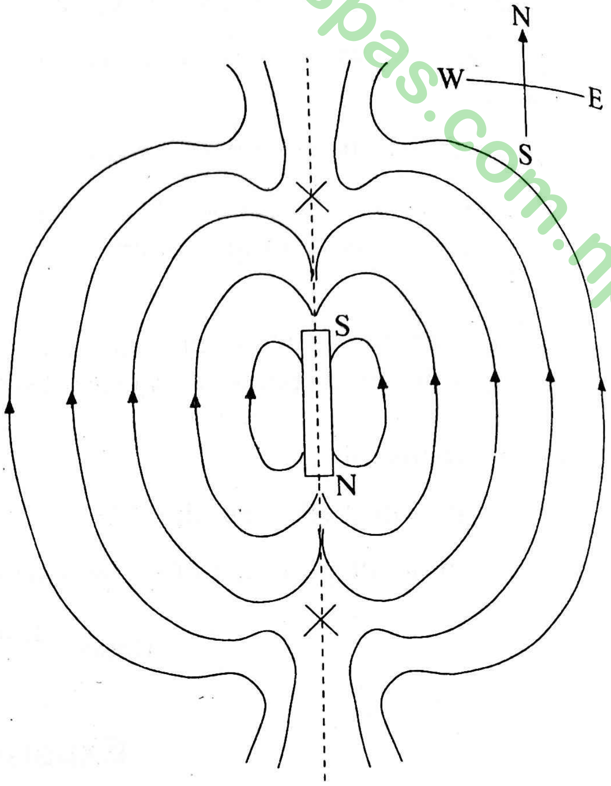


Fig. 14.3

(i) After removing all magnets and magnetic substances from the working table, a sheet of paper is fixed on the drawing board. The magnet is placed in the middle of the paper and its outline is drawn.

(ii) The magnet is removed. A long thread is stretched parallel to the outline of the magnet. A compass needle is placed on the out line of the magnet. The board is slowly rotated till the outline, the needle and the thread are parallel. A chalk mark is drawn all round the board.

(iii) The magnet is placed on its outline with its north pole pointing south. The compass needle is placed near the north pole of the magnet. When it becomes stationary, two dot marks are put on the paper corresponding to the ends of the needle. The needle is next shifted to the next position in such a way that its south pole is placed on the dot mark previously occupied by the north pole. The compass is thus shifted till the other end of the magnet is reached. A continuous free hand line is drawn through all these dot marks. In this way the whole of the paper on both sides of the magnet is filled up by drawing lines of force. The map of the lines of force, will be as shown in the diagram.

(iv) After drawing a large no. of lines of force, it will be observed that a small rectangular space will be left on each side of the magnet in the end on position. Ultimately a point will be found within this space where the needle will not show any particular direction. It can remain in equilibrium in all directions. It can point in any direction in which it is set. This gives us the neutral point. If correctly located, the neutral points in this case will be on the axial line produced both ways.

(v) The distance between the neutral points is measured. Half of this distance is the distance of the neutral point from the centre of the magnet.

(vi) Effective length of the magnet is obtained by multiplying the real length by 0.85.

(vii) Then the moment is calculated by applying the working formula given under theory.

4. Observations and Calculation

Distance between neutral points = 2d.........cms.

$\therefore$ d =.........cms.

Real length of the magnet = ... cms.

Effective length = $2l$ = Real length $\times$ 0.85 = ...cms.

l = ...cms.

H = ...Oersted (supplied)

we have,

$$\therefore \quad M = \frac{H(d^2 - l^2)^2}{2d} = \ldots\ldots\ldots$$

(b) When the magnet is placed along the magnetic meridian with its north pole pointing north, the neutral points will lie on the equatorial line on both sides of the magnet.

2. Theory

At the neutral point, F = H.

$$\frac{M}{(d^2 + l^2)^{3/2}} = H \qquad \ldots(2)$$

whered is the distance of the neutral point from the centre of the magnet, l is the semi magnetic length.

3. Procedure

Same as in the previous expt. The only difference here is to place the magnet in the magnetic meridian with its n-pole pointing north.

4. Observation and Calculation

Distance between neutral points = 2d = ...cm

∴ d = ...cms.

Effective length of the magnet = $2l$

= Real length × 0.85 = ...cms.

=.........

∴ l = ...

H = ...Oersted (supplied)

$M = H (d^2 + l^2)^{3/2}$ from (2) above.

Errors and Precautions

1. The board should not be turned outside the boundary chalk line, otherwise the nature of the line of force may change.
2. Lines of force must not cross each other.
3. The needle must be placed on the dot mark.
4. All magnetic materials must be removed from the vicinity.
5. The direction of the lines of force should be marked with arrow heads.

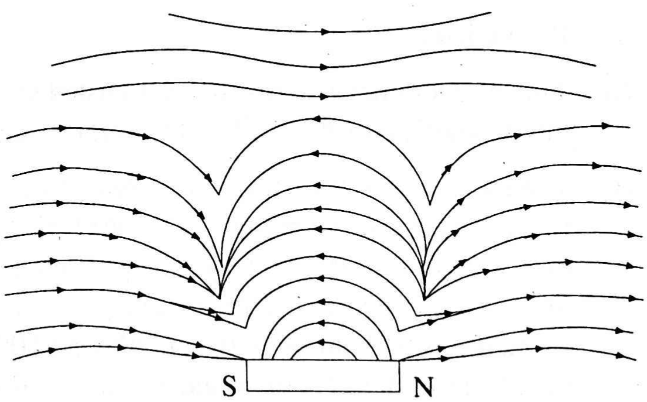


Fig. 14.4

Experiment No. 14.3

To use a Deflection Magnetometer to Determine the pole strength of the given bar magnet.

1. Apparatus Required

(i) Deflection Magnetometer

(ii) Bar magnet

2. Description of the Apparatus

Refer to any text book.

3. Theory

Tangent A position of Gauss.

In this position, the centre of the needle is on the prolongation of the axis of the bar magnet. Hence the intensity F due to the magnet is

$$F = \frac{2Md}{(d^2 - l^2)^2}$$

where M is the moment of the magnet, d is the distance of the centre of the needle from the centre of the magnet, l is the semi magnetic length of the magnet.

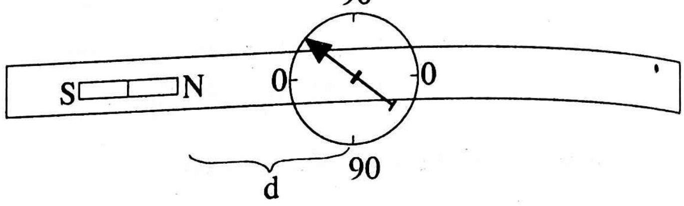


Fig. 14.5

Since the needle is under the influence of two mutually perpendicular fields F due to the magnet and H due to the earth, the Tangent law holds good.

$$F = H \tan\theta$$

From (1) and (2) we get

$$F = \frac{2Md}{(d^2 - l^2)^2} = H \tan\theta$$

or $$M = \frac{H(d^2 - l^2)^2}{2d} \tan\theta$$

or $$m = \frac{H(d^2 - l^2)^2}{2l \times 2d} \tan\theta$$

4. Procedure

(i) The magnetometer is first of all adjusted so that its arms are perpendicular to the magnetic meridian, when the pointer reads 90° - 90° in the scale.

(ii) The bar magnet NS is placed on one of the arms with its axis perpendicular to the magnetic meridian i.e. placed along the arms with its centre at a distance 'd' from the centre of the pivoted needle say with its n-pole pointing towards the needle. The distance 'd' should be adjusted such that the deflection θ should lie between 30° and 60°. The deflection of the needle is read from both the ends of the pointer. This gives two readings.

(iii) Next the magnet is placed on the same arm at the same distance with its S-pole pointing towards the needle. The deflection is again noted. This gives two more readings.

(iv) Operations (ii) and (iii) are repeated on the other arms at the same distance. This gives 4 more readings. Thus we have 8 readings, the mean of these give θ.

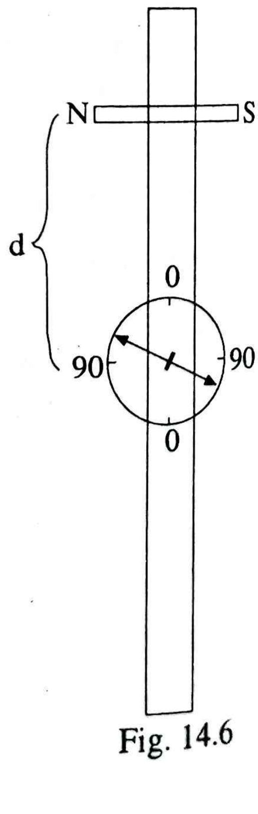


Fig. 14.6

5. Observations and Calculation

Real length of the magnet = x = ……cms.

$\therefore$ Effective ....$2l = x \times 0.85$

$= \ldots\ldots\ldots \times 0.85$

$\therefore$ l =......cms.

$$m = \frac{H(d^2 - l^2)^2}{2l \times 2d} \times \tan\theta$$

Value of H in the Lab. = ...Oersted Supplied

Table No. 14.1

No. of obs.	Dist. of the magnet cms.	Position of the magnet in the arm	n-pole pointing	Deflection θ			$m = \frac{H(d^2-l^2)^2}{2l \times 2d} \times \tan\theta$	Mean m
				End I	End II	Mean θ		
1		East	East					
			West					
		West	East					
			West					
2								
3								

3. Theory

Tangent B Position of Gauss: In this position the center of the needle is on the Equatorial line of the bar magnet. Hence the intensity F due to the magnet is

$$m = \frac{M}{(d^2 + l^2)^{3/2}} \qquad \ldots(1)$$

But according to the Tangent law of magnetic forces.

$$F = H \tan\theta \qquad \ldots(2)$$

From (1) and (2)

$$m = \frac{M}{(d^2 + l^2)^{3/2}} = H \tan\theta$$

or $$\frac{M}{H} = (d^2 + l^2)^{3/2} \tan\theta \qquad \ldots(3)$$

or $$M = H\,(d^2 + l^2)^{3/2} \tan\theta$$

or $$m.\,2l = H\,(d^2 + l^2)^{3/2} \tan\theta$$

$\therefore$ $$m = \frac{H(d^2 + l^2)^{3/2}}{2l} \tan\theta \qquad \ldots(4)$$

4. Procedure

(i) Magnetometer is adjusted so that its arms are along the magnetic meridian when the pointer reads 90° - 90°. Thus the arms will be pointing north and south.

(ii) The bar magnet NS is then placed in the north arm with its axis perpendicular to the magnetic meridian at a distance of d from the centre of the pivoted needle say with its n-pole pointing east. The distance 'd' should be so adjusted such that the deflection θ should lie preferably between 30° and 60°. The deflection of the needle is read from both the ends of the pointer. The reading observed should be subtracted from 90° to obtain θ. This gives two readings.

(iii) Placing the magnet at the same distance with its n-pole pointing west, the deflection is again noted. This gives two more readings.

(iv) Operations (iii) and (iv) are repeated on the other arm at the same distance. This gives 4 more readings. Thus we have 8 readings. The mean of these gives θ.

(v) Operation (ii), (iii) and (iv) are repeated for two more distances.

(vi) The real length of the magnet is measured. This multiplied by 0.85 gives the effective length $2l$..

5. Observations and Calculation

Real length of the magnet = x

Effective......x × 0.85 =...... cms.

Value of H in the Lab. = ... Oerested. Supplied.

Table No. 14.2

No. of obs.	Dist. of the magnet cms.	Position of the magnet in the arm	n-pole pointing	Deflection θ			$m = \frac{H(d^2-l^2)^2}{2l \times 2d} \times \tan\theta$	Mean m
				End I	End II	Mean θ		
1		North	East					
			West					
		South	East					
			West					
2								
3								

Errors

Same as in the previous expt.

Order of Accuracy

$$\frac{\partial M}{M} \times 100\% = \left\{ \frac{4d}{d} + \frac{\partial \theta}{\theta} \right\} \times 100\%$$

Experiment No. 14.4

To use a Deflection Magnetometer to compare the moments of two magnets by (i) Deflection method (ii) Null deflection method.

(i) Deflection Method

1. Apparatus Required

(i) Deflection Magnetometer (ii) Two bar magnets

2. Description of the Apparatus

Refer to any text book.

3. Theory

I. in tan A position.

For the first magnet,

$$\frac{M_1}{H} = \frac{(d^2 - l_1)^2}{2d} \tan \theta_1 = a \text{ (say)} \qquad \ldots(1)$$

where M_1 is the moment of the 1st magnet, d is the distance of the centere of the magnet from the centre of the nedle, l_1 is the semi- magnetic length of the first magnet, θ_1 is the mean deflection.

For the second magnet,

$$\frac{M_2}{H} = \frac{(d^2 - l_1)^2}{2d} \tan \theta_2 = b \qquad \ldots(2)$$

where the symbols represent the corresponding quantities for the second magnet.

Dividing (1) by (2)

$$\frac{M_1}{M_2} = \frac{a}{b} \qquad \ldots(3)$$

4. Procedure

Same as in the previous expt.

5. Observations and Calculation

Effective length $2l_1$ of the 2st magnet = Real length × 0.85 = ...

$\therefore \quad l_1 =$ ....

Effective length $2l_1$ of the 2nd magnet = Real length × 0.85 = ...

$\therefore \quad l_2 =$ ....

Table No. 14.3

No. of obs	Dist. of the magnet cms	Position of the magnet in the arm	n-pole pointing	Deflection θ			tan θ	$m = \frac{H(d^2-l^2)^2}{2l \times 2s} \times \tan\theta$	Mean $\frac{M}{H} = a$
				End I	End II	Mean θ			
1st mag		East	East						
			West						
		West	East						
			West						
2nd mag									

Thus $\frac{M_1}{H}$ (for the 1st magnet) = a = ...

$\frac{M_2}{H}$ for the 2nd magnet = b

$\therefore \quad \frac{M_1}{M_2} = \frac{a}{b} =$ ....

3. Theory

II Tangent B position

For the 1st magnet.

$$\frac{M_1}{H} = (d^2 - l^2)^{3/2} \tan\theta_1 = a \qquad ...(1)$$

For the 2nd magnet,

$$\frac{M_2}{H} = (d^2 + l^2)^{3/2} \tan\theta_2 = b \qquad ...(2)$$

where the symbols have their usual meanings,

∴ Dividing (1) by (2), we have

$$\frac{M_1}{M_2} = \frac{a}{b} \text{.........}$$

4. Procedure

Same as in the previous expt.

5. Observation and Calculation

(i) M/H for both the magnets is calculated.

Then $\frac{M_1}{M_2} = \frac{a}{b}$ is calculated.

(ii) Null Defection Method

3. Theory

Tangent A position of Gauss

The first magnet is placed on one of the arms of the magnetometer at distance d, from the centre producing a deflection θ so that

$$F_1 = \frac{2M_1d_1}{(d_1^2 - l_1^2)^2} = H\tan\theta \qquad ...(1)$$

The 2nd magnet is placed on the other arm with a similar pole pointing towards the needle and the distance adjusted such that the needle is brought back to zero position.

Then,
$$F_2 = \frac{2M_2d_2}{(d_2^2 - l_2^2)^2} = H\tan\theta \qquad ...(2)$$

That the needle is brought back to zero shows that the deflection in the 2nd case is the same as that in the 1st case, i. e.,

$$F_1 = F_2$$

or
$$\frac{2M_1d_1}{(d_1^2 - l_1^2)^2} = \frac{2M_2d_2}{(d_2^2 - l_2^2)^2}$$

∴
$$\frac{M_1}{M_2} = \frac{(d_1^2 - l_2^2)^2}{(d_1^2 - l_1^2)^2} \times \frac{d_2}{d_1} \qquad ...(3)$$

4. Procedure

(i) The deflection magnetometer is first of all placed in the magnetic meridian.

(ii) The 1^{st} magnet is placed on one of the arms say the east arm at a certain distance d_1, with its axis at rt. angles to the magnetic meridian and with its n-pole pointing towards the needle. This produces a certain deflection.

(iii) The 2^{nd} magnet is similarly placed on the other arm with its n-pole pointing towards the needle. Its distance is adjusted such that the needle is brought back to zero position. Then this distance d_2 is noted.

(iv) The first magnet is then placed in the same position with its south pole pointing towards the needle. The 2^{nd} magnet is also reversed and its distance d_2 is adjusted to produce null deflection.

(v) Placing the 1^{st} magnet on the west arm at the same distance d_1, operation (3) and (4) are repeated. The mean of these 4 readings gives the value of d_2 for the 1^{st} set of observations.

(vi) The 1^{st} magnet is then placed at some other distances and operations (3) to (5) are repeated.

5. Observations and Calculation

Effective length of the 1^{st} magnet = $2l_1$ = ...

$\therefore$ l_1 = ...

Effective length of the 2^{nd} magnet = $2\ l_2$ =.........

$\therefore$ l_2 = ...

Tangent A position of Gauss:

Table No. 14.4

No. of obs	Dist. of the magnet cms.	Position of the magnet	n-pole of the 1^{st} magnet pointing	Distance of the 2^{nd} magnet in the other arm	Mean d_2	$\frac{M_1}{M_2} = \frac{(d_1^2 - l_1^2)^2}{(d_1^2 - l_2^2)^2} \times \frac{d_2}{d_1}$	Mean $\frac{M}{H}$
1		East arm	East				
			West				
		West arm	East				
			West				
2							
3							

Tangent B Position of Gauss

3. Theory

Tangent B Positión of Gauss

$$F_1 = \frac{M_1}{(d_1^2 + l_2^2)^{3/2}} = H \tan \theta$$

$$F_2 = \frac{M_2}{(d_2^2 + l_2^2)^{3/2}} = H \tan \theta \qquad \ldots(2)$$

For null deflection,

$$F_1 = F_2$$

or $$F_1 = \frac{M_1}{(d_1^2 + l_2^2)^{3/2}} = \frac{M_2}{(d_2^2 + l_2^2)^{3/2}}$$

or $$\frac{M_1}{M_2} = \frac{(d_1^2 + l_1^2)^{3/2}}{(d_2^2 + l_2^2)^{3/2}} \quad \ldots(3)$$

4. Procedure

(i) The Deflection magnetometer is adjusted so that its arms are along the magnetic meridian. In this position, the pointer reads 90° - 90°.

(ii) The first magnet is placed on the north arm say, at distance d_1, with its north pole pointing east. It will produce a certain deflection.

(iii) The second magnet is then placed on the south arm with n-pole pointing west. Its distance is adjusted so that the needle is brought back to zero position. Then this distance is noted.

(iv) The first magnet is placed on the same position with its n-pole pointing west. The second magnet is also reversed and its distance d_2 is adjusted to produce null deflection.

(v) The first magnet is placed on the south arm at the same distance. The 2nd is placed on the north arm. Operations (iii) and (iv) are repeated. The mean of these 4 reading gives the value of d_2 for 1st set of observations.

(vi) The first magnet is then placed at some other distance and operations (iii) to (v) are repeated.

5. Observations and Calculation

Table No. 14.5

No. of obs	Dist. of 1st the magnet	Position of the 1st magnet	n-pole of the 1st magnet pointing	Distance of the 2nd magnet in the other arm	Mean d_2	$\frac{M_1}{M_2} = \frac{(d_1^2 + l_1^2)^2}{(d_1^2 + l_l^2)^2} \times \frac{d_2}{d_1}$	Mean $\frac{M_1}{M_2}$
1		East arm	East				
			West				
		West arm	East				
			West				
2							
3							

Sources of Error

These may arise due to

(i) The axis of the deflecting magnet not being perp. to the earth's field H.

(ii) The deflection not lying between 30° and 60°.

(iii) The centre of th deflecting magnet not lying along th axis of the neeld.

(iv) Presence of magnetic substances near the magnet.

(v) Parallax in reading deflection.

Experiment No. 14.5

To Verify the Law Inverse Squares of Magnetic Forces by (i) Deflection Magnetometer (ii) Graphical Method

(i) Deflection Magnetometer

1. Apparatus Required

(i) Deflection magnetometer (ii) A bar magnet.

2. Theory

The law of Inverse squares of magnetic forces states that the intensity of the magnetic field due to a magnet is inversely proportional to the square of the distance.

When a bar magnet is placed at a distance d in a Deflection magnetometer in Tangent A position of Gausses, we have,

$$F = \frac{2Md}{(d^2 - l^2)^2} \qquad ...(1)$$

But,

$$F = H \tan \theta_1$$

∴

$$\frac{2Md}{(d^2 - l^2)^2} = H \tan \theta_1 \qquad ...(2)$$

or

$$\frac{M}{H} = \frac{(d^2 - l^2)^2}{2d} \tan \theta_1 \qquad ...(3)$$

If the same magnet be placed at the same distance d in Tangent B position of Gauss, we have,

$$F = \frac{M}{(d^2 + l^2)^{3/2}} \qquad ...(4)$$

But,

$$F = H \tan \theta_2$$

∴

$$F = \frac{M}{(d^2 + l^2)^{3/2}} H \tan \theta_2 \qquad ...(5)$$

or

$$\frac{M}{H} = (d^2 + l^2)^{3/2} \tan \theta_2 \qquad ...(6)$$

Since $\frac{M}{H}$ for the same magnet is the same, we have from (3) and (6)

$$\frac{(d^2 - l^2)^2}{2d} \tan \theta_1 = (d^2 + l^2)^{3/2} \tan \theta_2$$

or

$$\frac{\tan \theta_1}{\tan \theta_2} = \frac{2d(d^2 + l^2)^{3/2}}{(d^2 - l^2)^2} \qquad ...(7)$$

The R.H.S. in equation (7) has been deduced on the assumption of the law of inverse squares. Hence if the L.H.S. could be shown to be equal to the R.H.S. by substituting the experimentally observed data, the law is verified.

3. Procedure

(i) The value of $\frac{M}{H}$ for the given bar magnet is determined for both tan A and tan B position of Gauss as in Expt. No. 14.4

(ii) From the observed data, the L.H.S. and R.H.S. of equation (7) are calculated and the conclusion is drawn.

(ii) Graphical Method

1. Apparatus Required

(i) A bar magnet (ii) Compass needle (iii) Thread

(iv) Drawing Board (v) Scale, set squares, a sheet of paper.

2. Theory

The Law of Inverse Squares of magnetic forces states that the intensity of the magnetic forces states that the intensity of the magnetic field due to a bar magnet is inversely proportional to the square of the distance.

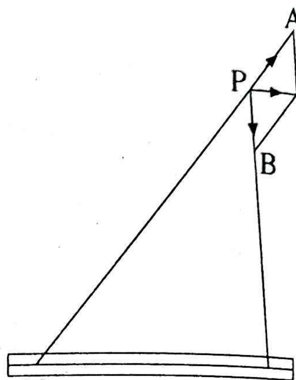


Fig. 14.7

Let P be a point in the field of a bar magnet NS. According to the law of Inverse Squares of the magnetic forces.

Intensity at P due to n-pole $F_n = \frac{m}{NP^2}$

Intensity at P due to s-pole $F_s = \frac{m}{PS^2}$

$$\therefore \quad \frac{F_n}{F_s} = \frac{PS^2}{NP^2} \quad \ldots(1)$$

$\therefore$ Let F_n and F_s be represented by the sides PA and PB of the parallelogram PARB. The resultant is represented in magnitude and direction by the diagonal PR.

Then $$\frac{F_n}{F_s} = \frac{PA}{PB} \quad \ldots(2)$$

$\therefore$ From (1) and (2) $\frac{PA}{PB} = \frac{PS^2}{NP^2}$ if the Law of Inverse Squares were true.

3. Procedure

(i) A sheet of paper is fixed on the drawing board. The outline of the magnet is drawn in the middle of the paper.

(ii) A thread is stretched across the board along the magnetic meridian.

(iii) A point such as P in fig. 14.7 in taken on one side of the magnet. A compass needle is placed at P. The paper is rotated such that the needle remains parallel to the thread stretched along the magnetic meridian. Dot marks are placed at the ends of the needle with the arrow mark in the direction in which the n-pole of the needle points. The outline is drawn around the compass needle.

(iv) Join PA and PB produce PA. Join dot marks, mark off at least 5 cm in the line joining the dot marks. Let it be PrT.

(v) With the help of set squares, draw st. lines AR parallel to PS, and RB parallel to PA.

(vi) Choose two more points P_2 , P_2 on the same side of P_1 and 3 points on the opposite side of the magnet, operations are noted and the result calculated as shown below.

4. Observations and Calculations

Table No. 14.6

No. of obs.	PA	PB	PS	NP	$\frac{PS^2}{NP^2}$	$\frac{PA}{PB}$	$\frac{PS^2}{NP^2} = \frac{PA}{PB}$	Remarks
1								
2								
3								
4								
5								
6								

Conclusion

Hence the Law of Inverse Squares is verified. If $\frac{PS^2}{NP^2} = \frac{PA}{PB}$

Experiment No. 14.6

To use an Oscillation Magnetometer to determine the moment of a magnet.

1. Apparatus Required

(i) Oscillation magnetometer (ii) Compass needle (iii) A bar magnet

(iv) Stop watch or stop clock (v) Balance with weight box.

2. Description the Apparatus

Refer to any text book.

3. Theory

The time period of oscillation of a bar magnet oscillating in the earth's field is given by

$$t = 2\pi\sqrt{\frac{I}{MH}} \qquad \ldots(1)$$

where I is the moment of Inertia of the magnet. M is the moment of the magnet. H is the horizontal component of the earth's field. $I = \frac{a^2 + b^2}{12} \times$ mass for a rectangular bar, a is the length of the bar and b is the breadth.........

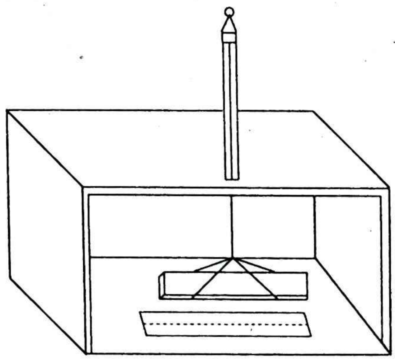


Fig. 14.8

or
$$t^2 = 4\pi^2 \frac{I}{MH}$$

or
$$MH = \frac{4\pi^2 I}{t^2} \qquad \ldots(2)$$

$\therefore$
$$M = \frac{4\pi^2 I}{Ht^2} \qquad \ldots(3)$$

4. **Procedure**

(i) A small compass needle is placed just over the line scratched alongside the thin strip of the plane mirror inside the oscillation magnetometer. The magnetometer is placed so that the line remains parallel to the needle. In this way the magnetometer is placed in the magnetic meridian. A chalk mark is drawn all round the magnetometer.

(ii) The dummy bar (brass bar) is placed in the strip. The torsion in the suspension thread is removed by turning the torsion head this way or that way. When the torsion is removed, the bar will oscillate equally on both sides of the scratched line.

(iii) The length and the breadth of the given bar magnet are measured. Its mass is determined by a balance. Then its moment of inertia is calculated.

(iv) Then the brass bar is replaced by the given bar magnet. It is slightly disturbed by a different magnet from outside the magnetometer. With the help of a stop watch or clock, the time for 20 oscillations is noted. This observation is repeated thrice. The time period is calculated in each case and the mean time period is found out.

5. **Observation**

Length of the magnet = a =.........cm.

Breadth .... = b =.........cm.

Mass .... = w =.........gms.

$\therefore$ Moment of Inertia $= I = \frac{a^2 + b^2}{12} \times$ mass = ... gm

Value of H .... oersted (supplied).

Table No. 14.7

No. of obs. secs.	Time for 20 Oscs.	Time period t secs	Mean t secs	$M = \frac{4\pi^2 I}{Ht^2}$
1				
2				
3				

Experiment No. 14.7

To use an Oscillation Magnetometer to compare the moments of two bar magnets (i) Using the magnets separately (ii) Using both the magnets together

(i) Using the magnets separately

1. **Apparatus Required**

(i) Oscillation magnetometer (ii) Compass needle (iii) Two given bar magnets

(iv) Stop watch stop clock (iv) Balance with weight box.

2. Theory

From eqation (2) of the previous expt., for the 1st magnet, we have

$$M_1 H = \frac{4\pi^2 I_1}{t^2_1} \quad \ldots(1)$$

For the 2nd magnet

$$M_2 H = \frac{4\pi^2 I_2}{t^2_2} \quad \ldots(2)$$

Dividing (1) and (2)

$$\frac{M_1}{M_2} = \frac{I_1}{I_2} \times \frac{t_2^2}{t^2} \quad \ldots(3)$$

3. Procedure

(i) I_1 and I_2 for both the magnets are determined as before.

(ii) All operations of the previous expt. are repeated for the 1st and 2nd magnet. The observations are noted as before.

(iii) The result is calculated by substituting the observation data in equation. (3) above.

(ii) Using both the magnets together

2. Theory

When the magnets are placed one above the other and the combination is used as a single magnet, the time period t_1, when like poles are together, is given by

$$t_1 = 2\pi \sqrt{\frac{(I_1 + I_2)}{(M_1 + M_2)\ H}}$$

or

$$t^2 = \frac{4\pi^2 (I_1 + I_2)}{(M_1 + M_2) H}$$

or

$$(M_1 + M_2)\ H = \frac{4\pi^2 (I_1 + I_2)}{t^2} \quad \ldots(1)$$

When unlike poles are together, the time period t_2 is given by

$$t_2 = 2\pi \sqrt{\frac{I_1 + I_2}{(M_1 + M_2)\ H}}$$

or

$$t_2^2 = 4\pi^2 \frac{(I_1 + I_2)}{(M_1 + M_2) H}$$

or

$$(M_1 + M_2) H = \frac{4\pi^2 (I_1 + I_2)}{t^2} \quad \ldots(2)$$

Dividing (1) by (2)

$$\frac{M_1 - M_2}{M_1 + M_2} = \frac{t_2^2}{t_1^2}$$

By Component and Dividend do we have,

$$\frac{M_1 + M_2 + M_1 - M_2}{M_1 + M_2 - M_1 + M_2} = \frac{t_2^2 + t_1^2}{t_2^2 - t_1^2}$$

$$\frac{M_1}{M_2} = \frac{t_2^2 + t_1^2}{t_2^2 - t_1^2} \quad \ldots(3)$$

3. Procedure

(i) Placing the magnetometer in the magnetic meridian, the torsion is removed in the suspension thread as described above.

(ii) One magnet is placed above the other with like poles together. The combination is allowed to oscillate and the mean time is determined as in the previous expt.

(iii Next the combination with the unlike poles together is allowed to oscillate and the mean time period t_2 is determined.

(iv) The result is calculated by substituting the observed data in eqn. (3) above.

4. Observation

Table No. 14.8

Position secs.	No. of obs.	Time for 20 oscillations secs	Time period t secs	Mean t
Like poles together	1			
	2			
	3			
Unlike poles together	4			
	5			
	6			

Calculation

$$\therefore \frac{M_1}{M_2} = \frac{t_2^2 + t_1^2}{t_2^2 - t_1^2} = \ldots\ldots\ldots\ldots$$

Sources of Error and Precautions

Errors may arise due to

(i) In exact setting of the magnetometer in the magnetic meridian.

(ii) Twist in the suspension fibre.

(iii) Presence of magnetic substances near the magnetometer. Hence the magnetometer must be placed in the magnetic meridian. The torsion in the silk thread should be removed. Magnetic substance, if any, should be removed.

Order of Accuracy

$$\frac{M_1}{M_2} = \left[\frac{2\delta t_2}{t_2} + \frac{2\partial t_1}{t_1}\right] \times 100$$

Experiment No. 14.8

To verify the Law of Inverse Squares of magnetic forces by using (I) Deflection Magnetometer.

1. Apparatus Required:

(i) Deflection magnetometer (ii) A short magnet (iii) Scale.

2. Theory

The magnetic intensity at a point in tan A and tan B position due to a bar magnet have been deduced on the assumption of the Law of Inverse squares which states that the force between magnetic poles is inversely proportional to the square of the distance between them.

Thus for a short magnet

$$F_A = \frac{2M}{d^3} = H \tan \theta_A \quad \text{and} \quad F_B = \frac{M}{d^3} = H \tan \theta_B$$

$$\therefore \quad \frac{F_A}{F_B} = 2 \text{ (approx.) to be shown by expt.} = \frac{\tan \theta_A}{\tan \theta_B}$$

3. Procedure

(i) The Deflection magnetometer is first of all placed in the magnetic meridian in tan A position.

(ii) The deflection of the needle due to the given short magnet at a certain distance are noted. This is repeated for two more distances.

(iii) Next the magnetometer is set in the tan B position and operation (2) is repeated for the same distances. Observations are noted.

4. Observations

Table No. 14.9

No. of obs	Dist. of the magnet	Position of the magnet		n-pole pointing	Deflection			tan θ	$\frac{\tan \theta_A}{\tan \theta_B} \simeq z$
					End I	End II	Mean θ		
1	....	tan A	East arm	East arm					
			West arm	West arm					
		Tan B	North arm	North arm					
			West arm	West arm					
2	....								
3	....								

Result

It will be found by expt. that $\frac{F_A}{F_B} = \frac{\tan \theta_A}{\tan \theta_B} = 2$ approx., thus verifying the law.

Sources of Error

Same as in the previous expt.

II. Using Searle's Magnetometer

1. Apparatus Required

(i) Searle's magnetometer (ii) Ball ended magnet
(iii) Stop watch (iv) Scale

2. Theory

The force between magnetic poles varies inversely as the square of the distance between them, i.e. $F \alpha \frac{1}{r_1^2}$. In the earth field alone,

$$H = K\eta_0^2 \qquad ...(1)$$

where k is a constant of the magnetometer.

$$\eta_0 = \text{no. of complete vibration/sec.} = \frac{1}{T_0}$$

In a combined field,

$$F_1 + H = K\eta_1^2 \qquad ...(2) \text{ where } F\alpha \frac{1}{r_1^2}$$

when the ball ended magnet is placed at a distance r_1 cm, from the oscillating needle.

$$F_2 + H = K\eta_1^2 \qquad ...(3) \text{ where } F_2 \alpha \frac{1}{r_2^2}$$

Thus from the Law of Inv. squares, $\frac{F_1}{F_2} = \frac{r_2^2}{r_1^2}$ ...(4)

From (1), (2), (3) and (4) may be shown that

$$\frac{F_1}{F_2} = \frac{\eta_1^2 - \eta_0^2}{\eta_2^2 - \eta_0^2} \qquad ...(5)$$

the law is verified $= \frac{\eta_1^2 - \eta_0^2}{\eta_2^2 - \eta_0^2} = \frac{r_2^2}{r_1^2}$

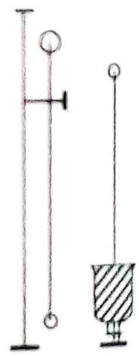


Fig. 14.9

i.e. if $(\eta_1^2 - \eta_0^2)\, r_1^2 = (\eta_2^2 - \eta_0^2)\, r_2^2 = \text{etc.} = \text{a const. } C.$

or $\eta_1^2 - \eta_0^2 = \frac{C}{r_1^2}$

or $\eta_1^2 = \frac{C}{r_1^2} + \eta_0^2$ the law is verified

A graph of η_1^2 against $\frac{1}{r_1^2}$ for diff. distances is drawn which will be a st. line not passing through the origin.

3. Procedure

(i) The magnetometer is placed on the sheet of paper fixed on a drawing board and its outline marked. A st. line is drawn from the center of the outline. Dot mark are made on the line at intervals of 2 or 3 cm.

(ii) The torsion is removed. The needle is distributed from outside by a second magnet. It is then allowed to oscillate in the earth's alone. Time for 20 oscillations is noted. T is calculated and hence no. of oscillations per sec.

(iii) Next the ball ended magnet is placed at 1 cm and operation (2) is repeated for different distances.

(iv) A graph of η^2 is drawn against $\frac{1}{{r_1}^2}$

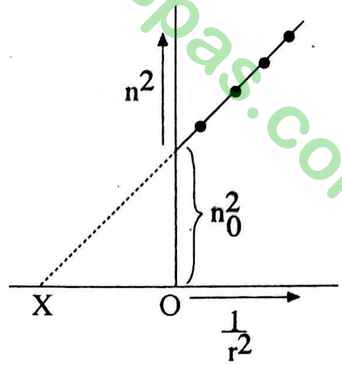


Fig. 14.10

4. Observations

Table No. 14.10

No. of obs.	Distance r cm	Time for 20 oscs	Time period sec.	$\eta = \frac{1}{t}$ Hz	η^2
1	r_o		....	....	
2	r_1				
3	r_2				
4	r_3				
5	r_4				

Conclusion

$$({\eta_1}^2 - {\eta_0}^2)\, {r_1}^2 = ({\eta_2}^2 - {\eta_0}^2)\, {r_2}^2 = \text{etc.}$$

Sources of Error

Same as in oscillation magnetometer

Another error may arise in the measurement of r.

Order of Accuracy

The line of greatest and least slopes are drawn as to pass through most of the plotted points. The variation in the slope gives the measures of the order of accuracy.

Experiment No. 14.9

To determine the absolute value of H is the lab.

1. Apparatus Required

(i) Deflection Magnetometer (ii) Oscillation Magnetometer (iii) Bar magnet.

2. Theory

Using a magnet in tan A position Gauss in a Deflection magnetometer, we have

$$\frac{M}{H} = \frac{(d^2 - l^2)^2}{2d} \times \tan\theta = a \qquad \ldots(1)$$

See. Determination of M by Deflection Magnetometer

Using the same magnet in an oscillation magnetometer,

$$MH = \frac{4\pi^2 I}{t^2} = b \qquad \ldots(2)$$

(See expt. with an Oscillation magnetometer)

Dividing (2) by (1)

$$H^2 = \frac{b}{a} = \ldots \quad \ldots(3)$$

$$\therefore \quad H = \sqrt{\frac{4\pi^2 I \times 2d}{t^2 \times (d^2 - l^2)^2 \tan\theta}}$$

$$= \frac{2\pi}{t(d^2 - l^2)} \sqrt{\frac{2Id}{\tan\theta}}$$

Order of Accuracy

The maximum of error in H is

$$\frac{\partial H}{H} \times 100 = \left[\frac{5}{2} \times \frac{\partial d}{d} + \frac{1}{2}\frac{\partial\theta}{\theta} + \frac{\theta t}{t}\right] \times 100$$

Magnetism

1. Define pole, unit pole, pole strength and magnetic moment.
2. What is the difference between the real length and the effective length. How are they related ?
3. State Coulomb's law of magnetic forces.
4. Define magnetic field. What is the intensity of magnetisation ?
5. What is line of force ?
6. Define a magnetic field and intensity of magnetic field.
7. What is neutral point ?
8. Define magnetic flux and flux density ?
9. Explain why the neutral points are obtained on the axis of the magnet produced when it is placed in the magnetic meridian with its n-pole pointing south, and on the equatorial line when placed with its n-pole pointing north.
10. What is meant by the horizontal component of the earth's field ?
11. What is a Gauss ?
12. What is Telsa ?
13. Can you isolate a single pole of a magnet ? Give reasons for your answer.
14. While performing experiments on magnetism, why is it necessary to remove other magnets and magnetic substances from the working table.
15. Why shouldn't you heat or rough handle a magnet ?
16. State Tangent law of magnetic forces.
17. What is a Deflection Magnetometer ? Why is it so called ?
18. What is Null Deflection method ?
19. What is an Oscillation magnetometer ?

Terrestrial Magnetism

A. Magnetic Elements at a Place

(i) Horizontal component of the earth's field at a place. It is the resolved part of the total intensity I at a place in the horizontal direction.

(ii) Vertical Component V

(iii) Declination: It is the angle between the geographical meridian and the magnetic meridian at a place.

(iv) Inclination Dip δ - It is the angle between the direction the total intensity I of the earth's field and its horizontal intensity.

Thus from fig. 14.11, we have,

$$H = I \cos \delta$$

$$V = I \sin \delta$$

$$H_2 + V_2 = I_2$$

$$\frac{V}{H} = \tan \delta$$

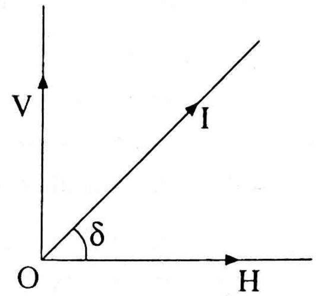


Fig. 14.11

B.

(a) When the dip circle is placed in a plane making an angle θ with the magnetic meridian, the angle of dip measured in this position is known as the apparatus dip δ_1 and is given by

$$\tan \delta = \cos \theta \tan \delta_1.$$

(b) If δ_2 be the angle of dip measured by the dip circle in another plane through OR_2 making an angle of 90° with OR_1, the true dip is given by

$$\cot^2\delta = \cot^2\delta_1 + 1 \cot^2\delta_2.$$

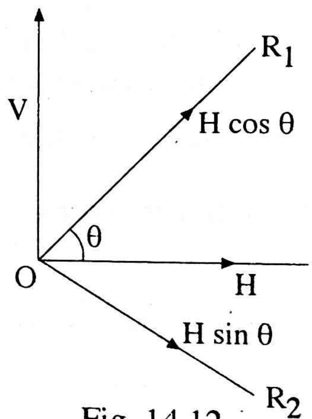


Fig. 14.12

Experiment No. 14.10

To Determine the Value of Dip in the Laboratory using a Dip circle

1. Apparatus Required

(i) Dip. circle (ii) A sprit level.

2. Description the Apparatus

Refer to any text book.

3. Theory

(a) Bringing the Dip. circle in the magnetic meridian.

The dip at a place may be defined as the angle between the direction of the total intensity of the earth's magnetic field and the horizontal component at that place.

4. Procedure

(i) The magnets and the magnetic substances are removed from the working tables.

(ii) The dip circle is levelled properly with the help of the levelling screws and the spirit level.

(iii) The box is rotated about a vertical axis till and magnetic needle becomes vertical and point along the line 90 - 90 line. The index mark is brought to zero position by rotating the horizontal circular scale at the base, turning a screw provided there.

(iv) From this position, the box is rotated further through 90° about the vertical axis over the horizontal scale to bring the needle in the magnetic meridian. The readings of the upper end and the lower end of the dip-needle are noted.

(v) The needle is reversed in its bearings. The readings of the upper end and the lower end of the dip-needle are noted.

(vi) The box is next turned through 180°. Here it will be in the position 270° in the horizontal scale. The above four readings are repeated.

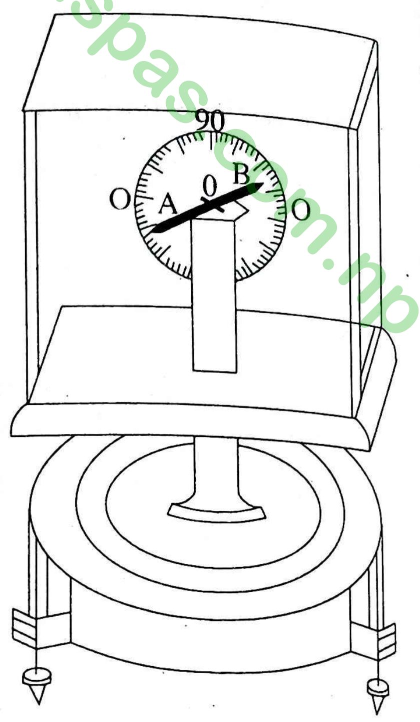


Fig. 14.13

(vii) The dip-needle is remagnetised so as to reverse its polarity by double touch method. All the above eight readings are repeated.

(viii) The mean of these 16 readings gives the value of true dip at a place.

5. Observations

Table No. 14.11

Position at which the box is fixed	Position of the needle	Needle Readings		Mean δ of 16 readings
		Upper end	Lower end	
90°	Front Reversed			
(Box turned through 180°) 270°	Front Reversed			
Needle Remagnetised				
90°	Front			
	Reversed			
(Box turned through 180°) 270°	Front Reversed			

3. Theory

(b) Without bringing the Dip- circle in the magnetic meridian.

If δ_1 and δ_2 be the values of the apparent dip at a place in any two positions of two vertical planes at right angles to each other, the value of true dip δ at that place is given by

$$\cot^2\delta = \cos^2\delta_1 + \cot^2\delta_2.$$

4. Procedure

(i) Operations (i), (ii) and (iii) of the previous expt. are repeated about the vertical axis over the horizontal scale, first eight readings of the previous expt. are repeated.

(iii) Next the box is rotated further through 90° over the horizontal scale i.e. it is kept at 90° + θ. The above eight readings are repeated.

(iv) The needle is remagnetised. Operation (ii) is repeated. The mean of those 16 readings gives the value of δ_1.

(v) Operation (iii) is repeated. The mean of these eight readings and those from operation (3) gives the value of δ_2 observations re-entered as shown below and the result is calculated.

5. Observations

Table no. 14.12

Position at which the box is fixed	Position of the needle	Needle Readings		Mean δ	Mean δ_1	Mean δ_2
		Upper end	Lower end			
1. θ°	Front Reversed					
(Box turned through 180°) 2. (θ+ 180°)	Front Reversed					
3. (θ + 90°)	Front Reversed					
4. (Box turned through 180°) (θ + 90° + 180°)						
Needle Remagnetised						
1. θ°	Front Reversed					
2 (θ + 180°)	Front Reversed					
3. (θ + 90°)	Front Reversed					
4. (θ + 90° + 180°)	Front Reversed					

Needle Remagnetised

Calculation

Hence $\cot^2\delta = \cot^2 \delta_1 + \cot^2 \delta_2$

$\therefore \quad \delta = \ldots\ldots\ldots$

Precaution

(1) The instrument must be properly levelled to make (a) the base horizontal (b) the plane of rotation of the needle vertical and (c) to avoid any obstruction the needle during its rotation.

(2) During the expt. all magnets and magnetic substance should be removed from the working table.

(3) Parallax should be removed while teaching observations.

Experiment No. 14.11

To determine the value of Dip. at a place using an Earth Inductor

1. Appratus Required

(i) Ballistic Galvanometer with Lamp and scale arrangement

(ii) Earth Inductor

(iii) Resistance box R

(iv) Compass needle

(v) Tapping key k_2

(vi) Flug key K_1.

2. Theory

The total charge Q in coulomb passing through the Ballistic galvanometer (B.G.) due to flux change Q weber in the coil is given by

$$Q = \frac{Q}{R} \quad ...(1)$$

where R is the resistance in ohm in the circuit with horizontal coil, $Q_1 = 2\eta$ abvη where η is the no. of turn in the coil of face are a A. Bv is the earth's vertical component of its magnetic flux density. With the coil vertical initially.

$$Q_2 = 2\eta \text{ ABH}$$

where BH is the horizontal component.

$$\therefore \quad \frac{Q_1}{Q_2} = \frac{B_v}{B_H}$$

But $\quad Q \propto \theta$

But $\quad Q \propto \theta$

$$\therefore \quad \frac{B_v}{B_H} = \frac{\theta_1}{\theta_2} = \tan\delta$$

$$\tan\delta = \frac{\theta_1}{\theta_2} \quad ...(2)$$

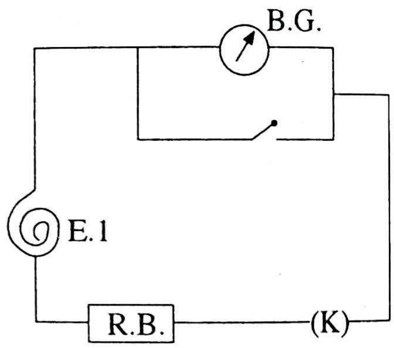


Fig. 14.14

where δ is the angle of dip.

3. Procedure

(i) The galvanometer, resistance box and the earth inductor coil via its slipping contacts are connected in series. Care should be taken to place the galvanometer well removed from the inductor, since it contains a strong magnet.

(ii) The earth inductor is adjusted to keep its axis horizontal and turned through 180°. The deflection of the galvanometer is observed. If it goes outside the scale the value of R is increased so as to keep the deflection just within it. The galvanometer throw is accurately measured on both sides of zero, for several quick turns of the coil starting with the coil horizontal.

(iii) Next the plane of the coil is placed vertical with its axis pointing east west. Rotating the coil through 180°, the throw of the galvanometer is measured.

4. Observation

Table No. 14.13

No. of obs.	Throws with coil				$\tan\delta = \frac{\theta_1}{\theta_2}$	δ
	Horizontal θ_1	Vertical θ_2	Mean θ_1	Mean θ_2		
1						
2						
3						

Conclusion

Thus the value of dip.........

Errors

The value of δ obtained from different values of throws θ should be evenly spread on either side of the mean value. The extent of this spread is a measure of the maximum error. There may be error due to damping in the measurement of θ. The value of θ is corrected for damping by adding to it $\frac{1}{4}(\theta - \theta_1)$ where θ_1 is the next throw of the needle on the same side as the first throw.

Chapter 15
Current Electricity

15.1 Preliminaries

Electrical Potential

It is the condition which determines the direction of flow of charge in much the same way as temperature which determines the direction of the flow of heat energy between two bodies. If two bodies are at different electrical potentials and are in metallic contact, positive charge always flows from the body at a higher potential to that at a lower potential. The flow continues so long as there is difference of potential.

Potential Difference (P.D.)

It is measured in terms of the amount of work done to move a unit positive charge from one point to the other. In S.I., it is known as volt. The P.D. between two points is one volt if one joule of work has to be done in carrying one coulomb of charge from one point to the other. It is measured by an instrument known as voltmeter which is always connected in parallel across the points between which the P.D. has to be measured.

Electric Current

An electric current is just the flow of charge. Conventionally the electric current flows from the higher potential anode to the lower potential cathode, while actually charge is carried by the electrons flowing in the opposite direction. It is an electron current.

The current is measured by the rate of flow of charge. Thus the current

$$I = \frac{\text{charge}}{\text{time}} = \frac{Q}{t}$$

where Q is the amount of charge flowing in time t sec.

In SI unit, it is expressed in ampere which is equal to the flow of one coulomb of electric charge in 1 sec. It is measured by means of an instrument called an ammeter which is always connected in series in the circuit.

Ohm's Law

Ohm's law states that the current I flowing through a conductor is directly proportional to the potential difference v across its ends, provided the physical conditions of the conductors of the conductor remain the same.

Thus $$I \propto V$$

or $$I = \frac{V}{R}$$

or $$\frac{V}{I} = R = \text{constant}$$

Where R is a constant depending on the dimensions and material of the conductor and is known as its electrical resistance. It has the property of opposing the flow of current through the conductor.

We have $$R \propto \frac{l}{a}$$

where l is the length of the conductor 'a' its cross section.

$$R = \rho \frac{l}{a}$$

where ρ is a constant called the resistivity depending on the nature of the material from which the wire is made.

Here when l is in m, a in m^2 and R in ohms, ρ is in ohm-meter.

Resistors in Series

If a no. of resistors be connected in series (i.e. end to end), then the total (or equivalent) resistance is the sum of the separate resistances. Thus if r_1, r_2 are two resistances in series, then the total resistance R is given by

$$R = r_1 + r_2.$$

Resistors in Parallel

If a no. of resistors be connected in parallel (i.e. the two ends of each are connected to two common points), then their equivalent resistance R is given by

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$$

$$\therefore \quad R = \frac{r_1 r_2}{r_1 + r_2}.$$

Experiment No. 15.1

To investigate the relation between the potential difference across a conductor and the current through it. Hence determine its resistance or To verify Ohm's law by Ammeter and Voltmeter

1. Apparatus Required:

(i) Ammeter (A) (ii) Voltmeter (V) (iii) Accumulators (iv) Plug key (K)

(v) Rheostat (R) (vi) Given Resistance wires (vii) Connecting wires.

2. Theory

Ohm's law state "At a constant temperature, the current flowing through any conductor is directly proportional to the difference of potential at its ends".

(A) First Method

If I and V represent respectively the ammeter and voltmeter readings, Ohm's law states that

$$I \propto V$$

or $I = \frac{V}{R}$ or $\frac{V}{I} = R$ (constant)

Thus the constant value of $\frac{V}{I}$ verifies Ohm's law.

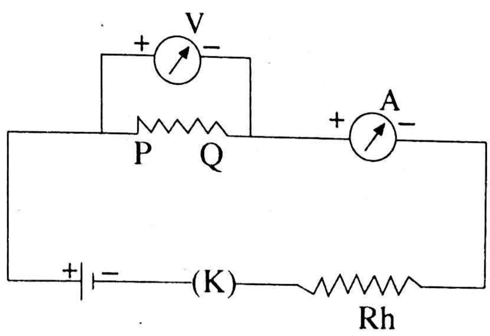


Fig. 15.1

Also V = RI

This equation is of the form y = mx which represents a straight line passing through the origin.

∴ the graph of V against I should be a st. line passing through the origin.

3. Procedure

(i) A circuit is completed as shown in the diagram. Starting from the positive pole of the battery, a connecting wire is joined to the left end of the wire PQ stretched alongside a meter scale fixed on a wooden board having binding screws at its ends. The + ve terminal of the voltmeter (V) is joined to the end P and the negative terminal to Q.

The negative terminal of the battery is then connected to be negative terminal of the ammeter, the positive of cohich is connected to Q through a rheostat Rh and a plug key K in between.

(ii) The value of 1 smallest division of the ammeter and the voltmeter are noted.

(iii) The Rheostat is adjusted to such a position for which the ammeter is giving a reading like 0.05 amp of 0.1 amp. The voltmeter corresponding to this is noted when the key is closed.

(iv) Operation (3) is repeated for at least 5 or 7 different readings in the ammeter as 0.05 amp. 0.1 amp, etc. Corresponding readings in the voltmeter are noted.

(v) Operations (3) and (4) are repeated for two more resistance wires X.

(vi) Finally, a graph of V (voltmeter) reading is plotted against I (ammeter) readings. It will be a straight line passing through the origin, which verifies the law.

4. Observations

Value of 10 smallest divisions of ammeter = ...volt.

∴ Value of 1 smallest divisions of ammeter = ...amp

Value of 10 smallest divisions of voltmeter = ...amp

∴ Value of 1 smallest divisions of voltmeter = ...volt

(a) Keeping the length of the stretched wire constant

Table No. 15.1

Position of X	No of obs.	Ammeter reading I amp.	Voltmeter reading V			$\frac{V}{I}=R$	Mean $\frac{V}{I}=R$	Remarks
			I - Increasing	Decreasing	Mean V volts			
	1							
	2							
X_1 = cm	3							
	4							
	5							
	1							
	2							
X_1 = cm	3							
	4							
	5							
	1							
	2							
X_1 = cm	3							
	4							
	5							

5. Conclusion

The value of $\frac{V}{I}$ is found to be sensibly constant. Also the graph of V against I is found to be straight line passing the origin. Hence Ohm's law is verified.

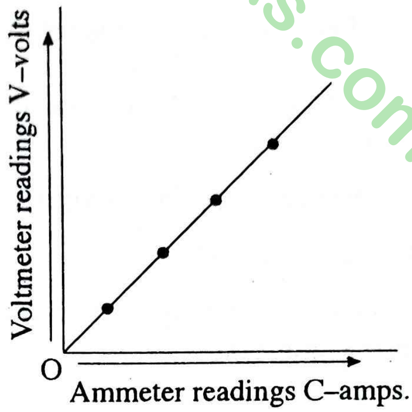


Fig. 15.2

(B) Second Method

As in the previous expt. according to Ohm's law,

$$I \propto V, I = \frac{V}{R}$$

where R is the resistance of the conductor.

Now if I be kept constant $\frac{V}{R} = I$ (constant)

or $V = IR = I_1$

∴ $R \propto l$ where l is the length of the conductor.

This equation is of the form y = mx which represents a straight line passing through the origin. Hence a graph of V and l should be a straight line through the origin.

Thus the constant value of $\frac{V}{l}$ verifies Ohm's Law.

3. Procedure

The position of the Rheostat is kept fixed so as to keep the current constant throughout the expt. The jockey is placed at say 20 cm. of the stretched wire. The key is closed and the voltmeter reading is noted. This operations of the jockey which ensure the different values of l and hence different values of R. Observations are noted as shown below.

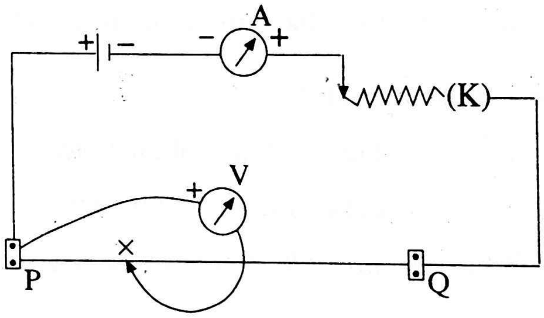


Fig. 15.3

4. Observation

Value of 10 divs. of the voltmeter = ...volts

∴ Value of 1 divs. of the voltmeter = ...volts.

(B) Keeping the ammeter reading (I) constant

Table No. 15.2

I Reading const. at	No. of obs.	Length of the stretched wire l cm.	Voltmeter (V) reading V			$\frac{V}{l}$	Mean $\frac{V}{l}$	Remarks
			l - Increasing	l – Decreasing	Mean V volts			
	1							
	2							
	3							

5. Conclusion

The value of $\frac{V}{l} = I$ is found to be sensibly constant.

The graph of V reading against l is found to be a straight line passing through the origin.

Hence Ohm's law is verified.

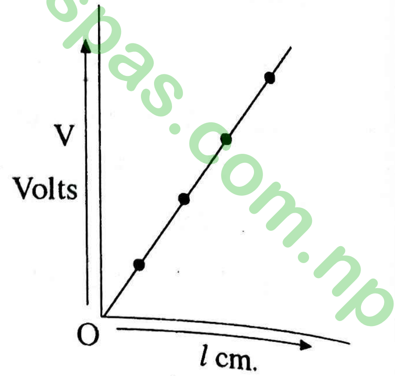


Fig. 15.4

(C) Third Method

Ohm's law may also be verified by varying I and l in such a way as to keep V constant.

$$\frac{V}{l} = I$$

Thus $$I_1 = V \text{ (constant)}$$

This equation is of the form xy = k. which represents a rectangular Hyperbola. Hence a graph of I and l should be a rectangular hyperbola.

3. Procedure

Hence the value of the voltmeter reading is kept constant at a certain value. The ammeter reading and the position of the jockey along the stretched wire are noted. Next the ammeter reading is altered in regular steps and the position of the jockey along the wire is also adjusted so as to keep the voltmeter reading constant at the same previous value. Observation are noted as shown below.

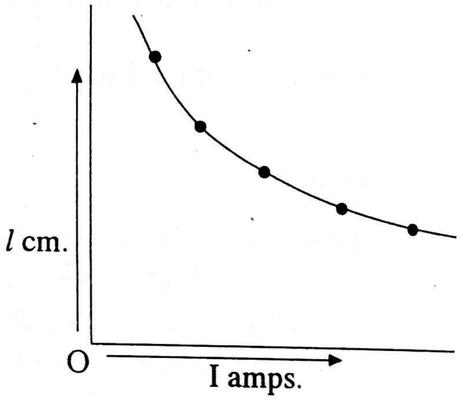


Fig. 15.5

4. Observations

Value of 10 divs of ammeter = ...amp

∴ Value of 1 divs of ammeter = ... amp

(C) Keeping the voltmeter reading constant

Table No. 15.3

Voltmeter Reading constant at	No. of obs.	Ammeter amps.	Position of the Jockey l			$Il = V$	Mean Il	Remarks
			I - Increasing	I - Decreasing	Mean l			
	1							
	2							
	3							
	4							
	5							
	...							
	...							

5. Conclusion

The product Il is found to be sensibly constant. The graph of l against I is found to be a rectangular hyperbola. Hence Ohm's law is verified.

Experiment No. 15.2

To verify the law of (a) Series and (b) Parallel resistors or resistances.

1. Apparatus Required

(i) Ammeter (ii) Voltmeter (iii) Rheostat (iv) Battery

(v) Two resistors (vi) Plug key (vii) Connecting wires.

2. Theory

(a) The law of series resistors states that the equivalent resistance of a number of resistors in series is equal to the sum of the individual resistances. Thus if r_1 and r_2 are the resistance of two resistors, then their equivalent resistance is given by

$$R = r_1 + r_2.$$

where r_1, r_2 and R can be known by applying Ohm's law as in expt. no. 15.1 (a).

(b) The law of parallel resistors states that the reciprocal of the equivalent resistance of a number of resistors in parallel is equal to the sum of the reciprocals of the individual resistances. Thus if r_1 and r_2 are the resistances of two resistors, then their equivalent resistance R is given by

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$$

$$\therefore \quad R = \frac{r_1 r_2}{r_1 + r_2}$$

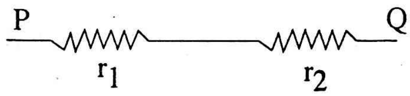


Fig. 15.5(a)

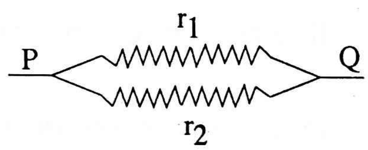


Fig. 15.5(b)

3. Procedure

(i) Connections are made as shown in fig. 15.5(a) and (b).

(ii) The value of the individual resistances r_1 and r_2 are determined as in expt. 15.1(a) using r_1 and r_2 in turn.

(iii) Then r_1 and r_2 are connected in series as in fig. 15.5(b) and total R determined as in operation (2).

(iv) r_1 and r_2 are connected in parallel as in fig. 15.5(b) and total R is determined.

(v) Then calculation is done as per theory (a) and (b).

Experiment No. 15.3

To verify Ohm's law by Tangent Galvanometer

1. Apparatus Required

(i) Tangent Galvanometer (ii) Accumulators (iii) Pohl's Commutator

(iv) Plug key (v) Resistance Box (vi) Connecting wires.

2. Theory

Ohm's law states - "At a constant temp., the current flowing through any conductor is directly proportional to the difference of potential at its ends".

If E be the e.m.*f*. of the whole circuit given below B the battery resistance, R the resistance from the box, the current I flowing through the circuit is given, according to Ohm;s law by

$$I = \frac{E}{G + R + B'} \quad ...(1)$$

where G is the resistance of the Tangent Galvanometer.

From the diagram, it is evident that I is also passing through the Tangent Galvanometer.

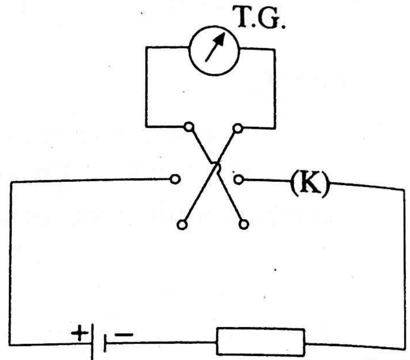


Fig. 15.6

$\therefore$ In a Tangent Galvanometer

$$I = 10 \, k \tan\theta \text{ amps} \quad ...(2)$$

where K is the reduction factor of the galvanometer and θ is the deflection produced in it.

From (1) and (2)

$$\frac{E}{G + R + B'} = 10K \tan\theta$$

when $B < (G + R)$, we have $\frac{E}{G + R} = 10 \, K \tan\theta$

$$(G + R) \tan\theta = \frac{E}{10K} = m \text{ (constant)} \quad ...(3)$$

If G be known, it may be enough to show that $(G + R) \tan\theta$ = a constant which verifies Ohm's law.

In case G is not known, we have from (3)

$$G + R = \frac{m}{\tan\theta} = m \cot\theta$$

or

$$R = m \cot\theta - G \quad ...(4)$$

This equation is of the form $y = mx + C$, which represents a straight line not passing through the origin. Hence the graph of $\cot\theta$ against R should be a straight line not passing through the origin.

3. Procedure

(i) A circuit is made as shown in the diagram.

(ii) The Tangent Galvanometer is properly levelled and adjusted carefully so as to keep it in the magnetic meridian. The no. of turns in it is adjusted so as to make the deflection not above 60° or 65° when the resistance in the box is zero.

(iii) With zero resistance in the box, the key is closed. The readings of both the ends of the galvanometer pointer are noted for direct current. Next the current is reversed by Pohl's commutator and the above reading are noted again.

(iv) The resistance in the box is gradually increased in regular steps. Operation (3) is repeated. At least seven different observations are taken. The deflection should lie between 30° and 60° or 65°. Readings are noted as shown below.

(v) The cotangent of different values of deflections is found out from Log tables. A graph of cot θ is plotted against R which will be a straight line not passing through the origin.

4. Observation

Table No. 15.4

No, of obs	R in Ohms from the Resistance Box	Deflection of the Pointer for Current				Mean θ	Cot. θ
		End I	End II	End I	End II		
1							
2							
3							
4							
5							
6							
7							
...							
...							

Conclusion

The graph of cot θ against R is found to be a straight line not passing through the origin, which verifies Ohm's law. Further from graph.

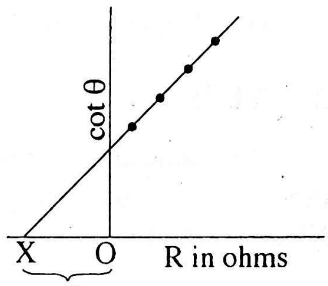


Fig. 15.7

At X, cot θ = O, or R = - OX

∴ from eqn. (4) R = m cot θ - G

we get, $-OX = m \times O - G$

∴ $OX = G$

∴ G = OX ohm

Thus the negative intercept along the x-axis gives the galvanometer resistance. Knowing the vaue of G, the following table is prepared with the help of the observations above.

Table No. 15.5

No. of obs	R in Ohms from the Resistance Box	Mean deflection θ	Tan θ	G from graph	R + G	(R + G) × tan θ	Remarks
1							
2							
3							
4							
5							
6							
7							
...							
...							

6. Conclusion

The graph of tan θ against R + G is found to be a Rectangular Hyperbola.

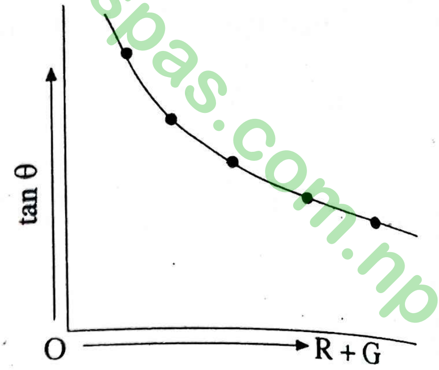


Fig. 15.8

Experiment No. 15.4

To determine (i) the reduction factor of a Tangent Galvanometer (ii) Electrochemical Equivalent of a metal (iii) the value of H using a Tangent Galvanometer.

1. Apparatus Required

(i) Tangent Galvanometer (ii) Copper Voltmeter (iii) Pohl's commutator

(iv) Plug key (v) Accumulators (vi) Rheostat

(vii) Balance weight box (viii) Stopwatch.

2. Theory

The amount of the ions (w) liberated at an electrode is, according to Faraday's first law of Electrolysis give by

$$w = ZIt \quad \ldots(1)$$

where Z is the electrochemical equivalent of the element, I is the current flowing through the circuit for t secs.

But the same current is flowing through the Tangent Galvanometer also,

$$\therefore \quad I = 10\,K \tan\theta \quad \ldots(2)$$

where K is the Reduction Factor of the Tangent Galvanometer, θ is the deflection in it.

From (1) and (2) we get

$$w = Zt.\ 10\,K\tan\theta$$

$$\therefore \quad K = \frac{w}{10Zt\tan\theta} \quad \ldots(3)$$

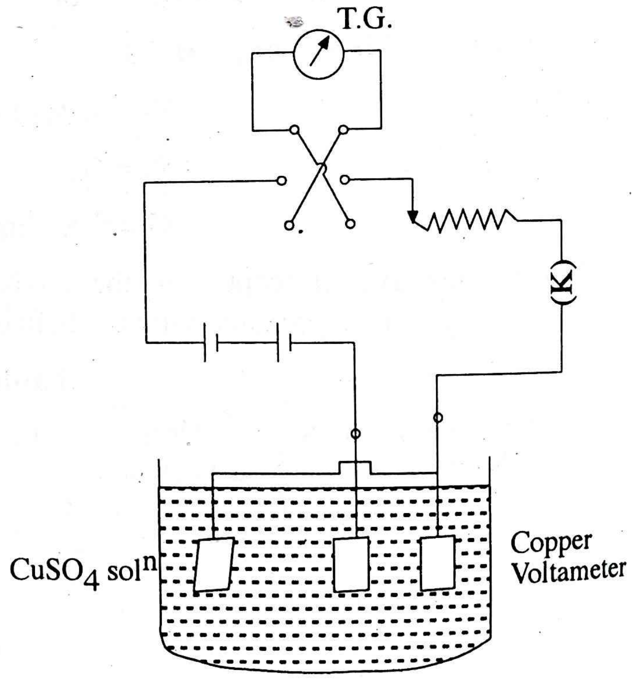


Fig. 15.8(a)

3. Procedure

(i) The Tangent Galvanometer is properly levelled and placed with the plane of its coil along the magnetic meridian In this position the pointer reads 0 - 0.

(ii) A circuit is made as shown in the diagram

(iii) The Rheostat is adjusted so as to produce a deflection of about 45°. The error will be minimum in this position. The circuit is tested by immersing a cathode plate in the copper voltammeter.

(iv) Another cathode plate is taken. The plate is rubbed several times with a piece of sand paper. It is rinsed in tap water, immersed in a breaker containing Sodium Hydroxide solution, then in another beaker containing a drop or two dilute sulphuric acid. This will ensure the removal of any greasy substance, if there be any. It is then finally rinsed with distilled water.

(v) The plate is then dried in a hot air-bath or by blowing hot air against it. It is weighed very accurately.

(vi) It is then replaced in the Copper Voltameter, containing 10 to 15% Copper sulphate solution. The current is switched on and stop watch is started simultaneously.

(vii) The current is contained for at least 30 to 45 minutes, reversing the current in the galvanometer every five minutes. During the interval, if the deflection slightly changes, it may be brought back to its original value by adjusting the rheostat.

(viii) After this interval, the current and the watch are simultaneously stopped. The cathode plate is removed and carefully washed in distilled water. It is then dried over a heater carefully holdings it at least one foot above to avoid oxidation. It is weighted again. The difference between this and the previous weight gives the amount w of the ions liberated.

(ix) The e.c.e. is noted from the Physical tables and K is calculated.

(x) The value of K obtained thus is checked by actual calculation and the % error is calculated.

4. Observations

Initial weight of the cathode plate = w_1 = ...gms.

Final weight of the cathode plate = ...w_2 = ...gms.

∴ Amount of the ions liberated = $w_2 - w_1 = w$ = ... gms.

Table No. 15.6

Time in min.	Current Direct		Current Reversed		Mean Deflection θ
	End I	End II	End I	End II	
0					
5					
10					
15					
...					
...					

5. Calculation

z for Cu from Physical Tables = 0.00033 gm/coulomb.

$$\therefore \quad K = \frac{w}{10Zt \tan\theta} = \ldots\ldots\ldots \text{(obs. value O)}$$

(C) = Correct value of $K = \frac{Hr}{2\pi n}$ where H is the value of the earth's field in the laboratory, r is the radius of the coil, n is the no. of turns of the coil.

$$\therefore \quad \% \text{ error} = \frac{C - O}{C} \times 100 = \ldots\ldots$$

Errors may be due to

1. error in weighing
2. errors in measuring time
3. errors in noting θ

Order of Accuracy

∴ The maximum % error I k is

$$\frac{\partial k}{K} \times 100\% = \left[\frac{\partial w}{w} + \frac{\partial t}{t} + \frac{\partial \theta}{\theta}\right] \times 100\%$$

(ii) Determination of the e.c.e. of a metal

From equation (3) above

$$\frac{Hr}{2\pi n} = \frac{w}{10Zt \tan\theta} \quad \ldots(4)$$

$$Z = \frac{2\pi nw}{10Hrt \tan\theta} \quad \ldots(5)$$

where n is the no. of turns in the Galv. r is the radius of the coil.

Procedure

Same as above

Order of Accuracy

The maximum % error in Z is

$$\frac{\delta Z}{Z} \times 100\% = \left[\frac{\delta w}{w} + \frac{\delta r}{r} + \frac{\delta t}{t} + \frac{\delta \theta}{\theta}\right] \times 100\%$$

(iii) Determination of the value of H.

from (4), we get

$$H = \frac{2\pi nw}{10Hrt \tan\theta} \quad \ldots(6)$$

Procedure

Same as above

Exercises

1. State Ohm's law. Why does Ohm's law insist that temperature should be constant ?
2. What is the unit of current and potential difference ?
3. What is an ampere ? What is a coulomb ?
4. What is an Ammeter ? What is a voltmeter ? How do you connect them in a circuit ?
5. What is the differences between e.m.f. and p.d. ?
6. What is the function of a Rheostat ?
7. Mention the factors on which the resistance of a conductor depend ?
8. Name the common materials used as resistance wires.
9. What are Ohmic and non-Ohmic conductors ?
10. What is a shunt ?
11. Define resistivity. State its units.
12. Why should a wire resist the flow of electrons through it ?
13. What is a cell or a battery ?
14. Distinguish between a Primary cell and a Secondary cell.
15. What are the defects of a simple cell ? How are they removed in a (i) Leclanche cell (ii) Deniell cell ?
16. What is a standard cell ?
17. What is a Tangent Galvanometer ? Why is it so called ?
18. What is the Reduction factor of a Tangent Galvanometer ?
19. State Faraday's laws of Electrolysis.
20. What is the e.c.e. of an element ?
21. What is the difference between a voltmeter and a voltameter ?

Experiment No. 15.5

To Use a Meter Bridge to (i) Determine the Specific resistance (resistivity) of the given wire (ii) Compare the resistances of two given wires.

1. Apparatus Required

(i) Meter Bridge	(ii) Two way key
(iii) resistance Box	(iv) Leclanche cell
(v) Connecting Wire	(vi) Screw Gauge.

2. Theory

The principle used in the determination of resistance by Meter Bridge lies in the application of Wheatstone Bridge.

According to Wheatstone Bridge Principle, if P, Q, R, X be four resistances (X) being an unknown resistance connected as shown in the diagram, G, a table moving coil galvanometer and E, a Leclanche cell, then for null deflection the galvanometer.

$$\frac{X}{R} = \frac{P}{Q} \qquad \ldots(1)$$

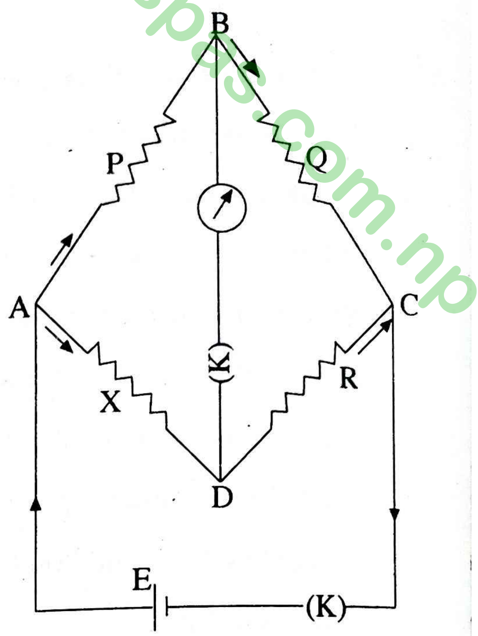


Fig. 15.9

Now if the above Wheatstone Bridge circuit be applied in the Meter Bridge, the circuit will be as shown in the diagram No. 15.10.

Let B be the point along the bridge wire when the galvanometer deflections zero. Then if r = resistance per cm. of the bridge wire, length of AB = l, and that of BC = 100 - l, then from (1)

$$\frac{X}{R} = \frac{P}{Q} = \frac{l_r}{(100 - l)\, r} = \frac{l_1}{100 - l} \qquad \ldots(2)$$

$$\therefore \quad X = \frac{l}{100 - l} \text{ R ohms} \qquad \ldots(3)$$

Next $\quad X = \rho\frac{L}{A}$

When ρ is the specific resistance of the material of the wire, which is nothing but the resistance of a unit length the wire of unit cross-section. A is the area of correction of the wire, L is the length of the cross-section wire used.

Thus $\quad A = \frac{\pi d^2}{4}$

where d is the diameter of the wire

$$\therefore \quad X = \rho\,\frac{4L}{\pi d^2}$$

$$\therefore \quad \rho = \frac{\pi d^2}{4L} \text{ X ohm m} \qquad \ldots(4)$$

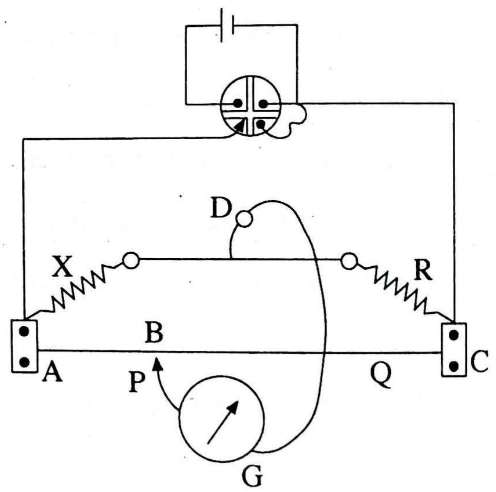


Fig. 15.10

3. Procedure

(i) A circuit diagram is drawn and completed as shown above.

(ii) The key is closed. The jockey is pressed at one end of the bridge wire. There will be a deflection in the galvanometer say to the left. Next the jockey is moved to the right end and pressed. If the circuit is all right, the deflection should be opposite to that observed just previous to this i.e. the deflection should now be right.

(iii) In the diagram, the unknown resistance X is in the left gap and the known resistance say one or 2 ohms is plugged out from the box R. Keeping the key closed, the jockey is moved from left to right and a null point such as B is obtained for which the galvanometer reads zero. The position of B along the wire is noted. It is again obtained and noted when the jockey is moved right to left.

(iv) The current is reversed by means of the two-way key in the battery circuit. Operation (3) is repeated.

(v) Next the resistances of 3 and 4 ohms are plugged out from the resistance box R and operations 3 and 4 are repeated in order.

(vi) After this, the resistance box and the unknown resistance X are interchanged. Operations (iii), (iv) and (v) are repeated. Observations are noted as shown in the table below.

(vii) The length of the wire X is measured with the help of a piece of thread and a scale.

(viii) The diameter of the wire is measured by means of a screw gauge at 5 different positions. The mean diameter is noted. Calculation is shown below.

4. Observations

Table No. 15.6

No. of Obs	Resistance in the gap		Position of the null point left				mean n l cm	100 - l ohm.	X-left $X = \frac{lR}{(100-l)}$	X = right $X = \frac{(100-l)}{l}R$	Mean x ohms
	left	right	Direction Current		Received current						
			sliding from left cm.	sliding from right cm.	sliding from left cm.	sliding from right cm.					
1	X	R									
	R	X									
2	X	R									
	R	X									
3	X	R									
	R	X									

Length of the wire = ...cms = Lm

Diameter of the wire = $\frac{1}{5}$ (......+ ......+ ......+......+.........)

5. Calculation = ...=......cms, = d.m

From equation (4) above,

$$\therefore \quad \rho = \frac{\pi d^2 X}{4\ L} = \text{........}$$

Standard value of ρ (from Physical Tables) = ...ohm.

$$\therefore \quad \%\text{error} = \frac{C - O}{C} \times 100\text{......}$$

Conclusion

Thus the resistance X measured is found to be ......Ω

Error

(i) The length l = ...(i.e. position of the jockey) may be read upto say = 1 mm.

(2) The accuracy of the location of the balance point is quite significant. To estimate this, the distance through which the jockey has to be moved to cause a just perceptible deflectionof the galvanometer is found out.

(3) The bridge may not be exactly l meter long. Its exact length should be recorded and used inthe calculation.

Order of Accuracy

The maximum % error in the measurement of X is given by: Maximum % error in

$$X = \frac{\partial X}{X} \times 100\% \left[\frac{\partial l}{l} + \frac{\partial(100 - l)}{l}\right] \times 100$$

(ii) Comparison of Resistance.

1. Apparatus Required

Same as in Expt. No. 15.5 (i)

2. Theory

Same as in Expt. No. 15.5(i)

3. Procedure

(i) Same as above

(ii) Same as above

(iii) X and R are both the unknown resistance to be compared. First X is inserted in left and R in the right. Now without any known resistance in the right gap, operations (3), (4) and (6) in the previous experiment are repeated. The same operations may be repeated by changing the current in the circuit by adjusting the Rheostat. Observations are noted as shown below.

4. Observations

No. of Obs	Resistance in the gap		Position of the null point left				point mean	100 - l ohm.	X-left $\frac{X}{R} = \frac{l}{100 - l}$	$\frac{X}{R} = \frac{(100-l)}{l}$	Mean $\frac{X}{R}$
	left	right	Direction Current		Received current		n l				
			sliding from left cm.	sliding from right cm.	sliding from left cm.	sliding from right cm.					

Experiment No. 15.6

To use a P.O. Box to (i) Determine the resistance of the given wire and hence calculate its resistivity (ii) Verify the laws of Series and Parallel Resistances.

(i) Apparatus required

(i) P.O. Box, (ii) Resistance Wire (iii) Leclanche cell (iv) Connecting Wires.

2. Description of P.O. Box

Refer to any text Book.

3. Theory

Whetstone Bridge Principle: Same as in the previous expt.

For null Deflection in the galvanometer,

$$\frac{X}{R} = \frac{P}{Q}$$

where P and Q are the resistances in the ratio arms, R that in the resistances in the ratio arms, R that in the resistance arm & X is the unknown resistance to be determined.

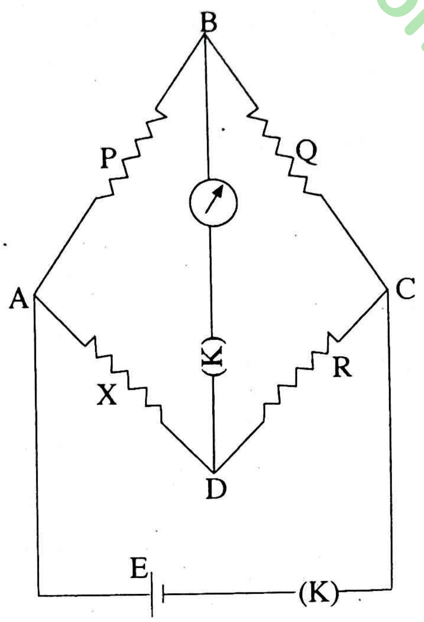


Fig. 15.11

$$\therefore \qquad X = R \times \frac{P}{Q} \qquad \ldots(1)$$

Hence the resistivity of the wire is

$$\rho = \frac{\pi d^2}{4} \cdot \frac{X}{L} \qquad \ldots(2)$$

where d is the diameter of the wire.

4. Procedure

(i) A circuit diagram is drawn and connections are made as shown in the diagram.

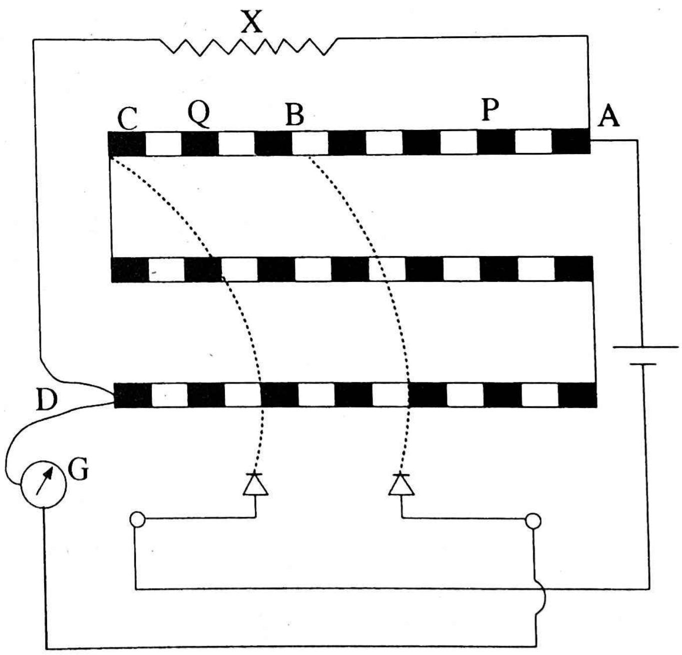


Fig. 15.12

(ii) Resistance plugs 10, 10 are taken out from the ratio arms AB and BC with Zero resistance in the third arm CD, the battery circuit is completed first and then the galvanometer circuit. If there be no break in the battery circuit, a deflection will be observed Next the plug marked "Infinity" is taken out and pressing the battery key and then the galvanometer key, the deflection is noted. If the connection is right, it should be in the opposite direction.

(iii) This operation is repeated by alternately taking out a low and a higher resistance plug from the resistance arm CD. Look for the opposite deflection in each case in order to determine the wide range between which the value of the unknown resistance lies. By trail deflections are obtained for a difference of 1 ohm. Thus the unknown resistance is known to be within one ohm.

(iv) Next resistance plugs 10 and 100 are taken out from the ratio arms AB and BC. The value of the resistance has also to be increased 10 times that in operation (3) Operation (3) is repeated till two values are obtained which differ by 1 ohm and for which the unknown resistance is known to be within a tenth of an ohm.

(v) Lastly inserting a resistance 10 times that in operation (4) from the resistance arm with the ratio arm 10:1000, the value of the unknown resistance is determined as in operation (3) till two values are obtained which differ by 1 ohm. Thus the value of X is known to be within a hundredth of an ohm.

(vi) If the deflections in the opposite directions are noted, the unknown resistance can be determined to the third decimal place. Observations are noted as shown below:

5. Obwrvations

Table No. 15.8

Ratio arms P:Q	Resistance in the third arm	Galvanometer Deflection	Inference about the unknown resistance compared to R
10:10	0	To the left	too small
	∞	.........right	too large
	10	slow...right	rather large
	5	slow...left	rather small
	6	slow...right	just large
			∴ X lies bet. 5 and 60
10:100	50	to the left	rather small
	60	.........right	rather large
	55	slow...left	just small
	56	slow...left	just small
	57	slow...right	just large
			∴ X lies bet. 5.6 and 5.7Ω
10:1000	560	to the left	small
	570	...... right	large
	565	... left (5 divs.)	just small
	566	... right (10 divs)	just large
			∴ X lies bet. 5.65 and 5.66Ω

Change in deflection of (5 + 10) i.e. 15 divs is due to a diff. of 1Ω

∴ ....1 div.........$\frac{1}{15}$

Hence......1 div.........$\frac{1}{15} \times 5$

∴ the required value of R = 565 + 0.333 = 565.333

We have,

$$\frac{X}{R} = \frac{P}{Q} = \frac{10}{1000} = \frac{1}{100}$$

∴ $$X = R \times \frac{1}{100}$$

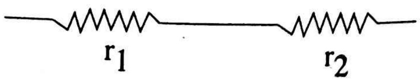


Fig. 15.13

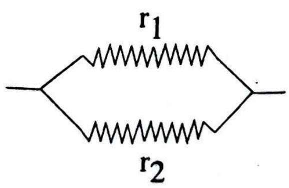


Fig. 15.14

$$= \frac{565.333}{100} = 5.65333\Omega$$

Hence the unknown resistance $X = 5.65333\ \Omega$

(ii) Verification of the laws of series and Parallel resistances.

1. Apparatus Required

Same as in the previous experiment

2. Theory

When resistance are joined in series, the equivalent resistance R is given by

$$R = r_1 + r_2 + \qquad ...(1)$$

where r_1, r_2...are the separate resistances.

When resistance are in parallel ,the equivalent resistance R is given by

$$\frac{1}{R'} = \frac{1}{r_1'} + \frac{1}{r_2} + \qquad ...(2)$$

3. Procedure

(i) Individual resistances r_1, r_2 etc. determined as in the previous expt.

(ii) They are then joined in series and then equivalent resistance R is determined.

(iii) They are then joined in parallel. The equivalent resistance R again determined.

(iv) Observations are entered and results calculated as shown below.

4. Observation

Table No. 15.9

Value of resistances					
$r_1\ \Omega$	$r_2\ \Omega$	$r_1 + r_2 = R$		$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$	
		Observed	Calculated	Observed	Calculated
1					
2					

Errors

1. In case the given galvanometer is relatively insensitive, then the error in X is clearly indicated by the range of values of R over which the null deflection is observable. For example, if opposite deflections are just detectable for $R = 566\ \Omega$ and $570\ \Omega$ then $R = 568 \pm 0.02\ \Omega$
2. The length of wire L should be actually the length between the points of emergence from the terminals. The error in the length is likely to be ± 2 mm. or more if care is not taken.
3. The errors in the measurements on the diameter d arise due to (i) lack of uniformity in the wire (ii) random errors of observation in the micrometer. Here the diameter being squared the error will be doubled & hence this is the most significant error.

Order of Accuracy

From the formula for ρ

Maximum % error in $\rho = \frac{\delta\rho}{\rho} \times 100\% = \left[\frac{\delta X}{X} + \frac{\delta L}{L} + \frac{2\delta d}{d}\right] \times 100\%$

Experiment No. 15.7

To use a Stretched Wire Potentiometer to compare the e.m.f's. of two cells.

1. Apparatus Required

(i) Stretched wire Potentiometer (ii) Accumulator (iii) Leclanche Cell

(iv) Daniell Cell (v) Table type moving coil galvanometer

(vi) Rheostat (vii) Two-way Key (viii) One-way Key, K1.

2. Theory

Let an accumulator of e.m.*f*. E, greater than that of the comparing cells of e.m.*f*s. E_1 and E_2, send a current from A to B through a long stretched uniform wire AB (representing the 10 wires of the potentiometer). Then there will be a gradual fall of potential along AB.

Now if a galvanometer be connected through a fairly high resistance R between A and a sliding key, on making contact with the potentiometer wire, a current depending on the P.D. across the length AP i.e. V_a - V. will flow through the galvanometer. However if two cells of e.m.*f*s. E_1 and E_2 be inserted between the galvanometer and the point A with a three way key in between them as shown in the diagram, (the + ve terminals being connected to A, so as to send an opposing current, the current through the galvanometer will now depend on the value $(V_a - V_p) - E_1$. If the sliding contact be made at P such that the galvanometer deflection be zero. Then $V_a - V_p = E_1$.

Hence the potential drop P.D. across the length l_1 of the potentiometer wire is equal to the e.m.*f*. of the cell E_1 as no current is being drawn from the cell. As the P.D. along a wire of uniform cross-section is proportional to the length

$$E_1 \propto l_1 \qquad ...(1)$$

Similarly, l_2 be the corresponding length for the cell E_2 for the null deflection of the galvanometer.

$$E_2 \propto l_2 \qquad ...(2)$$

Hence
$$\frac{E_1}{E_2} = \frac{l_1}{l_2} \qquad ...(3)$$

3. Procedure

(i) Connections are made as shown in the diagram.

(ii) The positive terminals of all the cells and the accumulator are connected to the point A. The negative terminals are connected as shown in the diagram.

(iii) The key is pressed on the first wire and almost the end of the last wire. Opposite deflections should be obtained. If so, connections are right. If not, the connections should be checked and necessary adjustment made so as to obtain opposite deflections.

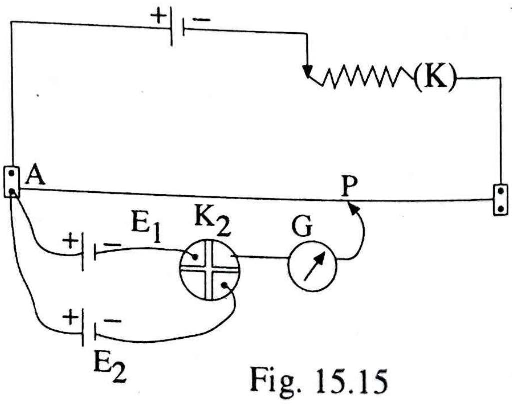


Fig. 15.15

(iv) The rheostat is so adjusted as to obtain the null point on the last or the last but one wire.

(v) Then the exact null point is determined sliding from left to right, and right to left. Each point is repeated thrice. The same is repeated for the cell E_2.

(vi) The Rheostat is changed slightly in the main circuit so as to change the P.D. along the potentiometer. Operation (5) is repeated for at least two such altered positions of the rheostat.

The mean null point is calculated for each set and $\frac{E_1}{E_2} = \frac{l_1}{l_2}$ is determined as shown below.

4. Observations

Table No. 15.10

No. of obs.	Null Point i.e. Length of the wire with Cell E_1 Mean l_1	Null Point i.e. Length of the wire with Cell E_2 Mean l_2	$\frac{E_1}{E_2}=\frac{l_1}{l_2}$	Mean $\frac{E_1}{E_2}$
1	....			
2	....			
3	....			

Error

1. During any set of measurements, the current in AB is assumed to remain steady. Any tendency of the balance point to drift towards B indicates that the accumulator is running down.
2. The distance through which the jockey is to be moved to cause a just perceptible deflection on the galvanometer is measured to estimate the error in locating the balance point.
3. The accuracy with which the position of the jockey can be read from the scale is = 1 mm. There may also be a zero error in the measurement of 1 as the end of the scale may not be exactly at the end of the wire.

Order of Accuracy

$$\text{Maximum \% error in E} = \frac{\delta E}{E_1} \times 100\% \; \frac{\delta l_1}{l_1} \left[\frac{\delta l_1}{l_1} + \frac{\delta l_2}{l_2}\right] \times 100\%$$

Experiment No. 15.8

To calibrate the given Ammeter by using a Potentiometer

1. Apparatus Required:

(i) Potentiometer (ii) Ammeter (iii) Voltmeter
(iv) Galvanometer G. (v) Rheostat R (vi) Protective resistance P.
(vii) Weston cell (viii) Standard resistance S. (1 Ω) (ix) Pug Keys K_1, K_2.

2. Theory

If E be the e.m.f. of the Standard Weston cell, l the length (balance point) corresponding to the e.m.f. of weston cell, l', Length corresponding to the pot, drop across S, we have

$$\frac{V}{E} = \frac{l'}{l}$$

$$\therefore \quad V = \frac{l'}{l} E \qquad \ldots(1)$$

$\therefore$ True current for 0.20 Ammeter Reading $= \frac{V}{S} = I'$

True current for 0.30 Ammeter Reading $= \frac{V}{S} = \ldots\ldots$

True current for 0.40 Ammeter Reading =.........etc.

The correction at each point of the ammeter scale is calculated.

3. Procedure

(i) The ammeter reading is adjusted at 0.20 amp by means of the rheostat. The balance point is obtained to the nearest cm. Next the protective resistance P is removed and find the balance point to within 1 mm.

(ii) The ammeter reading is set at 0.30, 0.40 amp etc. Operation (1) is repeated about 7 times. The current should not exceed 2 amp as it may heat S.

(iii) Next the ammeter circuit (E_2, R, A, S) is removed completely and replaced by a Standard Weston cell. The length l of the wire which balances this cell is measured using a protective resistance. Observations are noted as follows:

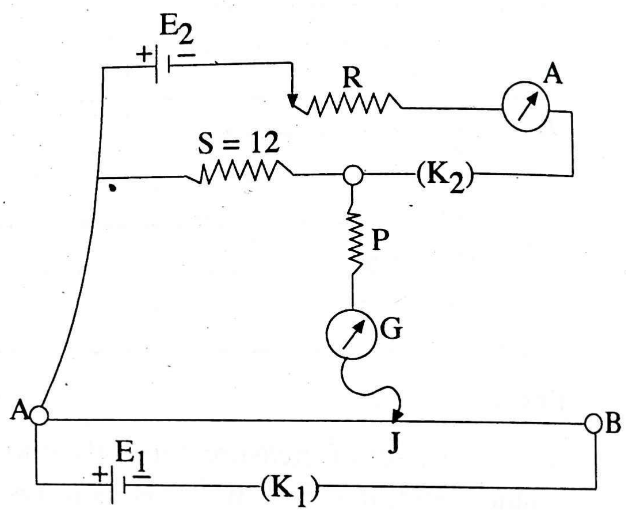


Fig. 15.16

4. Observation

Table No. 15.11

No. of obs.	Ammeter reading I amp.	Balance Point sliding from		Mean l' cm	V	$I' = \frac{V}{S}$ amp	Calculated error $I \sim I'$ amp.
		left	right				
1							
2							
3							
4							
5							
6							
7							

E.M.F of the Weston cell .... = ...volts

Length l corresponding to the e.m.f. of the cell = ...cm.

A graph of correction versus ammeter reading is drawn. The points are joined by a series of straight lines if errors bear no relation to each other.

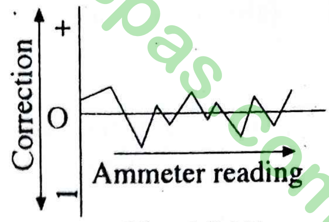


Fig. 15.17

Error

1. Expt. Valid only if the observed errors are considerably smaller than the actual errors present in the instrument.

2. Errors occur in the measurement $\frac{l'}{l}$ as in comparison of e.m.f'. s.

3. The value of true current will be systematically low if there be poor contact at the terminals of the standard resistance.

Order of Accuracy

Same as in comparison of e.m.f.'s.

Experiment No. 15.9

To calibrate a Voltmeter by using a Potentiometer

(b) To Calibrate a Voltmeter

Theory

If l be the balance length for a correct P.D. (V) across the voltmeter, then

$$\frac{V}{E} = \frac{l'}{l}$$

∴ Correction = V ~ voltmeter reading.

Procedure

(i) Connections are made as shown in the fig.

(ii) Using the rheostat as a potential divider, slider is moved so as to vary the reading on V between O and 2 volts.

(iii) The position of R is set so that the voltmeter indicates say 0.20 volt. The balance point is obtained to the nearest cm removing the protective resistance P the accurate balance length l' is found out.

(iv) Changing the reading to 0.40. 0.60 volt etc., the new balance length is obtained. This is repeated for at least about 7 voltmeter readings.

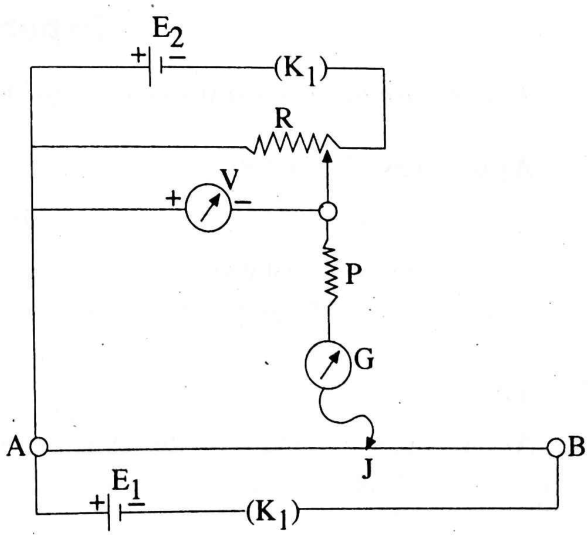


Fig. 15.18

(v) Next the P.D. circuit is replaced by a Weston Standard cell with a large series resistances to measure accurately the length l needed to balance the e.m.f. E of the standard cell.

4. Observations

Table No. 15.12

No. of obs.	Voltmeter reading Vamp.	Balance Point sliding from		Mean l' cm.	Calculated V' volt	Error V ~ V' volts
		Left	right			
1						
2						
3						
4						
5						
6						
7						

E.M. F. of Weston cell E = ...volt.

Balance length l = ...cm.

A graph of correction against voltmeter reading is drawn.

Conclusion

Corrections are shown in the graph.

Errors and Order of Accuracy

Same as in the previous expt.

Experiment No. 15.10

To compare the given resistances using potentiometer.

1. Apparatus Required

(i) Potentiometer
(ii) Two Accumulators
(iii) Galvanometers G.
(iv) Protective Resistance P
(v) Rheostat R
(vi) Resistances S_1 and S_2 to be compared
(vii) Plug keys k_1 and k_2.

2. Theory

At the balanced condition, the same current I is flowing through the resistances S_1 and S_2, the ratio of the P. D. across them is

$$\frac{V_1}{V_2} = \frac{l_1}{l_2} = \frac{IS_1}{IS_2}$$

$$\therefore \quad \frac{S_1}{S_2} = \frac{l_1}{l_2}$$

3. Procedure

(i) Connections are made as shown in the fig. 15.19.

(ii) The end A of the potentiometer wire is connected to the terminal 1 of the resistances. The galvanometer G along with jockey J and the protective resistance P is connected to 2^{nd} terminal of S_1.

(iii) The rheostat is adjusted so as to obtain the null point near the center of the wire AB.

(iv) Next A is connected to the terminal (2) and the galvanometer transferred to the terminal (3) The null point is located due to P.D. across S_2 near about the center of AB, this time also by adjusting R. After obtaining the approximate null point, the protective resistance P is removed and the exact balance point due to P.D. across S_1 and S_2 are located and noted.

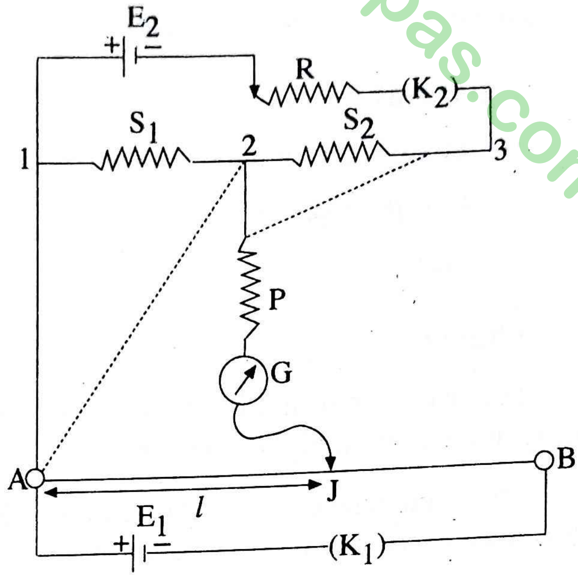


Fig. 15.19

(v) Operations 2, 3 and 4 are repeated thrice by different adjustment of R. For each pair R should remain constant.

4. Observations

Table No. 15.13

No. of obs.	Balance point for (Sliding from)						$\frac{S_1}{S_2} = \frac{l_1}{l_2}$	Mean
	S_1			S_2				
	left	l_1 cm right	l_2 cm. mean cm	left	right	mean cm		
1								
2								
3								

Conclusion

Thus $\frac{S_1}{S_2} = \ldots\ldots$

Errors

May arise due to

1. Errors in measuring 1,
2. S_1 and S_2 may be heated, so strong current should not be passed.
3. Variations in contact resistances. Leads must be cleaned properly.

Orde of Accuracy

Maximum % error in $\frac{S_1}{S_2} = \left[\frac{\delta l_1}{l_1} + \frac{\delta l_2}{l_2}\right] \times 100\%$

Experiment No. 15.11

To determine the internal resistance of a cell using a Potentiometer.

1. Apparatus Required

(i) Stretched wire Potentiometer (ii) Galvanometer G (iii) Rheostat R

(iv) Two plug keys K_1 and K_2 (v) Leclanche (or Daniell cell) (vi) Accumulator

(vii) Jockey J.

2. Theory

The two ends A and B of the potentiometer wire are maintained at a constant potential difference, A being at a potential higher than at B.

The total resistance in the circuit is R = r, R being the external resistance and r is the internal resistance of the cell E (Leclanche cell).

∴ The current passing through the circuit is

$$I = \frac{E}{R + r} \quad ...(1)$$

where E is the e.m.*f*. of the cell

Let V = P.D. across R

$$\therefore \quad I = \frac{V}{R} \quad ...(2)$$

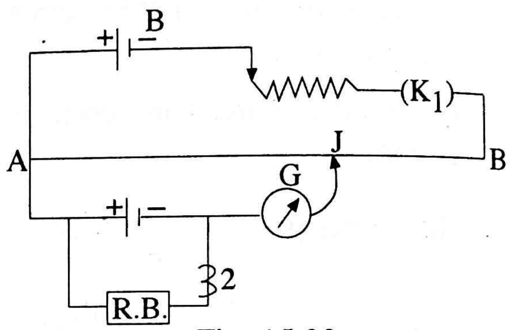


Fig. 15.20

$$\therefore \quad \frac{V}{R} = \frac{E}{R + r}$$

$$\text{or} \quad \frac{E}{V} = \frac{R + r}{R} = 1 + \frac{r}{R}$$

$$\text{or} \quad \frac{l_l}{l_2} = l + \frac{r}{R}$$

where l_l and l_2 represent the balancing lengths of the potentiometer wire with K_2 open and K_2 close respectively.

$$\therefore \quad \frac{r}{R} = \frac{l_1}{l_2} = \frac{l_l - l_2}{l_2} \quad ...(3)$$

$$\therefore \quad r = R\frac{(l_l - l_2)}{l_2} \quad ...(4)$$

3. Procedure

(i) Connections are made as shown in the diagram.

(ii) The balancing length l_1 with K_2 open is obtained by moving the jockey along the wires of the potentiometer.

(iii) Adjusting the resistance box to a suitable R, k_2 is closed and the new balancing length l_2 is obtained.

(iv) Operations (ii) and (iii) are repeated with 5 different values of R, for open and closed circuit of Leclanche cell alternately.

4. Observations

Table No. 15.14

No. of obs.	Resistance R	Null Point with the cell on		$r = R\frac{l_1 - l_2}{l_2}$	Mean r
		Open Circuit l_1 cm.	Closed circuit l_2 cm.		
1		.........;......{	.........;......{	...............{	...............{
2		.........;......{			
3					
4					
5					

Conclusion

Thus the internal resistance of the Leclanche cell = ...Ω

Graph:- From (3), a graph of $\frac{1}{R}$ and $\frac{1}{l_2}$ is drawn, It will be as straight line not passing through the origin.

$$\text{At } \times, \frac{1}{1} = 0$$

$$\therefore \quad \frac{1}{R} = \frac{1}{r} = OX$$

$$\therefore \quad r = \frac{1}{OX} \qquad \ldots(5)$$

Errors

1. Same as in Potentiometer expt, comparison of e.m.f.'s.
2. The cell is likely to polarise during the expt. which may cause the graph to be appreciably curved where $\frac{1}{R}$ is large.

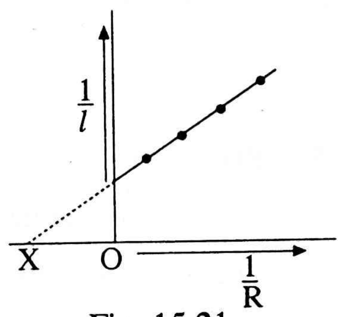


Fig. 15.21

Order of Accuracy

The max.^{m} diff. between the average value of r and individual values of r is estimated. The order of accuracy is then calculated.

$$\frac{\delta r}{r} \times 100^\circ = \left[\frac{\delta l_1}{l_l} + \frac{\delta l_2}{l_2}\right] \times 100^\circ$$

This is compared with the change in r produced by drawing other lines passing through l_1, which have slopes differing as widely as possible from the best line, while just agreeing with most of the plotted point.

Experiment No. 15.12

To determine the e.m.f. of a thermocouple by using a potentiometer and study its variation with temperature.

1. Apparatus

(i) Battery B(2 volt)

(ii) Constant -copper Thermocouple

(iii) Potentiometer

(iv) Very sensitive Galvanometer G

(v) High Resistance box (~thousand Ω)

(vi) Thermometer (0 - 3500°C)

(vii) Ice baths

(viii) Hot water baths

(ix) Heating arrangement

(x) P.O. Box.

2. Theory

The current flowing through the potentiometer wire is given by

$$I = \frac{E}{R + r} \quad \ldots(1)$$

where E = e.m.*f*. of the battery.

R = Resistance used in the high resistance box.

r = Resistance of the potentiometer wire.

∴ the fail of potential along the potentiometer wire is

$$I_r = \frac{E_r}{R + r} \quad \ldots(2)$$

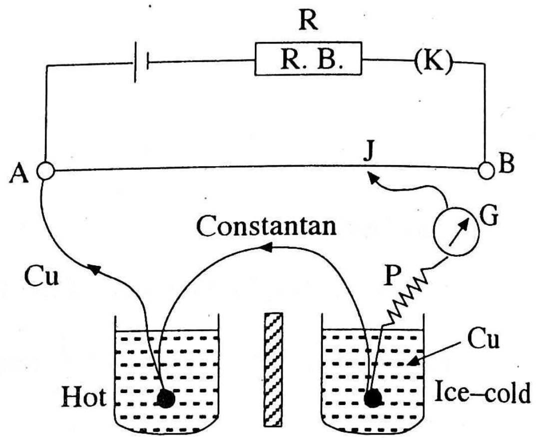


Fig. 15.22

Hence the fall of potential per unit length of the wire

$$e = \frac{Er}{E + r} \times \frac{1}{L}$$

where L = length of the potentiometer wire.

Now if e' be the thermo e.m.*f*. developed in the circuit balanced against l cm. length of the potentiometer wire,

$$\therefore \quad e' = el. = \frac{El}{R + rL} \quad \ldots(4)$$

3. Procedure

(i) Connections are made as shown in the fig.

(ii) The resistance r of the potentiometer wire is determined by using a P.O. Box. The e.m.*f*. E of the battery is noted using a battery voltmeter. The total length L of the potentiometer is also noted.

(iii) The hot water bath is raised to a steady temperature using a suitable high resistance from the resistance box R, the balance point is determined. The balancing length l and the temp. of the hot water bath are noted.

(iv) The water of hot bath is allowed to cool. The balance point is similarly determined after an interval of about 5° C until the temp. falls to about 40°C. Every time, the balancing length and the temp. of the bath are noted.

(v) The value of the thermo e.m.f. is calculated for each reading.

(vi) A graph of thermo e.m.f. against the temp. of the hot junction is drawn.

4. Observations

(i) Resistance of the potentiometer wire = r = ...Ω

(ii) e.m.f. of the battery = E =......volts

(iii) Total length of the potentiometer wire = L =........cm,

(iv) Resistance introduced in the high resistance box R = ...Ω

∴ Fall in potential per unit length.

$$e = \frac{E_r}{E + r}\frac{1}{L} \text{ volts/cm.}$$

Temp. of cold junction = ...°c

Table No. 15.15

No. of obs.	Temp. of hot junction°C	Potentiometer Balancing lengths		Themo. em$f$. e' = el micro volt
		l	mean l cm.	
1	....	.................{		
2	....	.................{		
3	....	.................{		
4	....	.................{		
5	....			
6	....			
7	....			
8	....			
9	....			

From the graph, the max^m em$f$ emax, the neutral temp. t_n is determined.

The slope $\frac{a}{b}$ at the origin is also measured.

This gives the constant A of the equation :- $e = At + Bt^2$. This represents the behaviour of most of the thermocouple.

At emax, $\frac{de}{dt} = 0$, the value of B may be found from A + 2Bt, = obtd by differentiating the formula for e.

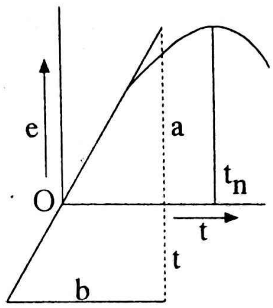


Fig. 15.23

Conclusion

Thus max e.m.f.= emax =......mv

Neutral temp. t_n = ...°c

Constant A =......mv.K^{-1}

Constant B =......mv. K^{-2}

Errors

These occur as in expt. on comparing the e.m.f. 's

Exercises

1. What is an Ammeter ? What is a voltmeter ? How do they differ from a galvanometer ? Why is the resistance of a voltmeter kept high ?
2. Define resistivity. State its unit.
3. What do you mean by the resistance of a wire ?
4. Why should the wire of a certain material resist the flow of electrons through it.
5. What is Wheatstone Bridge Principle ?
6. What is a P.O.Box. ?
7. What is meant by the sensitivity of a galvanometer ?
8. Why does the pointer in a table galvanometer move ?
9. What is a potentiometer ? Why is it so call ?
10. What is a Potential Divider ?
11. Why is the name dry cell given to the common battery used in flash lights and radio ?
12. Does a storage cell store up electricity ? Why is it properly called a Storage Cell ?
13. One should never hold a lighted match near an open storage battery ? Explain it.
14. A steady current of 10 amp. is maintained in a metal conductor for 2 min. What charge in coulomb is transferred through it in that time.
15. A 6.24 volt battery is connected for 3.33 hr. to a Rheostat and a current of 1477 mt. is noted.
    (a) What is the resistance of the rheostat ?
    (b) What charge is taken from the battery ?
16. What is the use of a Potentiometer ?
17. State the principle of a potentiometer.
18. What is the potential gradient ? On what factors does it depend ?
19. What do you mean by the sensitiveness of a potentiometer ? How can it be increased ?
20. On what factors does the accuracy if the potentiometer depend ?
21. Is it not better to measure the e.m.f. of a cell by a voltmeter ?
22. What type of cell hold be used in the main circuit.
23. Will you prefer the null point in the first wire or the last wire ?
24. Why are the readings given by a potentiometer more accurate than those of the voltmeter ?

Experiment No. 15.12

To determine the value of J by an Electrical Method.

1. Apparatus Required

(i) Joule's calorimeter
(ii) Accumulators
(iii) Plug Key
(iv) Ammeter
(v) Voltmeter
(vi) Rheostat
(vii) Centigrade thermometer
(viii) Connecting wires.

2. Theory

Let V be the potential difference across the heating coil in the Joule's calorimeter, and I the current flowing through it for t seconds. Then the energy given out as heat is

$$W = VI\,t \times 10^7 \text{ ergs} \quad \ldots(1)$$

But $$W = JH \quad \ldots(2)$$

where J is the mechanical equivalent of heat in ergs per calorie, H the amount of heat generated.

Then $$JH = VIt \times 10^7 \quad \ldots(3)$$

Now if mass of calorimeter with stirrer = w

Sp. heat ....= S

mass of cold water in it = m.

rise of temperature ....= θ

amount of heat generated in the coil $H = (ws + m)\,\theta$

$$\therefore \text{ from eqn. (3), } J = \frac{VIt}{(ws + m)\theta} \text{ ergs/cal} \quad \ldots(4)$$

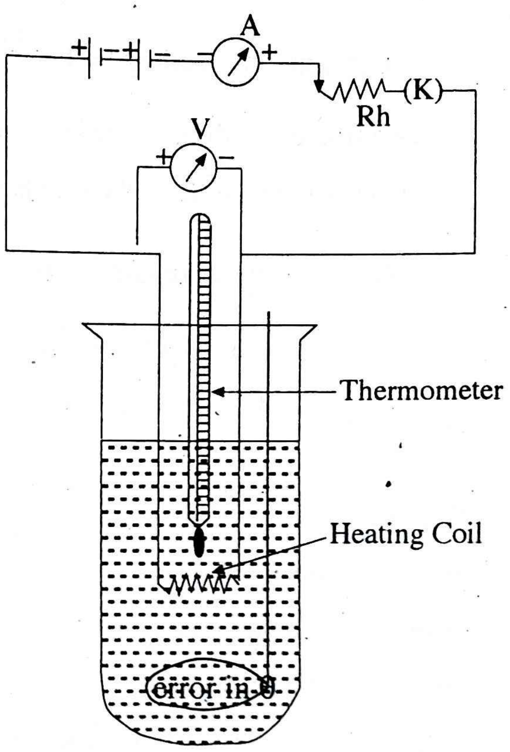


Fig. 15.24

3. Procedure

(i) The calorimeter is weighed accurately along with its stirrer.

(ii) It is then partly filled with water. The difference between this and the previous weight gives the mass of water taken. The initial temp. of the calorimeter and water is noted.

(iii) Connections are made as shown in the circuit diagram. The heostat is adjusted so as to pass about 1 to 1.5 amp of current.

(iv) The coil is immersed in water in the calorimeter and the circuit is completed. The current is allowed to pass for about 45 min. After every 5 min, the water is briskly stirred.

(v) The final temperature is noted. The ammeter readings are noted at the beginning and the end of the expt. The mean reading is taken. The result is calculated according to eqn. (4) under theory.

4. Observations

Mass of calorimeter with stirrer = w =...gms.

Mass of calorimeter + cold water = w_1 = ...gm.

∴ Mass of cold water taken = $w_1 - w = m$... gm.

Sp. heat of calorimeter = s (supplied) =...

Initial temperature of the cal and its contents = θ_1°C

final temperature = θ_2 °C

rise of temperature = $\theta_2 - \theta_1 = \theta$ °C

Time for which the current is passed = ...min = t secs.

Ammeter reading in the beginning = I_1 =

Ammeter reading in the end = I_2 = ...amp

∴ mean ammeter reading $= I = \frac{I_1 + I_2}{2}$

Voltmeter reading in the beginning E_1 = ...Volts

Voltmeter reading at the end E_2 = ...volts

Mean voltmeter reading $= E = \frac{E_1 + E_2}{2}$ ...Volts

∴ Standard value of J from physical tables = ...(C)

∴ % error $= \frac{C - O}{C} \times 100$ ....%

Errors may be due to

1. error in reading voltmeter.
2. error in reading ammeter
3. error in reading weighing
4. error in reading temperature reading
5. error in reading measuring time.

Order of Accuracy

Thus the maximum % error in J is given by

$$\text{Max}^m \text{ \% error in J} = \left[\frac{\delta V}{V} + \frac{\delta I}{I} + \frac{\delta t}{t} + \frac{\delta \omega}{\omega} + \frac{\delta \theta}{\theta}\right] \times 100$$

Experiment No. 15.13

To study the variation of the field due to a long straight wire carrying a current with distance.

1. Apparatus Required

(i) Long straight copper wire PQ (2 to 3 m)

(ii) Reversing key K

(iii) Deflection Magnetometer M

(iv) Rheostat R

(v) Accumulator E

(vi) Ammeter A

(vii) Leads

(viii) Wooden clamps

(ix) Half meter scale

(x) Travelling Microscope.

2. Theory

The field F due to a long straight wire $\alpha \frac{1}{r}$

Also $F \alpha \tan\theta$

i.e. $\frac{1}{r} \alpha \tan\theta$

$r \alpha \cot\theta$ where r is the distance.

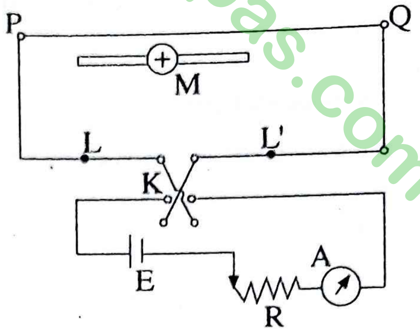


Fig. 15.25

3. Procedure

(i) The Deflection Magnetometer M is placed in the tan A position of Gauss.

(ii) The long straight wire PQ is fixed properly in the NS direction above the magnetometer.

(iii) The two ends of the wire are connected as shown in the diagram.

(iv) The wire is placed above M not further than $\frac{1}{10}$ of the length of PQ which reduces the error to less than 1%.

(v) The current is adjusted to about 2 - 3 amp. so that the deflection is at least 15° to 20°. The distance 'd' from the centre of the wire to the top surface of the cover glass of M is measured. Both ends of the pointer are read for direct and reversed currents.

(vi) Decreasing the distance in the steps of about 1 cm., the above operation is repeated 5 times. The current is kept constant.

(vii) The distance x from the magnetometer cover glass to the needle is measured by a travelling microscope and is added to d. Observation are repeated as follows:

4. Observations

Table No. 15.16

No. of obs.	Distance		Corrected. dist. r cm	Deflection θ				mean θ	tan θ	cot θ
	dcm.	x cm.		direct		reversed				
				End I	End II	End I	EndII			
1										
2										
3										
4										
5										

(viii) $\frac{1}{r}$ is plotted against tan θ. If r be varied in equal steps.

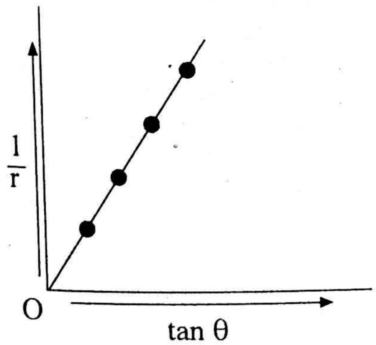


Fig. 15.26(a)

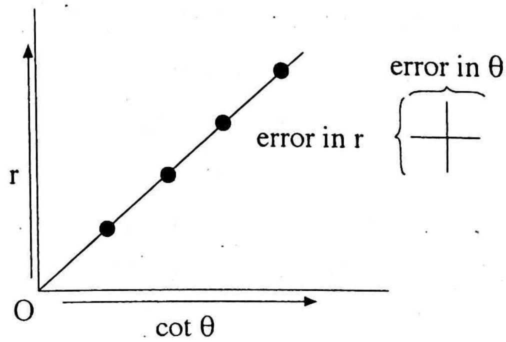


Fig. 15.26(b)

The points will gather together at one end of the scale, which may be avoided by plotting r against cot θ.

Conclusion

The graph is consistent with the relation......

Errors

These may arise due to

1. Error in reading the value of d. Besides the wire may sag.
2. The error in θ may be estimated from the variations in readings. The variations in cot θ due to these changes are found from tables.

Order of Accuracy of Graph

The vertical and horizontal lines are drawn through each plotted point. Their lengths should be equal to the estimated errors in r and cot θ respectively. If a st. line can be drawn, through the origin, which intersects each arm of each cross at some point, then the plotted points are consistent with the relation

$$r \propto \cot \theta.$$

Experiment No. 15.14

To convert the given Galvanometer into (i) an ammeter of given range. (ii) a voltmeter of a given range.

1. Apparatus required

(i) Weston type Galvanometer. (ii) P.O. Box. (iii) A battery.
(iv) Resistance Box. (v) Rheostat. (vi) An ammeter.
(vii) Connecting wires. (viii) Micrometer screw Gauge

2. Theory

The given Galvanometer can be converted into an Ammeter by connecting a suitable low resistance in parallel to the Galvanometer.

If I be the current required to produce a full scale deflection in the galvanometer, I the current range for conversion, we have

$$I_g = \frac{S}{S + G} I$$

where G is the galvanometer resistance and S is the required shunt.

or $$(I - I_g) S = G . I_g$$

∴ $$S = \frac{G I_g}{I - I_g} \quad ...(1)$$

This value of the shunt connected with the galvanometer will convert it into an ammeter of range I The experiment consists of four parts namely:

(A) To determine G, the galvanometer resistance.

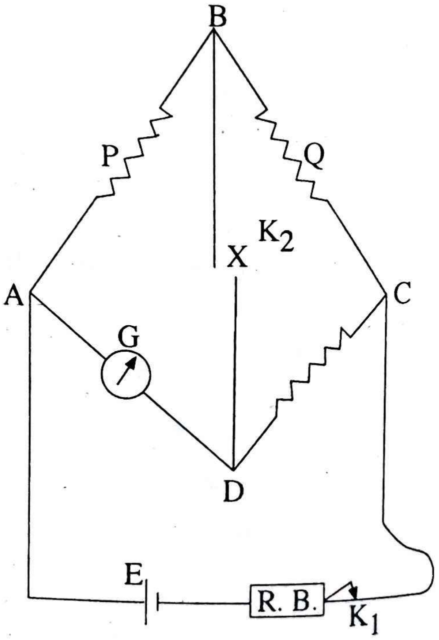


Fig. 15.27

(B) To determine the figure of merit of the Galvanometer which is the current required to produce a deflection of one scale division in it and hence to calculate Ig the current required to produce full-scale deflection in it.

(C) To calculate the length of the wire required to prepare a shunt resistance of the value given by eqn. (1) above

(D) To check whether the calculated shunt converts the galvanometer into an Ammeter of required range.

(E) To determine G, the Galvanometer resistance.

3. Procedure

To determine G. (i) In the usual Wheastone Bridge circuit the galvanometer is inserted in the fourth arm. In the place of the galvanometer a tapping key K_2 is used. In the cell circuit a resistance box is also used. So as to control the current whenever necessary.

N.B.: Here the galvanometer always shows some deflection on pressing the Key K_1. When a null point is obtained. There should not be any change of deflection on pressing the key K_2. It is not possible to adjust for zero deflection in this case.

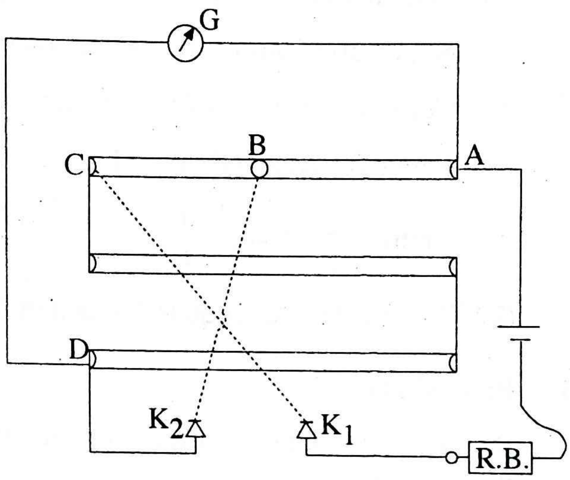


Fig. 15.28

(ii) The Wheatstone Bridge circuit is next applied in the P.O. box. circuit as shown in the diagram.

(iii) A resistance of say 1000 or 2000 Ω is plugged out from the resistance box so that the deflection lies within the scale.

(iv) Making the ratio arms. 10:10 and keeping R zero, the battery key K_1 is pressed. The resistance in R.B. is so adjusted as to deflect the galvanometer to 15 to 25 scale divisions. The connections are correct if the deflection decreases on pressing key K_2.

(v) Then following the procedure in P.O. Box. expt., the resistance of the galvanometer is determined by the relation $\frac{G}{R} = \frac{P}{Q}$.

$\therefore \quad G = \frac{P}{Q} \times R$, using the ratio arms. P: Q as 10:10, 10:100.

4. Observations and Calculations

Same as in Expt. no. 17(i)

(B) To determine the figure of merit of the Galvanometer.

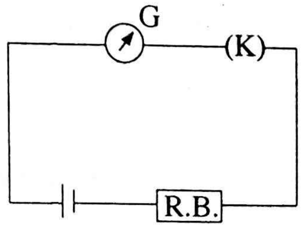


Fig. 15.29

3. Procedure

(i) The e.m.f. of the battery is read by means of a voltmeter.

(ii) The value of R in the Resistance Box R B. is adjusted to produce a deflection θ say about 25 scale divisions in the galvanometer. Then θ and R are noted.

Thus current reqd. for defl^n. of θ divs.$= \frac{E}{G + R}$; for 1 div. $= \frac{E}{(G + R)} \frac{1}{\theta}$

(iii) R is adjusted to some other value to produce a different deflection. Operation (2) and (3) are repeated at least thrice and λ calculated.

4. Observations

Table No. 15.17

No. of obs.	Resistance R Ω	Deflection θ divs.	$\lambda = \frac{E}{(G + R)\theta}$	Mean λ $\frac{amp}{div.}$
1				
2				
3				

To calculate the shunt:

No. of divisions of the galvanometer scale = n = ...

$\therefore$ Current Ig reqd. for full scale deflection $n\lambda$ = ...amp,

Range for conversion = I ....amp.

$\therefore$ shunt reqd. $S = \frac{IgG}{I - Ig}$

(D) To calculate the required length of the wire

3. Procedure

(i) Knowing the material of the specimen wire supplied, specific resistance (p) of the wire is noted form the physical tables.

(ii) The diameter of the wire is determined by means of a micrometer screw gauge.

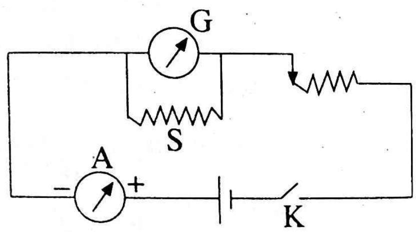


Fig. 15.30

....

....

....

Diameter d = ... Mean d = ...cms.

$\therefore$ Shunt resistance $S = p.\frac{l}{a}$,

where 1 its length and a is the cross -section of the wire.

$$1 = \frac{Sa}{P} = \frac{\pi d^2}{4p}.\ S$$

(D) To check the result.

3. Procedure

(i) A length of the wire 2 to 3 cm more than 1 as calculated above is cut. It is connected in parallel with the given galvanometer as shown in the fig. 15.30.

(ii) The battery is connected to the ammeter through a tapping key K, the converted galvanometer and a rheostat in series.

(iii) The rheostat is adjusted so as to produce the maximum deflection. The reading on the galvanometer scale and the corresponding reading on the ammeter are read. Five reading are taken for different values of the current.

4. Observation

One scale division after conversion. ...amp.

Table No. 15.18

No. of obs.	Galvanometer Reading		Ammeter reading y amp.	Difference = y - x amp.
	Deflection	Current in amp. x		
1				
2				
3				
4				
5				

(I) Conversion into a voltmeter

1. Apparatus required

(i) Westorn type galvanometer. (ii) P.O.Box. (iii) A battery
(iv) Resistance Box. (v) Rheostat. (vi) A voltmeter
(vii) Connecting wires. (viii) Micrometer Screw Gauge.

2. Theory

The given galvanometer can be converted into a voltmeter of required range by connecting a suitable high resistance in series with the galvanometer.

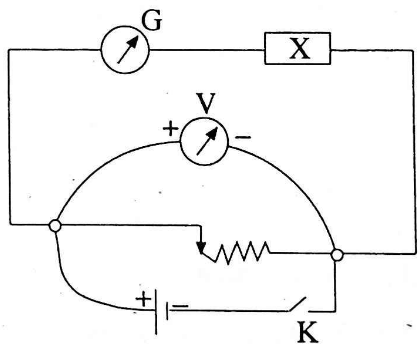


Fig. 15.31

If Ig be the current required to produce a full scale deflection in the galvanometer, E the voltmeter range for conversion, we have

$$Ig = \frac{E}{G + X}$$

where G is the galvanometer resistance and X is the required series resistance.

or $$Ig. X = E - Ig. G.$$

$$\therefore \quad X = \frac{E}{Ig} - G \qquad \ldots(2)$$

4. Procedure

(i) The values of G, Ig and X are determined as in the previous expt.

(D) To check the result,

(ii) A circuit is made as shown in the diagram.

(iii) The calculated resistance X is taken out from the resistance box, keeping the jockey of the rheostat to one end, the reading in the voltmeter and the converted galvanometer are noted.

(iv) Moving the variable contact to different positions, five readings are noted.

4. Observations

Table No. 15.19

No. of obs.	Galvanometer Reading		Voltmeter reading y volts	Difference = y - x
	Deflection X	PD. in volts		
1				
2				
3				
4				
5				

Experiment No. 15.15

To determine the unknown High Resistance by the substitution method.

1. Apparatus Required

(i) Unknown High Resistance X
(ii) Megohm Box R
(iii) Galvanometer (with Lamp and scale)
(iv) Two way key
(v) Rheostat
(vi) Accumulator.

2. Theory

The Galvanometer resistance G is generally small compared with X or R. If dx and dr denoted the deflections in the galvanometer corresponding to the high resistance X and R respectively,

$$\frac{X}{R} = \frac{dr}{dx}$$

$$\therefore \quad X = R.\frac{dr}{dx} \quad \ldots(1)$$

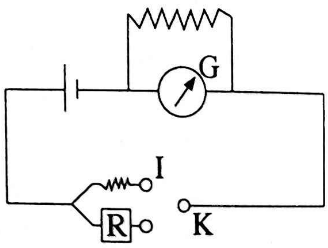


Fig. 15.32

3. Procedure

(i) A circuit is made as shown in the diagram.

(ii) The experimental high distance X is connected in series with an accumulator and a G galvanometer.

(iii) A rheostat is connected across the galvanometer to serve as a shunt. The rheostat is then adjusted so as to give a suitable Galvanometer deflection.

(iv) The unknown resistance is disconnected and the known resistance box Plugs are removed from it until the galvanometer gives the same deflection. The value of the box. resistance will be equal to X Ω.

(v) Next the shunt is slightly changed. Inserting the unknown resistance in the circuit, the deflection is noted.

(vi) Replacing X by another value of R, the new deflection dr is noted.

(vii) Operations (v) and (vi) are repeated from about 3 to 5 values of R.

4. Observations

Table No. 15. 20

No. of obs.	Galv. Deflection due to		$X = \frac{dr}{dx} R$	Mean X Ω
	R dr	X dx		
1				
2				
3				
4				
5				

Conclusion

Thus the value of X is ...Ω

Errors

May be due to

1. Error in noting dr and dx.
2. Pot. drop. in the accumulator if it is in discharging condition.

Order of Accuracy

The max^m % error is given by

$$\frac{8X}{X} \times 100° = \left[\frac{\delta dr}{dr} + \frac{\delta dx}{dx}\right] \times 100°$$

Experiment No. 15.16

To investigate the Anode and Mutual characteristics of a Triode valve.

1. Apparatus Required

(i) Triode valve.

(ii) High Tension battery (about 120 volt E_a.

(iii) 9 volt triode bias battery Eg.

(iv) Heater accumulator.

(v) Millimeter.

(vi) Potential Dividers.

2. Procedure

(i) Connection are made as shown in the diagram.

(ii) Anode characteristics (I_a - V_a, V_g const). The grid voltage is set at say - 9 volt. Starting with low values, the anode current Ia is measured for various values of a node voltage V_a. This is repeated for V_g = - 6 volt, - 4V, - 2V and 0 respectively. The grid should not be made positive.

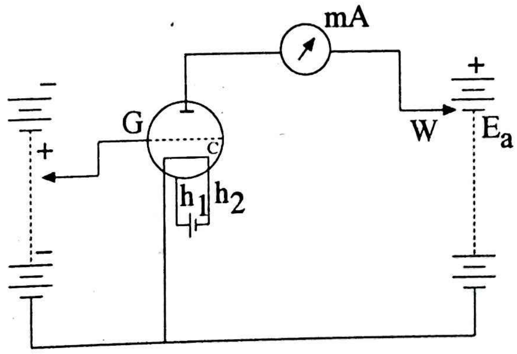


Fig. 15.33

(iii) Mutual Characteristics: (I_a - V_g. V_a constant) Keeping the anode voltage V_a fixed at some convenient value say 120 V, the grid voltage is varied from - 9 volt, to O, the corresponding currents I_a are measured. This is repeated for other values of anode voltage if 100V, 80V, 60V etc.

3. Observations

Table No. 15.21

(i) Anode characteristics V_g/volt

I_a mA V_g volt						
I_a V_g...						

(ii) Mutual characteristics V_a/V

I_a mA V_a volt						
I_a V_a...						

(1) Anode characteristics

I_a is plotted against V_a labeling each curve with constant value of V_g From the slope of the Linear part of the curve,

$$Ra = \frac{\delta Va}{\delta Ia} = \ldots\ldots\ldots\Omega.$$

Appendix 1
Theory of Errors

Physics has long been considered and accepted as a science of exact measurement. Be it the measurement of a physical constant or the verification of some physical laws or explaining some physical principles, it is desirable that the experimental value obtained should be within the best possible limits of error and should represent as nearly as possible, near the true value. However even when an efficient experimenter takes a large number of independent measurements of a quantity, it is always found to be slightly different from one another. If however, the number of observations are sufficiently large, most of the experimental results would be found to lie within a narrow limit. It is then possible to estimate a reasonably accurate true value of the quantity. Sometimes the accuracy of the result is limited by the least count of the apparatus. Further an instrument often gives results only after molesting the original physical quantity. For example when the bulb of a mercury thermometer is immersed in a hot cup of water the temperature of hot water first appears to decrease and then only the mercury in the thermometer rises. The environmental changes in temperature pressure are bound to influence the experiment as well as the measuring apparatus. Thus all measurements involve one or other kind of errors.

The various errors that may creep in during the experimental measurements may broadly be classified as follows:

Classification of Errors

(1) Constant or systematic errors (2) Random Errors

1. Constant or systematic errors

Systematic errors are those errors which in principle may be avoided or corrected. They can be further sub classified as follows:

(a) **Gross errors**: These are blunders of mistakes introduced due to carelessness, improper adjustments, computational mistakes etc. which can be avoided by careful working.

(b) **Instrumental errors:** These errors are due to short comings in the instrument like coarse least count zero error, faulty calibration, back lash etc. These can be eliminated by careful planning and applying corrections.

(c) **Environmental errors:** Environmental errors are the errors that creep into our experimental measurement due to changes in the external conditions, as temperature, humidity, pressure, earth's magnetic fields etc. These errors can be avoided by maintaining the standard condition during a set of measurement or by applying necessary condition.

(d) **Observational errors:** These errors are introduced by the bad habits and judgment of the observer. Parallax is one of such errors.

2. Random Errors

If the same measurement is repeated several times, usually the same result is not obtained inspite of taking full care of systematic errors showing thereby that over and above the systematic error, there are some other uncontrolled and unpredictable errors which may arise due to a variety of known or unknown causes. Since these errors arise from ambiguities or uncertainties in the process of measurement or from fluctuations which are too irregular or fast to be observed in details, corrections cannot be applied. These errors which often display fluctuations are called residual or random errors.

An estimate of random errors is made on the basis of statistical theory. Since the positive and negative random errors are equally probable, the arithmetic mean is considered to give the true value of the quantity under measurement. The degree of reliability that one can attach to the arithmetic mean depends on the mean square deviation and the number of observations.

Thus if n measurements of the quantity under consideration are made, all are equally reliable.

If the measured values are $x_1, x_2 \ldots\ldots x_n$, then the arithmetic mean

$$\bar{x} = \frac{1}{n}(x_1 + x_2 + \ldots\ldots x_n) = \frac{1}{n}\sum_{i=1}^{i=n} x_i$$

which is defined as the true value i.e. the mean of a large set of measurements under constant conditions.

The precision with which a physical quantity is measured depends inversely upon the deviation or dispersion of the set of measured values x_i about their dispersed or the observed values have a large deviation from the true value, the precision is said to be low.

The deviation $\delta_i = x_i - \bar{x}$

Average deviation $\bar{d} = (x_1 - \bar{x}) + (x_2 - \bar{x}) + (x_n - \bar{x})$

$$= \frac{\delta_1 + \delta_2 + \ldots\ldots\ldots \delta_n}{n} = \frac{\Sigma\delta_n}{n}$$

Standard deviation: The square root of the mean square deviation for an infinite set (large number) of measurements) is known as standard deviation (root mean square deviation) and is denoted by σ.

For the sufficiently large number of observations

$$\sigma = \sqrt{\frac{\delta_1^2 + \delta_2^2 + \ldots\ldots\ldots \delta_n^2}{n - 1}} = \sqrt{\frac{S}{n - 1}}$$ where $S = \delta_1^2 + \delta_2^2 + \delta_3^2 + \ldots\ldots\ldots \delta_n^2 = \sum_{i=1}^{n} \delta_i^2$

For a fairly large sample of measurements.

$$\frac{\text{Average deviation}}{\text{Standard deveiation}} = \frac{\bar{d}}{\sigma} = 0.80$$

Appendix 2
Physics Practical Preliminaries

Exercises 1

1. Express the following numbers in powers of ten notation:

   (a) 93,000,000 (b) 2,592,000 (c) 0.00006893

   (d) 0,0000167 (e) 0,00004912 (*f*) 21,2000,000,000

2. Express the following in an exponential form that is not a fraction

   (a) $\frac{1}{10^6}$ (b) $\frac{1}{10^{-7}}$ (c) $\frac{316}{10^4}$ (d) $\frac{0.006912}{10^4}$ (e) $\frac{5280}{10^{-3}}$

3. Solve each of the following problems and express your answers in powers of ten notation:

   (a) 5000×900 (b) 300×0.0069

   (c) $6.0 \times 10^{14} \times 5.50 \times 10^{-12}$ (d) $3500 \times 0.000480 \div 0.00120$

   (e) $2800 \times 0.00520 \div 0.0070$

4. The mass (which roughly means the amount of matter) of:

   (i) a proton is 1.67×10^{-27} kg. How many protons would be required to make 1 gm.

   (ii) an electron is 9.11×10^{-31} kg. How many electrons would be required to make 1 gm.

5. Suppose you read in a news article that Pokhara is 200 km. from Kathmandu. If you want to tell a friend who is not acquainted with the metric system about this town, how many miles should you say it is from Kathmandu ?

6. If you walk 3.5 miles to Bhaktapur, how many inches do you travel ?

   If you were in ametric country and walked 2.5 kms. How many millimeters do you travel ? Which is easier to compute and why ?

Appendix 3
Model Questions
Paper I

Set 1

1. Use a micrometer screw gauge to determine the diameter of the given ball and hence compute the value of π (density of a ball given).
2. Use hydrostatic balance to determine the specific gravity of the given solid heavier than but soluble in water.
3. Use Regnault's apparatus to determine the specific heat of the given solid.
4. Use Pullinger's apparatus to find the coefficient of volume expansion of the material of the rod.
5. Verify Hooke's law of elasticity for a wire supplied. Also determine any variation in the diameter of the wire with the maximum load from that without any load.
6. Verify Boyle's law. Also draw an isothermal curve of the gas.
7. Use a glass slab to show the variation of lateral shift and the angle of incidence.
8. Determine the refractive index of the given prism by symmetry method.
9. Determine the refractive index of water.

Set 2

1. Use a spherometer and a balance to determine the density of a given irregular glass plate.
2. Use Nicholson's hydrometer to determine the volume and the specific gravity of given piece of glass.
3. Determine the specific heat of given liquid by the method of cooling.
4. Determine the melting point of paraffin wax by the method of cooling.
5. Determine the latent heat of vaporization of water and hence calculate the amount of heat required to evaporate 10.5 cubic meter of water.
6. Verify Hooke's law of elasticity for the wire supplied. Hence calculate the total load required for an elongation 15 mm.
7. Use Boyle's law apparatus to determine the atmospheric pressure in your laboratory.
8. Draw a u-v graph for a concave mirror and hence calculate its focal length.
9. Use a glass slab to verify the laws of refraction. Draw a graph between angle i and angle r and find graphically the angle of refraction corresponding to the angle of incidence equal to 90°.
10. Show that the object distance is equal to the image distance in a plane mirror.

Set 3

1. Use a spherometer to determine the focal length of the given convex mirror.
2. Use a hydrostatic balance to determine the specific gravity of paraffin wax.
3. Determine the value of g. in the laboratory and show that the relation between the length of pendulum and its corresponding time period is parabolic.
4. Determine the melting point of the wax by the method of cooling.
5. Determine the coefficient of linear expansion of the given rod hence calculate the temperature at which the rod expands by 2 m.

6. Verify the laws of reflection at a plane surface and prove that the image distance is equal to the object distance for a plane mirror.
7. Draw a graph to show the variation of lateral shift with the angle of incidence in a glass slab and find the value of the lateral shift when the angle of incidence is 90°.
8. Use a travelling microscope to determine the refractive index of kerosene oil.
9. Determine the focal length of a convex lens by parallax method and hence show how the magnification varies with image distance.

Set 4

1. Use Vernier callipers to determine the volume of a given solid cylinder. Also find the density of the material of the cylinder.
2. Use specific gravity bottle to determine the specific gravity of kerosene oil.
3. Determine the specific heat of the given liquid by the method of cooling.
4. Determine the latent heat of fusion of ice and calculate the amount of heat required to raise the temp. of 1 kg. of ice at 0°C to the lab temperature.
5. Determine the Young's modulus of elasticity for a given wire.
6. Verify Boyle's law with the apparatus supplied.
7. Determine the focal length of the convex mirror.
8. Verify the laws of refraction of light by means of a glass slab and hence calculate its refractive index.
9. Determine the angle of the prism by optical method and the angle of minimum deviation by symmetry method to calculate the refractive index of the given prism.
10. Verify the law of rotation of light.

Set 5

1. Use a micrometer screw gauge and a balance to compute the density of a given steel ball.
2. Use a Nicholson's Hydrometer to determine the volume and the specific gravity of a given piece of glass.
3. Verify the law of length of a simple pendulum and hence calculate the acceleration due to gravity in your laboratory.
4. Determine the volume coefficient of expansion of the material of the given rod.
5. Determine the thermal capacity of given solid by the method of mixtures.
6. Verify Hooke's law of elasticity with the wire supplied and compare the diameter of the experimental wire with maximum and minimum loads.
7. Draw a graph to how the variatin of lateral shift with the angle incidence for the given glass slab.
8. Use a travelling microscope to determine the refractive index of the given liquid.
9. Determine the power of the given concave lens.
10. Draw I-D curve for the given prism and hence determine its refractive index.

Set 6

1. Use a spherometer and a balance to determine the density of a given irregular glass plate.
2. Use a hydrostatic balance to determine the specific gravity of a given solid heavier than and soluble in water.
3. Determine the length of Seconds pendulum in your laboratory and hence compare it with that at sea - level. (g at sea - level = 980 cms/sec^2)

4. Calibrate the given thermometer to determine accurately the temperature of tap water in your laboratory.
5. Determine the latent heat of condensation of steam and hence calculate the amount of heat required to completely evaporate water in a pond whose size in 100 m × 100 m × 10 mm.
6. Use Bolye's law apparatus to determine the atmospheric pressure in your laboratory.
7. Verify the law of rotation of light and hence show that the deviation of incident light changes by twice the angle through which the plane mirror rotates.
8. Determine the focal length of given concave mirror by double pin method.
9. Draw I - D curve for a glass prism and hence show that the angle of incidence is equal to the angle of emergence when the deviation is minimum.
10. Determine the power of the given convex lens.

Set 7

1. Use Vernier callipers to determine the density of the material of the given hollow cylinder.
2. Use a hydrostatic balance to determine the specific gravity of wax.
3. Use a Nicholson's hydrometer to determine the specific gravity of given piece of cork.
4. Determine the length of a Seconds pendulum in your laboratory and hence compare it with that at Sea-level (g at sea level = 980 cms/sec^2.
5. Calibrate a given thermometer and hence determine the temperature of tap water.
6. Determine the latent heat of fusion of ice and hence calculate the amount of heat. required to melt 1 kg of ice.
7. Verify Hooke's law of elasticity for the wire supplied and calculate its Young's modulus.
8. Use a travelling microscope to determine the critical angle for glass.
9. Determine the power of the given convex lenx.
10. Draw 1 - D curve for the given prism. Hence determine its refractive index.

Set 8

1. Determine the density of glass of the given capillary tube, by use of Archimedes' principle. Measure the external diameter and the length. Deduce the internal diameter.
2. Determine the number of steel balls embedded in a given piece of paraffin wax. Samples of steel balls and wax provided.
3. Determine the thermal capacity of the given lump of metal. Use it to determine the sp. heat of the liquid provided.
4. Determine the specific latent heat of ice and hence fine the amount of heat needed to convert 1 kg. of ice to water at 100 °C.
5. Determine the melting point of wax by capillary tube method.
6. Determine the coeff. of linear expansion the given rod.
7. Determine the Young's modulus of elasticity of the given wire. Hence calculate the load needed to produce an extension of 0.55 mm.
8. Verify the law of rotation of light.
9. Determine the refractive index of the given prism by symmetry method.
10. Draw u - v curve for the given convex lens. Hence determine its focal length.

Appendix 4

1. Physical Constants and Mathematical Tables

Table of Densities (in gm/c.c.)

Aluminium	2.70	Kerosene oil	0.85
Benzene	0.88	Lead	11.37
Brass	8.4 to 8.7	Marble	2.5 to 2.8
Common Salt	2.15	Mercury	13.6
Copper	8.9	Olive Oil	0.19
Cork	0.20 to 0.26	Petrol	0.807
Glass (Crown)	2.5	Sand	2.3 to 2.6
Glycerine	1.26	Silver	10.5
Gold	19.3	Sugar	1.59
Ice	0.917	Turpentine Oil	0.87
Iron	7.8	Wood	0.6 to 0.8
$CuSO_4$ Crystal	2.28	Zinc	7.1

2. Density in (gm/c.c.) or sp. gr. of water at different temperatures

Temp in °C		Temp in °C	
0	0.99987	22	0.99780
2	0.99988	24	0.99732
4	1.00000	26	0.99681
6	0.99998	28	0.99626
10	0.99998	32	0.99505
12	0.99953	34	0.99440
14	0.99933	36	0.99371
16	0.99997	38	0.99300
18	0.99865	40	0.99230
20	0.99823		

3. Coefficient of Limiting Friction

Wood on Wood	0.10	Metal on Metal	0.18
Wood on glass	0.08	Glass on Glass	0.08

4. Melting Points

Bees Wax	61 - 64 °C	Paraffin wax hard	52 - 56°C
Paraffin wax soft	31 - 52 °C	Napthalene	78 - 83 °C

5. Specific Heats

Aluminium	....	0.212	Marble	....	0.22
Brass	....	0.088	Mustard Oil	....	0.50
Copper	....	0.094	Sand	....	0.21
Glycerine	....	0.58	Silver	....	0.056
Iron	....	0.119	Tin	....	0.055
Ice Cream	....	0.502	Turpentine	....	0.43
Kerosene Oil	....	0.52	Water	....	1.0
Lead	....	0.031	Zinc	....	0.094
Glass	....	0.16 to 0.19	Mercury	....	0.033
			Petroleum	....	0.51

6. Refractive Indices (η) for sodium light

Glass	....	1.478 to 1.613	Glass (Soda)	....	1.50
Glass (Flint)	....	1.579 to 1.649	Water	....	1.33

7. E.M.Fs. of Common Cells (in volts)

Bunsen Cell	....	1.96	Leclanche Cell	....	1.45
Daniell Cell	....	1.08	Lead Storage Cell	....	2.0

8. Specific Resistance at 18°C (in ohm cm)

Aluminium	....	3.2×10^{-6}	Manganin	....	42.0×10^{-6}
Brass	....	$(6 - 9) \times 10^{-6}$	Mercury	....	95.6×10^{-6}
Constant an (Eureka)	....	49×10^{-6}	Nickel	....	11.8×10^{-6}
Copper	....	1.78×10^{-6}	Nichrome	....	110×10^{-6}
Iron	....	13.9×10^{-6}	Platinum	....	110×10^{-6}
Lead	....	20.8×10^{-6}	Silver	....	1.64×10^{-6}

9. Electro. Chemical Equivalents (in grams/Coulomb)

Copper	....	0.0003295	Silver	....	0.0011183

10.1 Tenacity is the Breaking stress in dynes per sq.cm.(Table 10.1 Breaking Stress)

Aluminium	$1.7 - 2 \times 10^9$	dynes/cm^2	= 2000kg/cm^2	Max approx.
Brass	$3.1 - 3.9 \times 10^9$	dynes/cm^2	= 4000 kg/cm^2	Max approx.
Copper	$2.8 - 4.6 \times 10^9$	dynes/cm^2	= 4700 kg/cm^2	Max approx.
Iron	$6.2 - 6.2 \times 10^9$	dynes/cm^2	= 6000 kg/cm^2	Max approx.
Steel	$11.0 - 23 \times 10^9$	dynes/cm^2	= 2300 kg/cm^2	Max approx.

10.2 Elastic Constants

Substance	Young's Modulus (γ) dyne per sq. cm. × 10^{11}	Modulus of rigidity (η) dyne per sq. cm. × 10^{11}	bulk modulus (k) dyne per sq. cm × 10^{11}	Poission's ratio (σ)
Aluminium	7.05	2.67	7.46	0.339
Brass	9.7 - 10.2	3.5	10.65	0.34 - 0.40
Bronze	8.08	3.34	9.52	0.358
Copper	12.4 - 12.9	3.9 - 4.0	14.3	0.26
Constantan	16.3	6.11	15.5	0.325
Glass (crown)	6.5 - 7.8	2.6 - 3.2	4.0 - 5.9	0.20 - 0.27
Glass (flint)	5.0 - 6.0	2.0 - 2.5	3.6 - 3.8	0.22 - 0.26
Iron (wrought)	19 - 20	7.7 - 8.3	14. 6	0.27
Iron (cast)	10 - 13	3.5 - 5.3	9.6	0.23 - 0.31
Manganin	12.4	4.65	12.1	0.329
Phosphor-bronze	12.04	4.36		0.38
Rubber, Soft Vulcanized	0.10 - 0.70	0.00016		0.46 - 0.49
Steel	19.5 - 20.6	7.5 - 8.9	18.1	0.25 - 0.33

11. Variation of Surface Tension and Viscosity of water with temperature.

Temperature	Surface Tension	Viscosity	Temperature °C	Surface Tension	Viscosity
0	74.98	0.01793	50	67.34	0.00550
10	73.53	0.01311	60	65.59	0.00469
15	72.80	0.01142	70	63.77	0.00406
20	71.07	0.01006	80	61.95	0.00356
30	70.62	0.00800	90	60.20	0.00316
40	68.94	0.00657	100	58.24	0.00284

12.(a) Properties of Solids

Substance	Density gm per c.c.	Specific Heat cal/gm	Thermal Conductivity cal cm^{-1} sec 10 C^{-1}	Coefficient of linear expansion × 10^6 per °C	Melting point in °C under normal pressure
Aluminium	2.70	0.22	0.504	22.4	657
Brass	8.4 - 8.7	0.092	0.260	18.9	900
Constantan	8.88	0.098	0.054	16.0	1300
Copper	8.80	0.093	0.918	17.0	1083
Cork	0.22 - 0.26	0.49	0.0012	......	......
Glass	2.4 - 2.8	0.16	0.0025	......	1000
Iron (cast)	7.6	0.119	0.114	10.2	1100
Iron (wrought)	7.85	0.115	0.144	11.9	1530
Steel	7.7	0.11	0.115	11.0	1400
Ice	0.916	0.50	0.0053	50.7	0
Lead	11.34	0.0305	0.083	29.2	327
Rubber	......	....	0.00045	......	......

12. (b) Properties of Liquids

Substance	Freezing Point °C	Boiling Point °C	Density at 20° in gm/c.c.	Specific heat in cal/gm/°C	Viscosity at 20°C centipoise	Surface tension at 20°C in dyne/cm
Alcohol (ethyl)	- 117.30	78.5	0.784	0.548	1.192	22.3
Alcohol(methyl)	-97.00	64.7	–	0.600	0.591	22.6
Benzene	5.48	80.2	0.879	0.410	0.654	28.9
Glycerine	20.00	290	1.260	0.575	8.300	63.0
Mercury	-38.87	356.9	13.596	0.033	1.560	52.5
Turpentine	-10.00	16.0	0.870	0.411	1.487	27.0
Water	0.00	10.0	0.998	1.000 at 15°C	1.005	72.7

12. (c) Properties of Gases

Substance	Density at N.T.P in gm/litre	Viscosity at 20°C in centipoise	Specific heat (Cp) in cal/gm °C	Ratio of the specific heat y $\frac{C_p}{C_v}$
Air	1.2929	0.0181	0.241	1.402
Carbon-dioxide	1.9769	0.0160	0.201	1.306
Hydrogen	0.0899	0.0095	3.402	1.419
Nitrogen	1.2505	0.0184	0.24	1.405
Oxygen	1.429	0.021	0.22	1.397
Steam	0.581	0.0132	0.488	1.305

13. Pressure of Saturated Water Vapour

Temp in °C	Pressure in mm of Hg.	Temp. in °C	Pressure in mm of Hg.	Temp in °C	Pressure in mm of Hg.	Temp in °C	Pressure in mm Hg.
16.0	13.6	21.0	18.6	26.0	25.1	31.0	33.6
16.5	14.1	21.5	19.2	26.5	25.9	31.5	34.6
17.0	14.5	22.0	19.8	27.0	26.7	32.0	35.5
17.5	15.0	22.5	20.4	27.5	27.5	32.5	36.6
18.0	15.5	23.0	21.0	28.0	28.3	33.0	37.6
18.5	16.0	23.5	21.7	28.5	29.1	33.5	38.7
19.0	16.5	24.0	22.3	29.0	29.9	34.0	39.8
19.5	17.0	24.5	23.0	29.5	30.8	34.5	40.9
20.0	17.5	25.0	23.7	30.5	32.7	42.0	......
20.5	18.1	25.5	24.4	31.0	35.7	......	......

14. Refractive Indices (μ) and Dispersive Powers (ω)

(λ) = 5893 A° U., Temp. = 15°C

Substance Liquid	μD	ω	Substance Glasses	μ	ω
Benzene......	1.501	0.033	Crown......	1.500	0.015
Ether......	1.354	0.017	Dense Crown...	1.620	0.018
Temperature...	1.470	0.021	Flint...	1.560	0.020
Water...	1.333	0.018	Dense Flint...	1.620	0.027
Isotropic Solids...			Extra dense flint...	1.650	0.030
Canada Balsam...	1.030		Very dense flint...	1.720	0.033
Diamond...	2.417		Uniaxial crystals...		
Ice......	1.310		Calcite ord......	1.658	0.020
			Calcite extra ord.	1.486	0.013
			Quartz ord.	1.544	0.014
			Quartz ext. ord.	1.533	0.015

Appendix 5

"Two minutes with an examiner"

Viva Questions & Answers

Exercise on Page 12

1. **What is a vernier and why is it so called ?**

The Vernier is a small scale which slides along the main scale. Its function is to enable a more accurate reading to be made. It is so graduated that its n divisions coincide with n - 1 divisions of the main scale. Hence a Vernier division is a little shorter than a main scale division.

It was first devised by P. Vernier and hence it is so called.

2. **Define a vernier constant and the least count.**

A Vernier division is a little shorter or a little longer than a main scale division.

The difference between a main scale division and a vernier scale division expressed in terms of the value of 1 main scale division is called a Vernier constant. It is also known as the least count of the Vernier. It is the least distance the Vernier can measure.

3. **Why is it necessary to take more readings for the diameter than for the length.**

Usually the length is involved in measuring the object in the first order as '1'. A slight error in its measurement does not involve a serious mistake and difference in the result whereas the diameter is involved in the measurement of the cross-section of a rod or the volume of a spherical body where a second degree in length as d^2 or third degree d^3 is involved. Hence a slight mistake in measuring d involves a serious mistake in calculating the cross section or the volume. Hence one should take more readings for the diameter than for the length.

4. **Take the given scale, thermometer or the stop watch.**

Count the no. of smallest division in 1 mm, 1 cm, 1°C or 1 sec. in a scale, a thermometer and a stopwatch respectively. Hence calculate the value of 1 smallest division. That gives the least count.

5. **Suppose you have Vernier calliper with 20 main scale division as amounting to 10 mm. 20 Vernier divs. coincide with 19 m.s. divs. Calculate the vernier constant.**

Here, 20 main scale divs. = 10 mm.

20 v. divs. coincide with 19 m.s. divs.

$\therefore$ 1 v. div. coincide with $\frac{19}{20}$ m.s. div.

$\therefore$ Diff. between 1 m.s. and 1 V.S. div = $1 - \frac{19}{20} = \frac{1}{20}$

$\therefore$ Vernier const. (V.C.) = $\frac{1}{20}$ × value of 1 div. = $\frac{1}{20}$ × 0.5 min. = 0.025 mm = 0.0025 cm.

Exercise on Page 15

1. **Define Pitch and Least count of a Screw Gange. How can the least count be made small ?**

Any instrument working on the principle of a screw has pitch, which is nothing but the linear distance travelled in one complete rotation of the screw head or the circular scale.

The circular scale has 50, or 100 or 200 divisions. In one rotation, it moves through these divisions i.e. 50 or 100 or 200 which is converted into the linear distance along the main scale. The linear distance moved along the linear scale when the circular scale is rotated through only one of its circular scale divisions is called the least count. Thus if P be the pitch of the screw and N the no. of circular scale divs. Then the least count (L.C.) = $\frac{P}{N}$. The L.C. can be made small by making the no. of circular screw divisions large.

2. **What is Backlash error ? How is it eliminated ?**

In an instrument working on the principle of a screw, sometimes it may so happen that the screw may not properly fit in the nut due to some looseness between the screw and the nut. In such a case, equal amount of linear motion of the point of the screw. Error due to this is called, Backlash error. It can be avoided by turning the screw always in the same direction while taking a reading.

3. **What is an instrumental error ?**

It is an error inherent in the apparatus itself and in the measuring instruments used, may be due to some imperfection in its graduation and calibration. So one should realize that not every piece of the apparatus specially in a teaching laboratory, is capable of giving measurements to a high degree of accuracy. The capabilities of each component used should be considered and the degree of accuracy in the final result, will not be greater than that of the least reliable instrument used.

4. **A screw gauge has 20 threads of a cm. and the no. of divisions on the circular scale is 100, what is the least count ?**

Here the value of each thread = $\frac{1}{20}$ cm. = 0.05 cm.

$\therefore$ L.C. = $\frac{\text{value of each thread}}{\text{No. of C.S. divs.}} = \frac{0.05}{100} = 0.0005$ cm.

5. **What is a Screw gauge ? Why is it called a Micrometer Screw Gauge ?**

An instrument working on the principle of a screw is called a screw gauge. A screw has a no. of threads etched on it. When the screw is driven in by a screw driver, it moves through a certain linear distance for each rotation of its screw head. This distance is called pitch. If the screw head is further divided into N circular scale divisions, there (i.e. N cir. scale divds.) move through in giving one rotation.

The least distance moved i.e. Least count is the least linear distance moved in giving the screw head a rotation of its one circular scale division. Usually in a very fine screw gauge, pitch is 0.1 mm and least count = 10^{-6} m. Thus it is one micrometer. Thus it is called a micrometer screw gauge which has got an accuracy of measuring upto to 10^{-6} m.

6. **In measuring the diameter of a wire, why should you take two readings indirection mutually perpendicular to each other at a single place ?**

Because the wire may not be very uniform throughout its length.

Reference Page 19

1. **In a spherometer, the screw has 20 threads to a cm. and the no. of divs. on the circular scale is 100. Calculated the least count.**

Here 20 rotations = 1 cm

$\therefore$ 1 rotation = $\frac{1}{20}$ = 0.05 cm = pitch

No of cir. scale divds. = 100 = N

$\therefore$ Least count = $\frac{P}{N} = \frac{0.05}{100} = 0.0005$ cm.

2. **What do you mean by pitch and least count zero error and Backlash error in a spherometer ?**

Pitch: It is the linear distance covered by the screw in one complete rotation of its circular scale.

Least Count: The circular scale is divided into a known no. say 100 (or 50) division. The least distance covered by the screw in rotating the circular head through only one div. of the circular scale.

$$\text{Least Count} = \frac{\text{Pitch}}{\text{no. of cir. sc. divs.}}$$

Zero Error

When the spherometer is levelled, all the four legs of the sphereo meter should just touch the plane surface of a glass plate. In this position, the zero of the circular scale must lie against the zero of the vertical (Pitch) scale. In this case there is no zero error. In case these zeroes do not coincide, there is an error.

Backlash error

See previous questions and its answer.

3. **Why is a spherometer so called ?**

It is so called because it can be used to measure the radius of curvature of a sphereical surface.

4. **How can the accuracy of a spherometer be increased ?**

It can be done by using a screw having many threads to a cm., thus making the value of pitch small and the circular scale divisions should be increased.

5. **How will you determine the volume of the glass plate ?**

Vol. of the glass plate = A × x where A is the area of the plate which is found by graphical method (if the plate be irregular shape), x is the thickness of the plate determined by a spherometer. Thus the volume of the plate is determined.

6. **When is the zero error (a) positive (b) negative} ?**

If the zero of the circular scale is above the zero line of the vertical scale of the spherometer, the error is said to be positive, when all the four legs are coplanar.

If it is below the zero line of the vertical scale, the error is negative.

7. **How will you avoid Backlash error in a spherometer ?**

The screw must always be turned in the same direction to avoid Backlash error.

8. **A spherometer has its linear scale graduated in 2 division to a mm. and the circular scale has (i) 100 divs. (ii) 50 divs.**

The circular scale moves through 1 div. In each rotation. Calculate the pitch and the Least count in each case.

Here value of 1 div. of the linear scale $= \frac{1}{2}$ mm = 0.5 mm

Pitch (P) = 1 div. = 0.5 mm

(i) no. of cir. scale divs. = N = 100

$\therefore$ L.C. $= \frac{P}{N} = \frac{0.5}{100} = 0.005$ mm

(ii) N = 50

$\therefore$ L.C. $= \frac{P}{N} = \frac{0.5}{50} = 0.01$ mm

Exercise on Page No. 31

1. **Distinguish between Moment of a force and momentum of a body. State their units and dimensions.**

The moment of a force is the turning effect of a force and is measured as the product of force and the perpendicular distance. i.e. $F \times S$ units is Nm.

Dimension: $MT^{-2} L = [ML^2T^{-2}]$

The momentum of a body is the physical property possessed by it by virtue of its mass and velocity. It is measured as mass times velocity.

i.e. $MV = kg.\ mS^{-1}$

Dimension is $[MLT^{-1}]$

2. **What is Torque ?**

The torque or the moment of a force about a point is the tendency of the force to rotate the body about a certain a xis. It is measured by the product of the force and the perpendicular distance between the line of action of the force and the point of the axis about which the body tends to rotate.

3. **What is a couple of forces ?**

A couple of forces is a pair of equal and unlike a parallel forces, the moment of which is given by the product of one of the forces and the perpendicular distance between them.

4. **Three forces in one plane act upon a rigid body. What are the conditions for equilibrium.**

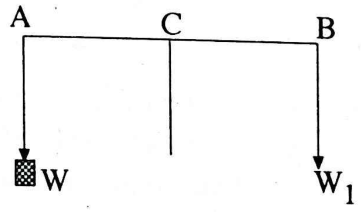
The forces must act such that the resultant of any two of them must be equal and opposite to the third force.

5. **State the principle of moments. How would you apply the principle to determine the sp. gr. of a solid.**

The principle of moment states that if a body is in such a rotational equilibrium that it will neither rotate nor rotate at a uniform rate, the sum of the clockwise moments is equal to the sum of the anticlock wise moments.

This principle may be used to find the magnitude and direction of a unknown force acting on a body in equilibrium.

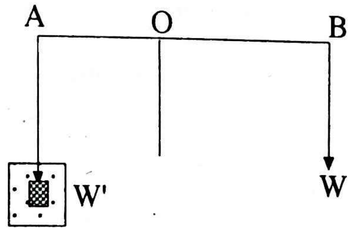
Let W be an unknown body load (body) and W_1 the known weight acting at A and B of a rigid scale AB in equilibrium at C, then



$$W \times AC = W_1 \times BC$$

$$\therefore \quad W = W_1 \times \frac{BC}{AC} \quad \ldots(1)$$

Let the known load (body) be now immersed in water in a beaker and be suspended from a point A in the scale, Let W_2 be the required known weight required to be suspended from the point B of the same so as to keep it in equilibrium as before, then



$$W' \times OA = W_2 \times OB$$

$$\therefore \quad W' = W_2 \times \frac{OB}{OA} \quad \ldots(2)$$

Now W and W' being known loss of weight in water = wt. of an equal vol. of water displaced

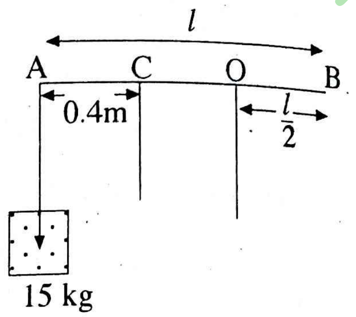
$\therefore$ sp. gr. of the body = $\frac{\text{wt. of the body}}{\text{wt. of an equal vol. of water displaced}} = \frac{W}{W - W'}$

This is how the sp. gr. of a body is determined by applying the principle of moments.

6. What is the center of gravity of a body ?

The center of gravity of a body is defined as the point through which the entire weight of the body acts irrespective of the position of the body. The C.G. of a body is fixed provided the size and shape of the body do not change.

7. A uniform rod weights 40 kg. With a 15 kg. wt. at one end, it balances at a point 0.4 m from the same end. Find the length of the rod.



Let AB be the length of the rod = ? l

Its weight 40 kg acts at the mid. point O. The rod is in equilibrium at C with a 15 kg. wt. suspended at the end A, distant 0.4 m from C.

$\therefore$ $W' \times AC = W \times OC$

or $15 \times 0.4 = 40\left(\frac{l}{2} - 0.4\right)$

or $6 = 20l - 16$

or $20l = 22$

$\therefore$ $l = \frac{22}{20} = \frac{11}{10} = 1.1$ m

8. Two bodies in free space have masses of 6 kg and 9 kg respectively are 8m apart. Where is their center of mass ?

Let the masses 6 kg an 9 kg act at point A and B, 8m apart. Let O be the position of the center of mass distant x from A.

By the principle of moments,

$6 \times x = 9 \times (8 - x) = 72 - 9x$

or $6x + 9x = 72$

or $15x = 72$

$\therefore$ $x = 4.8$ m from A.

9. A nail projects horizontally from a vertical wall. A string is attached with its head and is pulled at an angle of 60° to the wall with a force of 10 kg wt. Calculated the force tending to bend the nail and the force tending to pull the nail out of the wall.

AB is the vertical wall. A nail projects horizontally force F makes an ∠ 60° with the wall.

$\therefore$ force tending t pull the nail out of the wall

$= F \cos 30° = 10 \times \frac{\sqrt{3}}{2}$

$= 5\sqrt{3}$ kg. wt.

force tending to bend the nail

$= F \cos 60° = 10 \times \frac{1}{2} = 5$ kg. wt.

10. **Distinguish between vectors and scalars. Give three examples of each.**

Vectors and scalars are both physical quantities where as vectors have both magnitude and direction as force, momentum and velocity; scalars have magnitude only but no direction mass, speed, length etc.

11. **State the Law of Parallelogram of forces, triangle of forces and Lami's theorem.**

(a) **The Law of Parallelogram of forces may be stated as:** "If a body is acted upon simultaneously by two forces, represented in magnitude and direction by the two adjacent sides of a parallelogram drawn from a point, their resultant is represented in magnitude and direction by the diagonal of the parallelogram drawn from the same point."

(b) **Triangle of forces:** If a particle is simultaneously acted upon by two forces represented in magnitude and direction by the two sides of a triangle taken in order their resultant is completely represented in magnitude and direction by the third side of the triangle taken in opposite order.

This law may be stated in another form as follows: If a body is in equilibrium under the action of three forces, then they can be represented in magnitude and direction by the three sides of a triangle taken in order.

(c) **Lami's theorem:** "If a particle is acted upon simultaneously by three forces in equilibrium, then each force is proportional to the sine of the angles between the other two."

12. **Suppose the rain is falling vertically downwards. State why a person holds his umbrella straight while standing still and at some angle while walking ahead.**

While standing still the man has to consider only one vector i.e. the direction of fall of the rain. So he should hold the umbrella in the direction of the rain to protect himself from the rain. In case he is walking ahead he should consider two vectors i.e. the direction of motion of the rain and that of his own motion. So he should consider his motion relative to that of the rain and therefore should hold the umbrella inclined in the direction of the resultant velocity. Then only he will protect himself from the rain.

13. **Define force. State its units and dimension.**

Force is defined as any effort or anything that changes or tends to change the state of rest or uniform motion of a body.

It is expressed in dynes in cgs. unit in Newton in SI units. Its dimension is $[ML T^{-2}]$

14. **Suppoe two force of 25N and 80N simultaneously act on a body. What will the maximum and minimum force ?**

The resultant R = 80 + 25 = 105N maximum when they are in the same direction.

R = 80 - 25 = 55N where they are in opposite direction.

Exercise on Page 34

1. **What is friction ?**

Whenever a body moves over the surface of the other object, a kind of force will be called into play between these surfaces such that it tends to oppose the motion of the body. This force is called force of friction which is an opposing force.

2. **Distinguish between static friction, sliding friction and rolling friction.**

When there is no relative motion between the two surfaces in contact, the friction is called static friction.

Whenever one object slides over the surface of another object such that it moves with uniform velocity the frictional force that opposes the relative motion is called kinetic or sliding friction.

Rolling friction

Friction between two bodies when one rolls on the other is called rolling friction. It is found from experience that rolling friction is far less than sliding friction. Coeff. of rolling friction is much less.

3. **Define coefficient of friction and angle of uniform slip.**

Frictional force $F \propto$ Normal reaction.

i.e. $F = \mu R$, where μ is the coeff. of friction between the two surfaces.

$$\therefore \quad \mu = \frac{F}{R}$$

i.e. coeff. of friction is the ratio of the frictional force to the normal reaction. Angle of uniform slip: when a block is placed on an inclined plane which is gradually tilted until the block begins to just slide down with a constant speed, the angle of inclination at this stage is called the angle of uniform slip when.

$$\mu = \tan \theta.$$

4. **State the laws of limiting friction, limiting friction is the maximum force of interlocking between two surfaces i.e. the minimum force required to make the two surfaces slide against each other.**

Laws of limiting friction are:

(i) The force of limiting friction is directly proportional to the normal reaction between any two given surfaces in contact.

(ii) The force of limiting friction depends upon the nature of the material surfaces in contact.

(iii) The force of limiting friction does not depend on the area of the surfaces in contact as long as the normal reaction is the same.

5. **State the significance of friction in everyday life.**

Friction:

(i) Helps in walking

(ii) Stops vehicles by the use of brakes.

(iii) Holds screws on wood.

Thus friction is a necessity.

6. **What happens to the energy expended against friction ?**

The energy expended is dissipated as heat.

7. **Why should one take short steps than long ones while walking on ice ?**

While walking on ice one puts his leg at an angle θ with the vertical. The vertical component of the force R that he gives to the surface, $V = R \cos \theta$, and the horizontal component $H = R \sin \theta$. Correspondingly, the normal reaction given by ice on the foot of the man is $R \cos \theta$ and the frictional force given is $F = R \sin \theta$.

$\therefore \quad \mu = \frac{F}{N} = \frac{R \sin \theta}{R \cos \theta} = \tan \theta$ if θ becomes more, μ attains the value of the coeff. of limiting friction. If θ increases still further, his leg will slip over the surface. In order to walk on ice without any slip, he has to take short steps so that θ will be less and μ remain less than the coefficient of limiting friction.

8. **A 800 N- piano is moved 15 m across the floor by a horizontal force of 250 N. Find the coeff. of friction. What happens to the energy expended.**

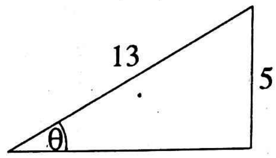
$$\mu = \frac{F}{N} = \frac{250}{1800} = \frac{5}{16} = 0.312$$

Energy expended = work done = 250 × 15 = 3750 J of energy is dissipated in the form of heat.

9. **A body of mass 20 kg. just slides down a rough inclined plane (without acceleration) of 5 in 13. Calculate the coeff. of friction**

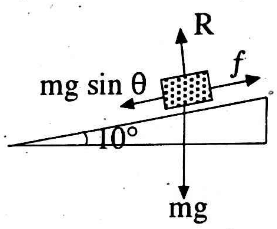
$$\mu = \tan \theta$$

Here, $\sin \theta = \frac{5}{13}$



$\therefore \quad \mu = \tan \theta = \frac{5}{12} = 0.41$

10. **A body of mass 25 kg slides down an inclined plane without acceleration when the inclination of the plane with the horizontal is 10°. When the inclination is changed to 30°. Find the acceleration of the body.**



Here, $\mu = \tan 10° = 0.176$

Resulting force downwar d = mg sin θ - f,

f = frictional force = μ mg cos θ

= mg sin 30 - μ mg cos 30

= mg [sin 30 - μ cos 30]

or ma = 250 [0.5 - 0.176 × 0.866] = 86.896

$\therefore \quad a = \frac{86.896}{20} = 4.34 \text{ m/s}^2$

Exercise on Page 40

1.(a) **Define density and sp. gr.**

Density is defined as mass per unit volume of the body.

$\therefore \quad D = \frac{M}{V}$ its unit is gm/c.c. or kg/m^3

Sp. gr. of a substance is the ratio of the wt. a certain volume of the substance to the wt. of an equal volume of water at 4°C.

It is also ratio of density of the substance to the density of water at 4°C. Since it is a ratio, it has no unit.

(b) Why is the density of one substance different from that of the other ?

Density is the mass per unit volume of the substance. Mass is the quantity of matter contained in the body. The quantity of matter contained in a unit volume of one substance is not the same as that contained in a unit volume of another substance. Hence density of one substance is different from that of the other.

(c) What is the unit of the density and sp gr. ?

Density is the mass per unit volume of the substance and is therefore expressed as gm per c .c. or kg. per m^3 or this per cu *ft*.

Sp. gr. is a ratio of the weight of a certain volume of the substance to the wt. of an equal volume of water at 4°C. Since t is a ratio, it has no unit.

2. Does density depend on temp ? If so, how ?

Density of a substance depends on temperature. It is defined as mass per unit volume whereas mass remain constant, volume of a substance change with temperature thus:

$$\text{mass } M = \text{vol.} \times \text{density}$$
$$= V_0 \times D_0 \text{ at } °C$$
$$= V_t \times D_t \text{ at } t\,°C$$
$$\therefore \quad V_0 D_0 = V_t D_t = V_0(1 + \gamma t)\, D_t$$

where γ is the coeff. of cubical expansion of the substance.

$\therefore \quad D_t = \dfrac{D_0}{1 + \gamma t}$ which shows that density decreases as temperature rises.

3. State Archimedes' Principle. What is Buoyancy ?

Archimedes' Principle states that when a solid is partly or wholly immersed in a certain liquid, it will displace its own volume of its immersed portion and will lose a part of its weight which is equal to the weight of the liquid displaced.

The body will displace its own volume of the immersed portion and the displaced liquid will rise above. While doing so, it will exert an up thrust. This upthrust of the liquid is known as the Buoyancy.

4. Can you know by Applying Archimedes Principle whether a given body is solid or hollow ? If so, how ?

Yes. This body is weighed in air and then in water. From the loss of weight in water, its volume is found out by dividing the loss of weight by density of water. Its volume is say V. The wt. of the body ins air is divided by its density. This gives the volume V'. If V > V' the body is hollow. If V = V', the body is solid.

5. State the law of floatation.

When a body floats in any liquid, the weight of the floating body is equal to the wt. of the displaced liquid.

6. Why is it necessary to heat the cork in boiling water, while determining its sp. gr. ?

A cork has some pores in it. As a result, when it is immersed air bubbles in it exert an upward pressure which will not be taken into account in calculating the loss of wt. of the cork and hence will affect the result. Hence before weighing it in water, it should be heated in boiling water for about 10 min. so as to remove all the air bubbles in its pores, so that there won't be any air bubbles to exert upward pressure when weighed in water.

7. **What is the difference between a hydrostatic balance and an ordinary physical balance ?**

A hydrostatic balance is a common balance with a little extra arrangement. To enable weighing of bodies in a liquid, a wooden bridge placed on the base board across the left hand scale pan such that the pan below it can swing in its own way quite freely without touching the sides of the bridge.

8. **Why is it necessary to apply temperature correction in sp. gr. determination ?**

The sp. gr. of a substance is defined as the ratio of the weight of a certain volume of the substance to the wt. of an equal volume of water at 4°C whereas the definition is with respect to water at 4°C. The expt. is generally done not at 4°C but at any other lab. temperature. So in order to obtain more accurate result, the result obtained should be multiplied by the sp. gr. of water at the ab. temp. This is known as temperature correction.

9. **Can you determine the diameter of a rod using a Hydrostatic balance ?**

Yes, the rod is weighted in air in a Hydrostatic balance. Next it is weighed in water. The loss of weight divided by density of water gives the volume of the rod.

$$\therefore \quad V = \frac{\pi}{4} d^2 l$$

knowing l, $d^2 = \dfrac{4V}{\pi l}$ from which d may be calculated.

10. **How will you determine the sp. gr. of a wooden cube without using balance ?**

The length of the cube is measured as l then its volume $= l^3$ then wt. of the wooden cube is

$$w = V.S. = l^3 \text{ S where S is its sp. gr.}$$

Then it is placed in water in a measuring cylinder. While floating vol. of water displaced is noted. From which wt. of displaced water is known.

Let it be A (known)

$$\therefore \quad l^3 S = A$$

$$\therefore \quad S = \frac{A}{l^3}$$

11. **Is it easier to float in fresh water or in sea water ? Why ?**

Sea water has density greater than one. So for a given volume of the immersed portion of body, the weight of sea water is greater than that of the same vol. of fresh water. So it is easier to float in sea water.

12. **Why should the air bubbless tuck to the side of a solid when immersed in water be removed ?**

Otherwise air bubbles also exert some upward pressure which does not come into our calculation.

Problems Page No. 41

1. **A body weight 25 gm in air and 15.9 gm in water. Find its volume and sp. gr.**

Here wt. of the body in air = 25 gm

.... water = 15.9 gm

∴ Loss of wt. in water = 9.1 gm = wt. of water displaced.

∴ Vol. of water displaced = 9.1 c.c. = vol. of the body

$$\therefore \quad \text{sp. gr.} = \frac{25}{9.1} = 2.7$$

2. **A porcelain piece weighs 12.5 gm in air, 7.9 gm in water and 8.8 gm in liquid. Calculate the volume of the porcelain and sp; gr. of the liquid.**

Here loss of wt. in water = 12.5 - 7.9 = 4.6 gm = wt. of water displaced.

∴ vol of the porcelain = 4.6 c.c.

loss of water in liquid = 12.5 - 8.8 = 3.7 gm

$$\text{sp. gr. of the liquid} = \frac{3.7}{4.6} = 0.80$$

3. **A metal cube of side 2.5 cm. Suffers a loss of wt. of 9 gms. in a liquid. Find the density of the liquid.**

Loss of wt. in liquid = wt. of an equal vol. of liquid displaced

= vol. of liquid × density

9 = vol. of solid × S = (2.5) 3.S

$$\therefore \quad S = \frac{9}{(25)^3} = \frac{9}{15.625} = 0.576$$

4. **A piece of wax weighing 4.4 gm is attached to a piece of lead and the two together are found to weigh 19.88 gm in water. If the weighting the piece of lead along in water is 20.48 gm, find the sp. gr. of wax.**

wt. of wax in air = w = 4.4 gm

wt of wax in air + lead in water = w_1 = 4.4 + 20.48 = 24.88

wt. of wax and lead together = w_2 = 19.88

∴ Loss of wt. in water = $w_1 - w_2$ = 5.0 gm

$$\text{sp. gr. of wax} = \frac{w}{w_1 - w_2} = \frac{4.4}{5} = 0.88$$

5. **A piece of alloy consisting of gold and silver weighs 20 gms in air and 18.4 in water. How much gold is there in the alloy ?**

sp. gr. of gold = 19.3, that of silver = 10.5

Here, loss of wt. in water = 20 - 18.7 = 1.3 gm

= wt. of water displaced = vol. of water displaced × density of water

or 1.3 = vol. of alloy × 1

$$= \text{vol. of gold} + \text{vol. of silver} = \frac{m_1}{s_1} + \frac{m_2}{s_2}$$

or $$1.3 = \frac{m_1}{19.3} + \frac{20 - m_1}{10.5}$$

or $1.3 \times 9.3 \times 10.5 = 10.5\, m_1 + 3.86 - 19.3\, m_1$

or $263.4 = 386 - 8.8 m_1$

or $8.8\, m_1 = 386 - 263.4 = 122.6$

$$\therefore \quad m_1 = \frac{122.6}{8.8} = 13.93 \text{ gm of gold}$$

6. **A silver ornament suspected to be hollow, weights 288.75 gm in air and can displace 30 c.c. of water. Given sp. gr. of silver to be 10.5, find the vol. of the cavity.**

Here Actual vol. of silver = $\frac{288.75}{10.}$ = 27.5 c.c.

vol. of water displaced = 30 c.c. = vol. of the ornament

∴ vol. of cavity = 30 - 27.5 = 2.5 c.c.

7. **A piece of lead weigh 100 gm in water. What does it weight in air ?**

Density of lead = 11.3 gm/c.c. = volume of the ornament

Wt. of lead in air = w

Wt. of lead in water = w_1 = 100 gm

∴ Loss of wt. in water = $w - w_1 = w - 100$

= wt. of water displaced

= vol. of water displaced

= vol. of lead × 1

∴ density of lead = W = $\frac{w}{w - 100}$

or 11.3 w - w = 1130

or 10.3 w = 1130

∴ w = 109.7 gm.

Exercise on page 50

1. **What is a Simple Pendulum ?**

A simple pendulum is a heavy materiel bob suspended from a rigid support by means of a light, inextensible and flexible string.

2. **Define effective length time period and amplitude of vibration ?**

The distance between the point of suspension and the C.G of the bob is called the effective length of the pendulum;

Amplitude: The amplitude of vibration is the maximum angular displacement of the bob from it undisturbed position on either side.

Time Period: It is the time taken for a complete oscillation which means two swings.

3. **Distinguish between gravitation and gravity.**

Gravitation is the force of attraction between two material bodies both very big, or both very small or one big and the other small. It is one of the basic forces of nature.

Gravity: It is a special case of gravitation. When we talk about it on the earth, one of the two bodies mentioned above the earth, the force of attraction of the earth on the other body is called the force of gravity of the earth on it. On the moon, it is the force of gravity of the moon on the body.

4. **What do you understand by acceleration due to the gravity ?**

The acceleration due to gravity is the force of attraction of the earth on a body. On the moon, the acceleration due to gravity is the force attraction of the moon on the body and so on.

5. **If your pendulum bob were a hollow one and half filled with mercury, will the effective length increase or decrease ?**

If the pendulum bob were solid, its c.g. will be at the centre of the bob. but when the bob were hollow and half filled with mercury, its c.g. will be lowered slightly. Hence the effective length will be slightly increased.

6. **Why should the amplitude of vibration be as small as 4° ?**

While performing expt. on a simple pendulum, we have to make use of the pendulum equation

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

The derivation of this formula makes use of the assumptions $\sin\theta \approx \theta$ when θ is small. Hence θ the angular amplitude should be as small as 4°.

7. **What is the value 'g' in your lab. Should it be 9.8 m/s^2, more or less than this ?**

The value of 'g' here (at Kathmandu) should be less than 9.8 m/s^2 which is the value at the sea level. Since Kathmandu is at a altitude (≈ 4483 *ft*. about sea level), the value of 'g' should be less than 9.8 m/s^2.

It should be approx. 'g' at Kathmandu = $g - \frac{2gh}{R}$, where g = 9.8 m/s^2, R is the radius of the earth and h is the altitude of the place of observation.

8. **What type of graph do you expect between (i) *l* and t, (ii) *l* and t^2, and why ?**

We have,

$t = 2\pi\sqrt{\frac{l}{g}}$ or, $t^2 = \left(\frac{4\pi+2}{g}\right) l$ which is the eqn. of a st. line passing through the origin.

Thus the graph and l and t^2 will be a st. line passing through the origin whereas the graph between l and t give a parabola.

9. **Is it possible to determine the height of a place using a pendulum ? If so how ?**

The time period of a pendulum is $t = 2\pi\sqrt{\frac{l}{g}}$ on the surface of the earth.

Next at a place height 'h' above the surface, the time period is given, by

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

$$\therefore \quad \frac{t}{t'} = \frac{\sqrt{g'}}{\sqrt{g}}$$

$$\frac{g'}{g} = \frac{\frac{GM}{(R+h)^2}}{\frac{GM}{R^2}} = \frac{R^2}{(R+h)^2}$$

$$\therefore \quad \frac{t}{t'} = \frac{\sqrt{R^2}}{\sqrt{(R+h)^2}} = \frac{R}{R+h}$$

or $\frac{t'}{t} = \frac{R + h}{R} = 1 + \frac{h}{R}$

or $\frac{h}{R} = \frac{t'}{t} - 1 = \frac{t' - t}{t}$

$\therefore$ $h = \frac{R(t' - t)}{r}$

Thus knowing t, t' and R, the height of a place h can be determined.

10. **Calculate the length of the Seconds' Pendulum at a place where the value of g is (a) 9.8 m/s^2 (b) 9.7 m/s^2**

(a) We have

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

or $t^2 = 4\pi^2 \frac{l}{g}$

or $g = 4\pi^2 \frac{l}{t^2} = 4\pi^2 \frac{l}{4}$

$\therefore$ $t = 2s.$

$\therefore$ $l = \frac{g}{\pi^2}$

(a) $l = \frac{9.8}{9.86} = 0.994$ m

(b) $l = \frac{9.7}{9.86} = 0.984$m

for a second period.

11. **The following table gives the value of T, the timing of a complete small angled oscillation of a simple pendulum corresponding to its various lengths.**

(i) Plot the graph of T^2 against L using scales starting from zero on both axes and deduce the slope of the best line. Hence calculate the value of 'g'.

(ii) Plot the graph of T against L. Hence read off the length of the seconds Pendulum.

12. **A second Pendulum at a place where g is 9.8 m/s^2 is taken to another place where g is 9.75 m/s^2. How many seconds will it gain or lose day ?**

We have,

$$t_1 = 2\pi \sqrt{\frac{l}{g_1}} = 2\pi \sqrt{\frac{l}{9.81}}$$

where $t_1 = 2$ secs

$\therefore$ $n_1 = \frac{86400}{2}$ per day = 43200 per day

$$t_2 = 2\pi \sqrt{\frac{l}{g_2}} = 2\pi. \sqrt{\frac{l}{9.75}}$$

$\therefore \quad \frac{t_1}{t_2} = \sqrt{\frac{9.75}{9.81}} = \left(1 - \frac{0.06}{9.81}\right)^{1/2}$

or $\quad \frac{n_2}{n_1} = 1 - \frac{1}{2} \times \frac{0.06}{9.81} +$ higher terms

$n_2 = n_1 \left(1 - \frac{1}{2} \times \frac{0.06}{9.81}\right) = 43200 - \frac{43200 \times 0.06}{2 \times 9.81}$

$\therefore$ loss in no. of complete vibs/day $= \frac{43200 \times 0.06}{2 \times 9.81}$

$\therefore$ loss in time $= \frac{43200 + 0.06}{1 \times 9.81} \times 2 = 264.2$ sec/day

$\therefore$ the pendulum will lose 264.2 sec/day.

13. Calculate the period of oscillation of a simple pendulum of length 15 m with a bob of mass 1.2 kg. What assumption is made in this calculation ? ($g = 10\ m/s^2$). If the bob of this pendulum is pulled side a horizontal distance of 15 cm and then released, what will be the value of the kinetic energy and (ii) the velocity of the bob at the lowest point of the swing ? (iii) After 50 complete swings, the maximum horizontal distance of the bob has become 7.5 cm, what fraction of the initial energy has been lost ?

We have,

$$t = 2\pi\sqrt{\frac{l}{g}} = 2 \times 3.14\sqrt{\frac{1.5}{10}} = 2.43s$$

$V^2 = U^2 + 2gh = 0 + 2 \times 10 \times 0.008 = 0.16$

$\therefore \quad V = 0.4$ m/s

$\therefore$ K.E. at the lowest point $= \frac{1}{2} mV^2 = \frac{1}{2} \times 1.2 \times 0.16 = 0.096J$

After 50 swings, CB = 0.075 m

$\therefore \quad OC^2 = (1.5)^2 - (0.75)^2$

$OC^2 = (1.5 + 0.075)(1.5 - 0.075)$

$= 1.575 + 1.425 = 2.244$

OC = 1.498 m

$\therefore$ CA = 0.002 m

$\therefore \quad V^2 = U^2 + 2gh = 0 + 2 \times 10 \times 0.002 = 0.04$

$\therefore \quad V^2 = U^2 + 2gh = 0 + 2 \times 10 \times 0.002 = 0.04$

$\therefore$ K.E. $= \frac{1}{2} mV^2 = \frac{1}{2} \times 1.2 \times 0.04 = 0.024J$

Loss of K.E. = 0.096 - 0.024 = 0.072 J

$\therefore$ fraction of energy lost $= \frac{0.072}{0.096} = 0.75$

14. **What is simple harmonic motion ? State its characteristics.**

The simple harmonic motion is a periodic to and from motion in a straight line such that

(i) the acceleration and the restoring force on it are always directly proportional to its displacement.

(ii) the acceleration is oppositely directed to its displacement.

15. **What is Compound Pendulum ?**

A compound Pendulum is a rigid body of any arbitrary shape, which can oscillate freely about a horizontal axis passing through it. The time period of such a pendulum is given by

$$t = 2\pi\sqrt{\frac{l^2 + k^2}{lg}}$$

where l is the distance of the point of suspension from the center of gravity and K is the radius of Gyration about an axis passing through the center of gravity.

Exercise on page 52

1. **What is a barometer ?**

A barometer is an instrument used for measurement of the atmospheric pressure at a certain place. By fixing a Torricellian tube in a permanent position, we obtain a means of measuring the amount of the atmospheric pressure at any moment. The pressure is measured by the weight of the column of mercury which it supports. Such an instrument is called a barometer.

2. **What is an Aneroid Barometer ?**

It is also an instrument used for the measurement of atmospheric pressure. Here no liquid is used. But it is not so accurate as a mercurial barometer but it is light enough and is quite portable.

3. **What is the average atmospheric pressure ?**

The average atmospheric pressure at the sea level is the weight of a column of mercury of height 76 cm. supported by the atmospheric pressure.

= wt. of 76 cm of mercury per unit area

= wt. of 76. c.c. of mercury = $76 \times 13.6 \times 980$

= 1.013×10^5 dynes per sq. cm. = 1.01×10^5 N/m^2

4. **What is the average atmospheric pressure on your body.**

It is 14.7 $l$bs wt. per sq. in. = 15 $l$bs. per sq. in.

5. **What is the unit of Atmospheric Pressure ?**

It is expressed in dyne/sq. cm or $\frac{N}{m^2}$

6. **How is it that water does not boil exactly at 100°C at Kathmandu ?**

Water boils at 100°C at sea level. But Kathmandu is at an attitude of about 4483 ft. or 3470.7 m, about sea level. The boiling point is given by {100 - (76 - P) × 0.37} where P is the atmospheric pressure in cm. of Hg. at Kathmandu. If P is about say 65.0 cm as shown by Barometer on a particular day.

The boiling Point = 100 - (76 - 65) × 0.37

$= 100 - 4.07 = 95.97°C$

7. **Why do you use mercury in a Barometer ? Could you use water ?**

Mercury is the most convenient liquid for use in a barometer for it as high sp. gr. (13.6). So a comparatively short column about 30 in. or 76 cm. of it will balance the atmospheric pressure at sea level. Other liquids such as water or glycerine etc. may also be used but then the column would be inconveniently long due to its low sp. gr. for example in the case of water, 76 cm. of Hg. would be about 34 *ft*. of water which is quite inconvenient. So water is not used.

8. **Will the barometer reading be the same always ?**

It will not be the same always. It depends on the amount of moisture content in the atmosphere.

9. **What are the uses of barometer reading ?**

A barometer may be used to measure (i) the atmospheric pressure (ii) the height of a mountain the height attained by a balloon etc. (iii) determine the state of weather and use it for weather forecast.

10. **How does the barometer help to determine the boiling point of water ?**

The boiling point of water at sea level (atmospheric pressure 76 cm. of Hg.) is 100°C. It has been found out by experimental observation that for every 1000 *ft*. increase in altitude, there will be a decrease of 1 cm. of Hg in the barometric height and there will be a corresponding decrease in the boiling point of water by 0.37°C. If the atmospheric pressure at a place on a particular day is P cm. of mercury, the true boiling point will be $100 - \{(76 - P) \times 0.37\}$ °C.

Exercise on page 57

1. **Why should the mercury level in a barometer be adjusted so as to just touch the ivory point ?**

The scale attached with a barometer is so adjusted that its zero coincides with the ivory point touching the surface of mercury in the cistern.

2. **State Boyle's law. Is it true for all temperatures and pressures ?**

Temperature remaining constant, the volume of a given mass of an enclosed dry gas varies inversely as the pressure to which it is subjected.

It does not hold good for high pressure and high temperature.

There will be deviation from Boyle's law at high pressure, and high temperatures.

3. **In verifying Boyle's law, why the volume of air should not be changed suddenly ?**

The open tube in the Boyle's law apparatus should be raised or lowered very slowly and gently. After changing the position we should wait for 5 or 6 mins. so that the enclosed air attains a constant temperature. If we raise or lower the tube more rapidly, the volume of air is compressed or rarefied very suddenly so that there will be a slight change in temp., violating the required condition of the experiment.

4. **State the nature of the graph between (i) P an V (ii) P and $\frac{1}{V}$ (iii) PV and P.**

Boyle's law states that at constant temperature.

$$V \propto \frac{1}{P} \qquad \text{i.e.} \quad K\frac{1}{P}$$

or $PV = K$

which represents a rectangular hyperbola.

∴ the graph of P and V should be rectangular hyperbola.

Next $P = K \frac{1}{V}$ which represents a st. line passing through the origin.

The graph of P and $\frac{1}{V}$ is a st. line passing through the origin.

5. **What is Normal Atmospheric Pressure ?**

The normal atmospheric pressure is the pressure exerted by a column of mercury 76 cm. high at sea level and is given by the wt. of a 76 cm. column of Hg on a unit area. It is found to be 1.013×10^5 dyne/cm^2. in. or. 1.01×10^5 N/m^2.

Exercise on Elasticity Page 62

1. **State the difference between plasticity and elasticity.**

Plasticity is the property possessed by a body by virtue of which it changes its shape and size on the application of some deforming force but does not come back to its original shape and size on removal of the force.

Elasticity is the property possessed by a material by virtue of which it changes its shape and size on the application of some deforming force but comes back to its original condition on removal of the force provided the force applied is within some limit known as elastic limit.

2. **State Hooke's law of elasticity.**

Hooke's law of elasticity states that:

Withinelastic limit, stress is directly proportional to strain. Stress is the deforming force per unit area.

Strain is the ratio of the change produced to its original condition such as change in length to its original length etc.

3. **Define stress, strain, elastic limit, breaking stress. State the unit in each case.**

Stress is defined as the restoring or deforming force per unit area and expressed in teems of $\frac{N}{m^2}$. Strain is the ratio of the change in length or volume to its original length or original volume.

Elastic limit: As we apply stress to an elastic body, the body will be subjected to a strain. As we go on increasing the load to increase the stress, the strain will also gradually increase to such an extent that on increasing the stress further, the body will have undergone a permanent change or will not come back to its original condition on removing the load. That extent is the elastic limit for that material.

Breaking stress: The maximum load that can be applied on an elastic body per its unit area without having to lose its property of elasticity is defined as the Breaking stress and is expressed in kg per cm^2 or m^2 or Newton per m^2.

4. **What is elastic fatigue ?**

Whenever a machine part is subjected to repeated stresses over long periods of time, the internal structure of the material is changed. Each time the stress is applied, the molecules and the crystals realign, and each time the stress is removed, this alignment remains some permanent set. As this process continues, certain regions weakened, particularly around areas where there are microscopic cracks on the surface. This loss of strength because of repeated stresses is called elastic fatigue.

5. **Define Young's modulus of elasticity. State its units and dimensions.**

Young's modulus of elasticity Y is defined as $Y = \frac{\text{Tensile stress}}{\text{Longitudinal strain}} = \frac{\frac{F}{a}}{\frac{x}{L}}$

where the load applied on a wire of length L, a its cross section and x the change in length produced.

Y is expressed in $\frac{N}{m^2}$, strain has no unit.

Dimension of $Y = \frac{MLT^{-2}}{L^2} = [ML^{-1}T^{-2}]$

6. **Do you prefer a long wire or a short wire in this expt. on elasticity ? Give your reason.**

A slight error in the measurement of length of a long wire will produce a negligible effect on the over all result than that in the case of a short wire.

7. **Which is more elastic steel or rubber ?**

Steel undergoes a small strain than rubber on applying the same stress on both.

∴ Steel is more elastic than rubber.

8. **Why is it necessary to wait for some time after loading and unloading the wire ?**

On loading the wire, the molecules in it take some time to stretch. Hence some time say 3 to 4 min should be allowed for the wire to get stretched. Similarly in case of unloading too.

9. **A load of 7 kg wt. produces an extension of 0.5 mm in a wire 2.5 m log and 1 mm diameter. Calculate the Young's modulus of the wire. (g = 9.8 m/S²)**

We have,

$$Y = \frac{wgL}{\pi r^2 x} = \frac{7 \times 9.8 \times 2.5}{3.14 \times (0.5 \times 10^{-3})^2 \times 0.5 \times 10^{-3}}$$

$$= 4.37 \times 10^{11} Nm^{-2}$$

10. **Young's modulus for the tendon in a man's leg is 1.6×10^8 N/m². If the tendon is 10 cm long and 0.45 cm in diameter. How much will it be stretched by a force of 10N ?**

We have,

$$Y = \frac{wgL}{\pi r^2 x}$$

$$\therefore \quad x = \frac{wg}{\pi r^2 y} = \frac{10 \times 0.1}{10^{-2}(0.225 \times 10^{-2})^2}$$

$$= \frac{0.1 \times 10^{-4}}{3.14(0.225)^2 \times 1.6 \times 10^8} = \frac{0.1 \times 10^{-4} \times 10^{-8}}{0.2543}$$

$$= 0.0392 \times 10^{-12} \text{ m} = 0.3932 \times 10^{-9} \text{ mm}$$

Exercise on Surface Tension page 65

1. **Define surface tension. State its units and dimensions.**

The surface tension T of a liquid, sometimes called the coefficient of surface tension is defined as the force per area unit acting on the surface at right angles to one side of a line drawn on the surface. Its unit is force per unit length. = Nm^{-1} or dynes cm^{-1}.

$$\text{The dimension of surface tension} = \frac{\text{Dimension of force}}{\text{dimension of length}}$$

$$= \frac{MLT^{-2}}{L} = [MT^{-2}]$$

2. **Explain why water rises in a capillary tube.**

Water rises in a capillary tube due to surface tension which arises on account of a force of cohesion between the molecules of a liquid. When the liquid is placed in a container (say a glass tube) then a force of adhesion also begins to act between the molecules of the liquid and those of the container. In water the force of adhesion is greater than cohesion. So here level of water rises inside the tube to such a height that the weight of a column of water is equal to the force of surface tension acting upwards. Hence the meniscus is concave.

3. **What is angle of contact ?**

In case of water in a clean glass capillary tube, the glass surface is tangential to the meniscus where water touches it. The tangent to the liquid surface where it touches the glass may make an acute angle θ. This angle θ is called the angle of contact.

4. **Does surface tension depend on temperature ? How.**

It depends on temperature. As temperature rises, density falls. The surface tension T slightly decreases with rise in temperature.

6. **If you incline the capillary tube. What will happen ?**

The length of the boundary of the meniscus will become greater than $2\pi r$. Moreover some of the weight of the liquid column will be supported by the sides of the capillary.

7. **Distinguish between adhesive and cohesive forces.**

Cohesive force is the force of attraction between like molecules whereas a adhesive force is the force of attraction between unlike molecules as between glass and water.

8. **Calculate the height to which water will rise in a capillary tube of diameter 0.5 min. in an expt. to determine the surface tension of water. Determine the surface tension of water.**

Give T for water = 72 dynes per cm.

The surface tension T is given by

$$T = \frac{rh\rho g}{2}$$

or $72 = \frac{0.025 \times h \times 1 \times 980}{2}$

$\therefore \quad h = \frac{2 \times 72}{0.025 \times 980} = \frac{144}{245} = 5.87$ cm

9. What are the limitations of this method ?

(i) Contamination of the liquid surface cannot be prevented.

(ii) Capillary bore may not be exactly circular.

(iii) It is difficult to break the capillary just at the level of the meniscus.

10. On what factor does the surface tension of a liquid depend ?

It depends on the

(i) the nature of the liquid.

(ii) the nature of the surfaces in contact.

(iii) the temperature of the liquid. Higher the temperature, less the surface tension.

Exercise on page 68

1. What is viscosity ?

The property of a fluid by virtue of which retarding forces are called into play within it. When any relative motion between its parts occurs is called the viscosity of fluids. State its units and dimensions.

2. Define coefficient of viscosity.

The coefficient of viscosity η is defined as the tangential force per unit area required to maintain a unit velocity gradient in the field. It is measured in poise. Its dimensions are $\{ML^{-1} T^{-1}]$

3. What do you mean by velocity gradient and pressure gradient ?

Whenever a layer of liquid moves over the next layer of the liquid surface, the variation of its relative velocity u with its distance between layers is called velocity gradient. Thus $\frac{du}{dx}$ is the velocity gradient.

When a liquid flows through a capillary tube in stream line motion under a pressure P applied at its one end, then the variation P with l (length of the tube) is called pressure gradient $\frac{P}{l}$.

4. State Stoke's law.

For a small sphere of radius r falling through a viscous medium of coeff. of viscosity η, the viscous force F is given by

$F = 6\pi\eta\, rU_0$ where U_0 is the terminal velocity of the body is given by $U_0 = \frac{2r^2}{9\eta}(\rho - \sigma)g$

ρ is the density of the material of the sphere, σ is the density of the liquid.

5. Distinguish between stream line. and turbulent motion of a liquid.

If the path of every moving particle of a fluid coincides with the line of motion of the fluid as a whole, the motion is said to be a stream line motion. If the motion of the particles of a fluid is disorderly i.e. in directions other than the line of motion of the fluid as a whole the motion is said to be turbulent.

In stream line motion, under a given pressure gradient, the flow of a liquid through a narrow tube is decided mainly by its viscosity, whereas in turbulent motion, it is shelly governed by its density and very little by its viscosity.

Exercise on Page 73

1. **What are the fixed points of a thermometer ?**

There are two fixed point in a thermometer.

(i) The lower fixed point: It is the temperature at which pure ice melts. It is 0°C in centigrade scale and 32° F in Fahrenheit scale.

(ii) The upper fixed point: It is the temperature of the boiling point of water at normal atmospheric pressure (76 cm of Hg). It is 100°C or 212°F.

2. **What is fundamental interval ?**

The interval between the upper and lower fixed points of a thermometer is called the fundamental interval.

3. **Why is it that hot water boils at Kathmandu at a temperature less than 100°C ?**

Water boil at 100°C at sea level at normal atmospheric pressure (76 cm. of Hg.) But Kathmandu is at an altitude of 4483 *ft*. (or 1366 m) approx. above sea level. Considering an ascent of every 100 m above sea level causing a decrease of 3.7°C in the boiling point of water boils at Kathmandu at (100 - 5.05 i.e. 94.95 approx. 95°C.

4. **How does the pressure affect the boiling point of a liquid ?**

As temperature rises, the volume of a liquid increases consequently pressure falls. Thus the change of pressure causes a change in the boiling point. Thus as pressure decreases, the boiling takes place earlier i.e. at a lower temp.

5. **What do you mean by the steam point ?**

The temperature at which pure water boils is called its steam point.

6. **A faulty thermometer has its fixed point marked - 0.5° and 96°. What is the correct Celsius temperature when this thermometer reads 22° ?**

$$\frac{C - O}{100} = \frac{x - (-0.5)}{96 - (-05)} = \frac{x + 0.5}{96.5}$$

or $100x + 50 = 96.5C$

or $100 \times 22 + 50 = 96.5C$

or $2250 = 96.6C$

$\therefore \quad C = \frac{2250}{96.5} = 23.3°C$

Exercise on Page 75

1. **Determine the increase in length of the given tube when heated 40°C.**

Suppose given tube is of aluminum and is 100 cm long.

$\therefore$ Increase in length $= l_0 \alpha t = 100 \times 0.000022 \times 40 = 0.022$ cm $= 0.22$ mm

2. **Determine the temperature upto which the given tube is to be heated in order that it its length may increase by $\frac{1}{7}$ mm.**

Suppose the tube is 100 cm long and is of iron and its initial temperature 25°C.

Let x be the temp. upto which it is to be heated.

$\therefore$ rise of temp. = (x - 25) = t

Increase in length = $l_0 \alpha t$

or $$\frac{1}{70} = l_0 \alpha t = 100 \times 22 \times 10^{-6} \times (x - 25)$$

or $$x - 25 = \frac{1}{100 \times 70 \times 22 \times 10^{-6}} = \frac{100}{15.4}$$

$$= 6.49 = 25 + 6.49 = 31.49°C$$

3. **What is meant by thermal expansion ?**

When a certain body is heated, increase in length, breadth and thickness is known as its thermal expansion.

4. **Define coeffs. of linear and cubical expansion. State their units.**

The coeff. of linear expansion α of a solid is its increase in length per unit length per unit rise of temperature. Its unit is per 0°C. Superficial expansion β is the increase in its surface area per unit area per unit rise in temperature. It is expressed per °C.

The coeff. of cubical expansion γ is the increase in volume per unit volume per unit rise of temperature.

5. **State the relation between α, β and γ.**

We have $\beta = 2\alpha, \alpha = \frac{1}{2\beta}$,

$\gamma = 3\alpha, \alpha = \frac{1}{3\gamma}$

$\therefore \quad \alpha = \frac{1}{2\beta} = \frac{1}{3\gamma}$

6. **Explain the statement.**

The linear expansivity of copper is 0.0000167/°K

The statement means a unit length say 1m length of a copper tube or copper rod is heated through 1°k, it will increase by 0.0000167m.

Thermal Expansion

Exercise Page 92

1. **State the difference between heat and temperature.**

Heat is a form of energy and is the physical cause of warmth or coolness experienced by us. If we get heat, we feel warm while on losing it we feel cold.

Temperature of a body is the degree of hotness or coolness in it. It is that thermal condition of the body which determines the direction flow of heat when the body is placed in contact with another body.

2. **Define specific heat capacity. What is its unit ?**

The specific heat capacity of a body can be defined in two different ways.

It is numerically equal to the amount of heat required to raise the temperature of unit mass of the substance through unit degree.

Sp. heat has no unit. That is why the word numerically above. In absence of this word numerically, the sp. heat of a body would have a unit like this.

Using $Q = ms\theta$

$$\therefore \quad S = \frac{Q}{m\theta} = \frac{\text{Cals}}{\text{gm}^\circ\text{C}} = \text{cal/gm/}^\circ\text{C or J/kg/}^\circ\text{K}$$

It may be defined in the following way also amount of heat reqd. to raise.

$$S = \frac{\text{amount of heat reqd. to raise the temp. of a body through } \theta}{\text{amount of heat reqd. to raise the same mass of water through } \theta}$$

Since S is a ratio, it is a pure number and has no unit.

3. **Define thermal capacity and water equivalent. What is the difference between them.**

The thermal capacity of a body is the amount of heat to raise its temperature by 1°C. Thus thermal capacity = mS1 = mS cals.

For unit mass, the thermal capacity per unit mass = S i.e. numerically equal to its sp. heat.

Water Equivalent of a body is the mass of water which takes or gives the same quantity of heat as is done by the body when heated or cooled through a unit degree. Water equivalent is expressed in gm. whereas thermal capacity in cals.

4. **Explain why the temperature remains constant during the change of state of a substance. Define latent heat of fusion of ice and latent heat of steam.**

A substance absorbs or liberates a certain definite amount of heat energy at particular temperature to change its state. Hence the temperature should remain constant during the change of state.

The latent heat of fusion of ice (or water) is defined as the amount of heat required to change unit mass of ice into water without any change in temp. In cgs unit, the latent heat of ice is 80 cal/gm which means that to convert 1 gm of ice at 0°C into water at 0°C, we have to supply 80 cals of heat.

The latent heat of steam is defined as the quantity of heat required to change unit mass of boiling water into steam at the same temperature.

5. **Which is more severe, burn due to steam or boiling water at 100°C ?**

It is found that 540 cals of heat are required to convert 1 gm of water at its boiling point to steam at the same temp. Conversely 1 gm of steam condenses into 1 gm of boiling water at 100°C by liberating 540 cals of heat. It is due to this additional 540 calories of heat per gm. that steam give a more severe burn than boiling water at the same temperature.

6. **What is a calorie ?**

Calorie is a unit of measurement of heat. It is the amount of heat required to raise the temperature of 1 gm of water through 1°C i.e. from 14.5°C to 15.5°c.

7. **What is the use of drying ice with a blotting paper before adding it to water in a calorimeter ?**

If we don't dry it, some few drops of water adhering to ice may also drop into the calorimeter, which will add to the mass of water in the calorimeter. As a result, we may be taking the extra mass as the mass of ice melted which is not the actual case. This may result in giving as lightly less value for the latent heat of ice.

8. **Explain the use of steam trap and condenser while finding the latent heat of steam.**

Without steam trap and condenser, hot water along with steam may get into the water in the calorimeter. The hot water will increase the mass but will not add up to the latent heat. Thus the result will be affected. It will give a slightly lesser value for L.

9. **Why is it that steam burn is more severe than burn due to boiling water ?**

Burn due to boiling water is due to the heat content in the boiling water along. But burn due to steam at the same temp. will be due to the additional 540 cals. of heat per gm. of steam condensed plus the heat a content in the same mass of boiling water at the same temperature. Hence steam burn in more serious than burn due to boiling water.

10. **What is the use of polishing the calorimeter ?**

The amount of heat that tries go out of the inner wall of the calorimeter will be reflected back to its contents themselves. Heat loss is thus controlled.

11. **Why do you use a stirrer in a calorimeter ?**

To make the temperature uniform throughout the mass of the contents of the calorimeter.

12. **Why do you use a wire gauge stirrer in an expt. on latent heat of ice ?**

Ice is lighter than water and will float in it. If we don't use a wire gauge stirrer ice added will be partly in air and the rest inside water in the calorimeter. When all ice will melt, the mass of ice melted will found to more than ice inside water which alone will contribute to the latent heat gained from water. The ice exposed above the surface will be gaining heat from air above the surface of water and will not come into our calculation and hence will affect our result. The purpose of wire gauge stirrer is to keep the ice well under water.

13. **How does the specific heat of water vary with temperature ?**

In defining a calorie, it is stated an the amount of heat reqd. to raise the temp. of 1 gm. of water through 1°C i.e. from 14.5 t 15.5 C. The specific range should be mentioned because the sp. heat of water is not a constant but varies with temp. At 15°C, the sp. heat of pure water is 0.9999 of that of normal water with rise in temp, it will be slightly less.

14. **Does a gas possess one or two sp. heats ? Why ?**

A gas can be heated under two conditions. Once by keeping the pressure constant and the other by keeping its volume constant. If we keep the pressure constant and find the amount of heat required to heat a unit mass though 1°C, it will be the sp. heat capacity of gas at constant pressure C_P and if we heat a unit mass of the gas at constant volume, it will be the sp. heat capacity at constant volume C_V.

15. Which of them is greater and why ?

One keeping the volume constant the amount of heat supplied will be completely used up in increasing the internal energy of the gas. Whereas on keeping the pressure constant, volume is allowed to expand. Hence part of the heat energy supplied will be used up in doing the external work in expansion. So some extra heat is needed to raise the unit mass of gas through the same range. Hence $C_p > C_v$.

16. 150 gm of iron of sp. heat 0.112 at 95° C is dropped into a calorimeter containing 200 gm of oil of sp. heat 0.8. The final temperature of the mixture is 65°C and water equivalent of the calorimeter is 10 gm. Calculate the initial temperature of the oil.

Let x be the initial temp. of the oil.

$\therefore$ rise of temperature $\theta = (65 - x)$

Heat gained by calorimeter and oil $= (ws + ms)\ \theta$

$= (10 + 200 \times 0.8)\ (65 - x)$

$= 170\ (65 - x) = 11050 - 170x$

Heat lost by iron $= MS\theta = 150 \times 0.112\ (95 - 65)$

$= 150 \times 0.112 \times 30 = 504$

$\therefore$ Heat lost = Heat gained

$504 = 11050 - 170x$

or $170x = 11050 - 504 = 10546$

$\therefore$ $x = \dfrac{10596}{170} = 62°C$

17. The temperature of 500 gm of a certain metal is raised to 100°C and is then placed in 200 gm of water at 15°C. If the final steady temp. rises to 21°C, calculate the sp. heat capacity of the metal.

Heat lost by the metal $= MS\theta = 500S\ (100 - 21)$

$= 500\ S \times 79 = 39500\ S$

Heat gained by water $= wl\ \theta = 200 \times 1 \times (21 - 15)$

$200 \times 6 = 12100$

$\therefore$ $39500\ S = 1200$

$\therefore$ $39500S = 1200$

$\therefore$ $S = \dfrac{1200}{39500} = 0.0303$

18. Calculate the quantity of heat required to convert 2 kg. of ice at - 12°C to steam at 100°C.

S for ice $= 2 \times 10^3$ J/Kg k°

S for water $= 4.2 \times 10^3$ J/Kg k°

L for ice $= 3.4 \times 10^5$ J/Kg

Total amount of heat required $= mS\theta + mL + mS'\theta' + mL$

$= 2\ (2 \times 10^3 \times 12 + 3.4 \times 10^3 + 4.2 \times 10^3 \times 100 + 3.4 \times 10^5.$

Total amount of heat required = $ms\theta + mL + ms'\theta' + mL$

$= 2(2 \times 10^3 \times 12 + 3.4 \times 10^5 + 4.2 \times 10^3 \times 100 + 3.3 \times 10^5)$

$= 2 \times 10^3 [24 + 3.4 \times 100 + 420 + 3.3 \times 100]$

$= 2.228 \times 10^6$ J

19. 500 c.c. of water and an equal volume of a liquid of density 0.8 gm/cc are poured successively into the same calorimeter and they are cooled from 60°C to 55°C in 2.5 min and 1.5 min. respectively. Find the sp. heat of the liquid water equivalent of the calorimeter is 20 gm.

Rate of loss of heat by water $= \dfrac{(ws + m)(\theta_1 - \theta_2)}{t_1}$

$= \dfrac{(20 + 500)(60 - 55)}{2.5 \times 60} = \dfrac{520 \times 5}{2.5 \times 60}$

Rate of loss of heat by reqd. $= \dfrac{(ws + Ms)(\theta_1 - \theta_2)}{t_2}$

$= \dfrac{(20 + 500 \times 0.8s)5}{1.5 \times 60} = \dfrac{(20 + 400s)5}{1.5 \times 60}$

By law of cooling,

$$\frac{(20 + 400s)5}{1.5 \times 60} = \frac{520 \times 5}{25 \times 60}$$

or $\quad 20 + 400s = \dfrac{520 \times 15}{25} = 312$

or $\quad 400s = 312 - 20 = 292$

$\therefore \quad s = \dfrac{292}{400} = 0.73$

Exercise on Page 92

1. Define melting point and freezing point.

The melting point of a solid is the temperature at which it melts into its liquid state without change in temperature.

If some heat is extracted from water at 0°C it gradually freezes. Similarly a liquid (say liquid wax) while cooling from a certain high temp. will reach a certain temp. at which it a begins to solidify. During their change of state, the temperature remains constant. This constant temperature is called the freezing point.

2. Why does the temperature remain constant during change of state ?

During the change of states, the amount of heat remaining in the latent state is being used. So there won't be any changes in temperature.

Exercise Page 98

1. **Define dew point.**

Dew Point is the temperature to which air must be cooled to constant pressure to produce the saturation vapour.

2. **What do you understand by saturated and unsaturated vapour.**

Any closed space at a particular temperature has got a limited capacity of holding the vapour of a particular liquid. When the closed space holds the maximum amount of vapour that it can hold at that temperature, it is said to be saturated with that vapour. But if the space contain less than the maximum amount of vapour, then it is said to be unsaturated and the pressure exerted by the vapour is called unsaturated vapour pressure.

3. **What is relative humidity ?**

Relative humidity is the ratio of the actual vapour pressure to the saturated vapour at that temperature.

4. **What is absolute humidity ?**

Absolute humidity is the amount of water vapoure per unit volume of air.

5. **What is a dew Point hygrometer.**

A hygrometer, an instrument used to determine the hygrometeric state of air by observing the dew point on a particular day is called a dew point hygrometer.

6. **Why do wet clothes dry slower in rainy season than in summer ?**

During rainy season the atmosphere contains higher percentage of vapour than that in summer. So the atmosphere cannot absorb the water vapour from wet clothes rapidly.

7. **What is the importance of the knowledge of hygrometry in everyday life ?**

The study of hygrometry helps in weather forecast which is very essential for our activities of the whole day. Besides, its study is also useful for agricultural purposes, health, medicine, seasoning of wood, air conditioning textile and paper industries etc. Certain medicines are to be kept in dry place so as not to soak water from the air and get spoilt. Natural seasoning of wood (from 50% to about 15%) takes two or three years but the process can be carried out in a few weeks in a seasoning kiln in which the temp. and humidity are carefully controlled.

8. **On a particular day, the dew point was observed to be 12.5°C, when the temperature of air was 18.7°C Calculate the relative humidity on the day.**

We have

$$\text{R.H.} = \frac{\text{S.V. P. at dew point } (12.5°\text{C})}{\text{S.V.P. at temp t}(18.7°\text{C})} \times 100 = \frac{10.86}{16.16} \times 100 = 67.2\%$$

Reflection at Plane and Spherical Surfaces

Exercise on Page 111

1. **What is Reflection ?**

When a beam of light falls on a smooth polished surface say a glass plate, stainless steel plate, surface of water, mercury, a part of it is turned back into the same medium from which it comes.

This phenomenon of turning back the ray of light is called Reflection of light. The ray turned back is called the reflected ray.

2. **What do you mean by Regular and Diffused Reflection ?**

When a beam of light falls on a smooth surface, it will be reflected in a regular pattern. But when it falls on a rough surface at different angles of incidence, the reflected beam will be scattered or diffused.

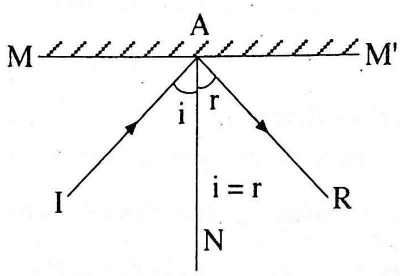
3. **State the laws of Reflection light.**

The laws are

(i) The incident ray, the normal to the reflecting surface at the point of incidence and the reflected ray, all lie in one plane, the plane of incidence or the plane of reflection.

(ii) The angle of incidence is equal to the angle of reflection i.e. $\angle i = \angle r$.

4. **Use a diagram to define and angle of incidence and angle of reflection.**



5. **What is the difference between an image and a shadow ?**

An image is formed by reflection from a plane or a spherical mirror, refraction through a lens, but a shadow is formed by placing an obstacle in the path of the rays of light.

7. **How can a real image be distinguished form a virtual image ? Can each type be projected on a screen, Why ?**

A real image is formed by the actual intersection of the rays of light reflected from a mirror or refracted through a lens. It can be projected on a screen. A virtual image is formed behind the mirror or in front of a lens by the virtual intersection of the rays. It cannot be received on a screen.

8. **What is the relation between the objected distance and the image distance in a plane mirror.**

Object distance = Image distance.

9. **What is lateral Inversion ?**

the image formed by a plane mirror is sidewise reflected and laterally inverted. i.e. the right appears as left and vice-verse. This inversion is called 'Lateral Inversion' of the image.

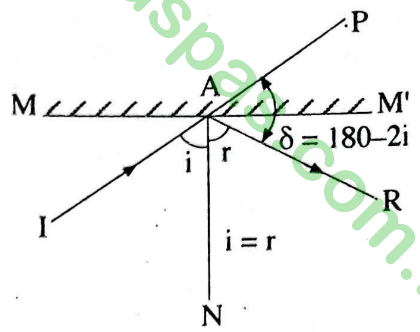
10. **State the Law of Rotation of light.**

This Law of Rotation states that if a mirror is rotated through an angle θ the reflected ray rotates through 2 θ.

11. **What do you mean by the deviation of a ray of light in a plane mirror ?**

When a ray of light IA is incident on a plane mirror at A at same angle of incidence i. It is reflected along AR making an angle of reflect r = i.

$\therefore$ deviation $\delta = 180 - (i + r) = 180 - 2i$



12. **Define principal focus, pole, center of curvature, radius of curvature, focal length of a spherical mirror.**

Pole: The center of the reflecting surface of a spherical mirror is called its pole.

Principal focus: A pencil of rays coming parallel to the principal axis of a spherical mirror after reflection, either actually converges to or appears to diverge from a point on the principal axis. This point is called the principal focus of the mirror.

Center of Curvature: The center of curvature is the center of the sphere of which the mirror is a part.

Radius of curvature: It is the radius of the sphere of which the mirror is a part and is equal to the distance between the pole and the center of curvature of the mirror.

Focal length of a spherical mirror: The distance between the pole and the principal focus of the mirror is called its focal length.

13. **What type of image do you see in this experiment on a concave mirror ? Is it real or virtual ?**

The image is real if the object is placed beyond the focal length of the mirror and will be virtual if the object is placed within the focal length.

14. **Does a concave mirror form a real image ? If not, when does it form a virtual image ?**

Yes, if the object is beyond its focal length . It forms a virtual image if the object is held within the focal length of the mirror.

15. **State some of the uses of (i) a concave mirror (ii) a convex mirror.**

Uses of a

(a) Concave mirror

(i) Concentrating light on a given spot.

(ii) E.N.T. specialist use concave mirror for focusing light in the throat or ear.

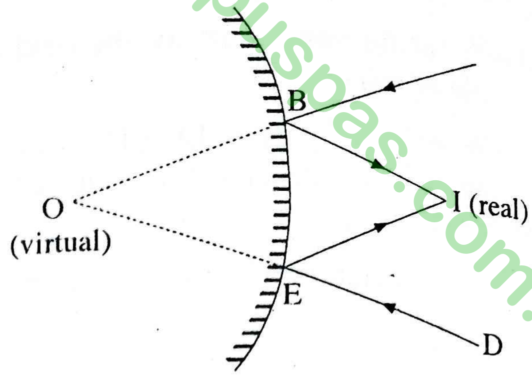
(iii) Shaving

(iv) Used a Reflectors in cinema projection.

(b) Convex mirror

(i) Driving mirror to get a clean view of everying at the back of the car.

16. Does a convex mirror form an inverted image ? Illustrate by ray diagrams.



Yes, a convex mirror may sometimes produce a real image of a virtual object.

Consider an incident beam of light bounded by AB and DE. Converging to a point O behind the mirror (fig.) O is regarded as a virtual object and if its distance from the mirror is 10 cm. Suppose the convex mirror has a focal length 15 cm. i.e. f = - 15 cm, than

$$\frac{1}{V}+\frac{1}{U}=\frac{1}{f}=-\frac{1}{15}$$

or $\frac{1}{V}+\frac{1}{-10}=-\frac{1}{15}$

or $\frac{1}{V}=\frac{1}{10}-\frac{1}{15}=\frac{1}{30}$ $\qquad$ ($\therefore$ V = 30 cm)

17. What type of graph do you expect between

(i) U and V
(ii) U and m } **of a concave mirror**
(iii) V and m

(i) a rectangular hyperbola

(ii) a rectangular hyperbola

(iii) a st. line not passing through the origin.

18. Sketch and calculate the image formed by an object placed 2 cm. in front of (i) concave mirror (ii) a convex mirror of focal length 15 cm. What is the magnification in this case ?

(i) f = 15 cm

$$\frac{1}{V}+\frac{1}{U}=\frac{1}{f}$$

or $\frac{1}{V}+\frac{1}{2}=\frac{1}{15}$

or $\frac{1}{V}=\frac{1}{15}-\frac{1}{2}=\frac{-13}{30}$

$\therefore$ $V=\frac{30}{13}$ cm = - 2.3 cm.

$$m=\frac{V}{U}=\frac{30}{13\times 2}=\frac{15}{13}$$

(ii) $\frac{1}{V}+\frac{1}{U}=\frac{1}{f}$ or, $\frac{1}{V}+\frac{1}{2}=-\frac{1}{15}$

or $\frac{1}{V}=-\frac{1}{2}-\frac{1}{15}=-\frac{-15-2}{30}$

$$V = -\frac{30}{17}$$

$$\therefore \quad m = \frac{V}{U} = \frac{30}{17} \times \frac{13}{30} = \frac{13}{17}$$

19. An observer walks towards a plane mirror in a speed of 3 m/s. With what speed does he approach his image ?

Same speed of 3 ms^{-1}.

20. In what position in front of a spherical concave mirror should an object be placed to produce a real image magnified 3 times if its radius of curvature is 18 cm.

$$\frac{1}{V} + \frac{1}{U} = \frac{1}{f}$$

$$\text{or} \quad \frac{1}{3U} + \frac{1}{U} = \frac{1}{9}$$

$$\text{or} \quad \frac{4}{3U} = \frac{1}{9} \quad \text{or} \quad 3U = 3r$$

$$\therefore \quad U = 12 \text{ cm infront}$$

21. Show in a diagram the image formed by placing an object 30 cm in front of a convex mirror of focal length 10 cm. Calculate its magnification.

$$\frac{1}{V} + \frac{1}{U} = \frac{1}{f} = -\frac{1}{10}$$

$$\text{or} \quad \frac{1}{V} + \frac{1}{30} = -\frac{1}{10}$$

$$\text{or} \quad \frac{1}{V} = -\frac{1}{10} - \frac{1}{30} = \frac{-4}{30}$$

$$\text{or} \quad V = \frac{-30}{4} = -\frac{15}{2} = -7.5 \text{ cm behind}$$

$$m = \frac{V}{U} = \frac{-15}{2 \times 30} = -\frac{1}{4} = -0.25 \text{ virtual and diminished.}$$

Refraction at Plane Surfaces

Exercise on Page 127

1. What is refraction ?

Refraction is the bending of a ray of light at the surface of separation when it proceeds from one medium to another. It bends towards the normal when it proceeds from a rarer to a denser medium and away from the normal when it proceeds from a denser to a rarer medium.

2. State the laws of refraction. Explain why a beam of light is refracted when it enters a new medium at an angle of incidence.

(i) The incident ray, the normal at the point of incidence and the refracted ray all lie on the same plane.

(ii) The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for any two given media. i.e.

$$\eta = \frac{\sin i}{\sin r}$$

When it proceeds from one medium to another having different densities, there is a discontinuity of refractive index. Hence refraction occurs. Besides velocity of light in the two media would be different. Hence bending occurs.

3. **Does light travel faster in air or in water ?**

It travels faster in air than in water as supported by Foucault's expt. on velocity of light.

4. **Define refractive index. Account for the difference in the index of refraction of glass for red light and violet light.**

The refractive index of glass for any color is defined as

$$\eta = \frac{\text{velocity of light in air or vacuum}}{\text{velocity of light in the medium}}$$

Since the velocity of the light is different for different medium of different color, η is different.

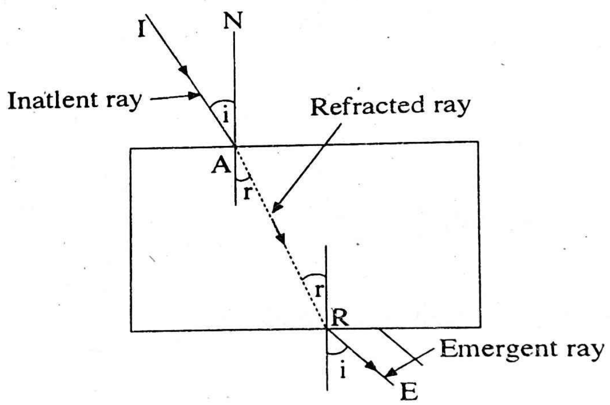
5. **What is lateral shift ? How does it vary with angle of incidence ?**

The lateral shift is the perpendicular distance between the incident ray produced and the emergent when a ray is proceeding from air on to a glass slab and emerges out into the air again. It is given by

$$\text{Lateral shift } p = \frac{t \sin (i - r)}{\cos r}$$

where t is the thickness of the slab. Thus p varies as t and $p = t$ when $i = 90°$.

6. **In your diagram for verify the laws of refraction, show the incident ray, refracted ray and emergent ray.**



7. **What is total internal reflection ? Under what conditions does it occur ? What is critical angle ?**

When a ray of light proceeds from a denser medium to a rarer medium, the ray bends away from the normal. When the angle of incidence inside the denser medium is such that the ray while going out grazes along the surface of separation. This angle of incidence is called critical angle. If the ray makes an angle of incidence inside the denser medium, greater than the critical angle, the rays will be totally reflected back into the same medium following the laws of reflection of light. This type of Reflection is called Total Internal Reflection of light.

Conditions for total internalreflection:

(i) The ray must be proceeding from a denser medium to rarer medium.

(ii) The ray must make an angle of indicence inside the denser medium greater than the critical angle for that medium.

8. **Why does a swimming pool appear shallower than its actual depth ?**

Because of refraction of light from the bottom of water coming to the rarer medium.

$$\eta = \frac{\text{Real Depth}}{\text{Apperent Depth}}$$

$$\text{App. depth} = \frac{\text{Real Depth}}{\eta}$$

$$\eta > 1.$$

$\therefore$ App. depth < Real Depth

9. **What do you mean by real Depth and apparent depth. state the relation between them.**

Real Depth is the actual perpendicular distance from an object at the bottom of the denser medium to the surface of separation of the medium.

Due to refraction, the object at the bottom of the denser medium appears to be raised up. So the perpendicular distance from the apparent position to a point on the surface of separation is the apparent depth which is related to the real depth as

$$\eta = \frac{\text{Real Depth}}{\text{Apperent Depth}}$$

$$\text{App. depth} = \frac{\text{Real Depth}}{\eta}$$

since $\eta > 1$ for a medium denser than air,

App. depth < Real depth.

10. **What is deviation of a ray of light ?**

When a ray of light proceeds from one medium to another refraction takes place. Hence the ray deviates from its original direction. The angle between the incident ray produced and the final emergent ray is the angle of deviation.

11. **What is meant by the minimum deviation of a ray through a prism ? For what position of a prism is the deviation minimum ?**

As the angle of incidence for a ray passing through a prism increases, the corresponding deviation reaches a certain minimum for a particular value of i after which it increases again for higher values of i. This occurs when the ray passes through the prism symmetrically. i.e. when i = i' where i' is the angle of emergence.

12. **What do you mean by the principle of reversibility of light ?**

According to the principle of reversibility of light, if a ray of light, after suffering any number of reflections and refractions, falls normally upon a mirror so that its final path is reversed, then it travels back along the same path in the reversed direction.

13. **A ray of light strikes a water surface at an angle of incidence of 40°. What is the angle of refraction in water ? $_a\eta_w = 1.33$**

We have

$$\eta = \frac{\sin i}{\sin r}$$

$$\therefore \quad \sin r = \frac{\sin 40^\circ}{\eta} = \frac{0.6427}{1.33} = 0.4832$$

$$\therefore \quad r = 28^\circ 9$$

14. When a ray of light is incident on the surface of a certain liquid at an angle of incidence of 48°, the angle of refraction within the liquid is 35°. What is the index of refraction of the liquid ?

We have, $\eta = \frac{\sin i}{\sin r} = \frac{\sin 48°}{\sin 35°} = \frac{0.7431}{0.5735} = 1.295$

15. The velocity of light in a liquid is 0.80 as fast as it is in air. What is the index of refraction of the liquid.

We have $\eta_e = \frac{\text{vel. of light in air}}{\text{vel. of light in liquid}} = \frac{C}{0.8C} = 1.25$

16. The water in a swimming pool is 6m deep. How deep does it appear to a diver looking straight down into it ? $_a\eta_w = 1.33$

$$\eta = \frac{\text{Real depth}}{\text{App. depth}}$$

or $1.33 = \frac{6}{\text{App.depth}}$

$\therefore$ $\text{App. depth} = \frac{6}{1.33} = 4.5\ 1\text{m}$

17. At what angle of incidence should a ray of light approach the surface of diamond $\eta = 2.42$ from within in order that the emerging ray shall just graze the surface ?

$\eta = \frac{1}{\sin C}$ or $\sin C = \frac{1}{\eta}$

or $\sin C = \frac{1}{\eta} = \frac{1}{2.42} = 0.4132$

$\therefore$ $C = 24°.4$

18. A hollow prism having 60° apex angle is made with parallel glass plates and filled with carbon disulphide ($\eta = 1.643$). Find the angle of minimum deviation for this prism.

$$\eta = \frac{\sin \frac{D_m + A}{2}}{\sin \frac{A}{2}} \quad \text{or} \quad 1.643 = \frac{\sin \frac{D_m + 60}{2}}{\sin 30}$$

or $\sin \frac{D_m + 60}{2} = 1.643 \times \sin 30 = 1.643 \times \frac{1}{2} = 0.8215 = \sin 55.2$ or $\frac{D_m + 60}{2} = 55.2$

$\therefore$ $D_m = 110.4 - 60 = 50°.4$

Refraction through lenses

Exercise on Page 137

1. **How would you distinguish between a convex lens and a concave lens ?**

A convex lens is thicker at the middle and thinner at the edges whereas a concave lens is thinner at the middle and thicker at the edges.

2. **Define optical center, principal focus, focal length, focal plane and principal axis of a lens.**

Principal axis: The straight line joining the centers of the two spherical surfaces of the lens and extended upto infinity is called the principal axis.

Principal focus: When a pencil of parallel rays is incident on a lens in a direction parallel to the principal axis of the lens, the rays after refraction through the lens approximately converge to or appear to diverge from a point on the principal axis, this point is the (second) principal focus of the lens. In the case of the convex, it is real and in the latter case the principal focus is virtual.

Optical Center: If a ray of light incident on one face of a lens emerges out after refraction through the lens in a direction parallel to the direction of the incident ray, the refracted ray within the lens intersects the principal axis at a point known as optical center. It has a special property. Any ray passing through it emerges out undeviated.

Focal length: The distance between the optical center and the principal focus is called the focal length of the lens. According to New convention of signs the focal length of a convex lens is positive and that of a concave lens is negative.

Focal plane: It is the vertical plane passing through the principal focus of a lens.

3. **What is the difference between a real image and a virtual image ?**

A real image is the image formed by the actual intersection of the rays from the object on its opposite side of the lens. It can be received on a screen., It is inverted and may be diminished or enlarged according as the object is beyond $2f$ or between f and $2f$.

A virtual image is the image formed by the virtual intersection on the same side of the object of the rays form the object. It cannot be received on a screen. It is diminished in size.

4. **Does a convex lens always form a real image ? If not when does it form a virtual image ?**

No. it forms a real image when the object is held in front of the lens beyond its focal length. If the object is held within its focal length, the image is virtual, erect and magnified in the case of a convex lens.

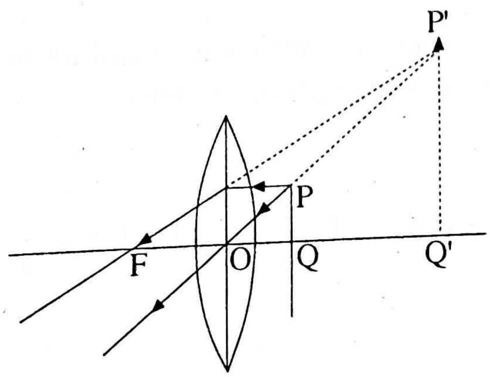
5. **What is parallax ?**

When an object is held in front of a convex lens at a distance beyond its focal length, the rays of light from it are incident on it and get refracted on the other side of the lens. If we look from the other side, a real and inverted image is seen along with the object. Adjusting the distance of the object, the image can be made to just coincide with the object pin. When the head is moved side -ways, the object and the image seen are found to have a relative separation or displacement if not properly adjusted. This relative displacement between the object and the image is called parallax.

6. **Using a sketch, explain why light is bent towards the thickest part of the lens.**

The lens can be considered to be made up of glass blocks of different shapes like prism, slab etc. In the prism it is found that a ray incident on any one face is found to emerge from the other face and deviated towards the lbase i.e. the thicker part. The same happens in a lens.

7. **Trace the course of the rays through a double convex lens to show the formation of a virtual image.**



8. **What is meant by the power of a lens ? In what units can it be expressed ?**

The power P of a lens is the reciprocal of its focal length expressed in meter. Thus the power $P = \frac{1}{f(m)}$. Its unit is Dioptre.

9. **Is the observed focal length of a lens in water longer or shorter than in air. Explain.**

The focal length of a lens is given by Len's Maker's formula.

$$\frac{1}{f} = (\eta_g - 1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \qquad ...(1)$$

where ηg is the refractive index of glass with respect to air. when the lens is in water.

$$\frac{1}{f'} = ({}_w\eta_g - 1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \qquad ...(2)$$

Since $\quad {}_w\eta_g < {}_a\eta_g, \frac{1}{f'} < f$

$\therefore \quad f' > f$

f' in water appears $>f$

10. **What two factors determine whether a lens is covering or diverging. Convex lens is thick at the center and thin at the edge. It gives a real and inverted image.**

Concave lens: Thin at the center and thick at the edges.

It always gives virtual and erect image.

11. **In determining the focal length of a lens by displacement method, what should be the minimum distance between the object and screen.**

Minimum distance should be $4f$ where f is the focal length of the lens.

12. **A straight filament lamp is placed 5.0 cm in front of a convex lens of focal length 2.0 cm. How far from the lens will an image of the filament be formed.**

We have $\frac{1}{V} + \frac{1}{U} = \frac{1}{f}$

or $\quad \frac{1}{V} + \frac{1}{5} = \frac{1}{2} \quad$ or $\quad \frac{1}{V} = \frac{1}{2} - \frac{1}{5} = \frac{5-2}{10} = \frac{1}{10}$

$\therefore \quad V = 10$ cm

Real and inverted image 10 m behind the lens.

13. **A double convex lens, both surface of which have radii of 20 cm is made of glass whose index of refraction is 1.50. Find the focal length of the lens.**

We have,

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right) = (15-1)\left(\frac{1}{20} + \frac{1}{20}\right) = 0.5 \times \frac{2}{20} = \frac{1}{20}$$

$\therefore \quad f = 20$ cm

Sound

Exercise on Page 143

1. **What is forced vibration ?**

The vibration that is produced on some medium or a body by the influence of some other body is called Forced Vibration. For example, column of air in a closed pipe is set to vibration by holding a vibrating turning fork over its open end.

2. **What is Resonance ?**

When the length of the air column in the tube is adjusted so that the air column will vibrate with the same frequency as that of the vibrating tuning fork held over its open end, then the sound intensity will be maximum. The air column is said to be in resonant vibration. Thus resonance is a special case of forced vibration when the frequency of the forcing body is equal to that of the forced body.

3. **Define wavelength, frequency, amplitude of vibration.**

Wave length: It is the distance covered by one complete wave.

Frequency: The no. of complete vibrations made per sec is called frequency and is expressed in cycles per sec. or Hertz (Hz).

Amplitude of vibration: It is the maximum displacement of the particle from its equilibrium position.

4. **Why is it necessary to apply end correction in a resonance tube ? What is end correction ?**

When a reading of the resonating air column is taken, we note the length just upto the open end of the tube, where as resonance takes place a little above the open end. So in every measurement, a slight error is being made, correction for that is known as the end correction.

We have in a closed organ pipe.

$V = 4nl$ without end correction.

For the 1^{st} resonance with correction, $V = 4n(l + x)$

Where l is the length of the 1^{st} resonance and x is the end correction.

5. **Distinguish between (i) Harmonics and overtones. (ii) Nodes and antinodes.**

Harmonics are the notes having frequencies higher than the fundamental frequency and which are exact multiplies of the fundamental frequency.

Overtones are the notes having higher or lower frequency than the fundamental but not the exact multiplies of the fundamental frequencies.

6. **What is N.T.P ?**

N.T.P. stands for normal temp. an pressure which is pressure due to 76 cm. of Hg at 0°C.

7. **Will your value of the velocity of sound in the lab. be greater or less than that at N.T.P.? Give reasons for your answer.**

The velocity of sound in the lab will be greater or less than that at N.T.P. according as the temp. of air in the lab. is grater than 0°c or less than 0°C because $V \propto \sqrt{T}$.

8. What is aqueous tension ? How does the moisture affect the velocity of sound in air ?

Aqueou tension is the pressure exerted by the water vapour present in air. Moist air (atmosphere containing water vapour) is lighter than dry air alone. Since velocity of sound is inversely proportional to the sq. root of the density of the medium, the presence of moisture in the atmosphere will make the air less dense and hence will increase the value of velocity of sound in moist air accordingly.

9. How does temperature affect the velocity of sound in air ?

The vel. of sound in air is directly proportional to $\sqrt{T}$ where T is the absolute temp. It has been found that $V_t = V_0 + 0.61\ t$.

where t is the temp. of the air in °C. V_0 is the vel. at 0°C which is 330 m/s.

10. What is closed and open organ pipe ?

A closed organ pipe is a glass or metal pipe closed at one end. In the closed organ pipe vel. of sound $V = 4nl$ where n is the frequency of the tuning fork, l is the resonating length of the air column.

An open pipe has both ends open.

In it $V = 2nl$

11. At what position do you expect second resonance to take place in a closed organ pipe ?

In a closed organ pipe stationary waves are formed when a vibrating tuning fork is held near its open end, stationary waves are formed inside with an antinode at the open end and node at the closed end. So the waves are formed for the 2^{nd} resonance as shown:

The 2^{nd} resonance will be obtained slightly above 3 times the length of the 1^{st} resonance.

12. The vel. of sound in air at N.T.P. is 3.32 m./s. Calculate the temperature at which the vel. of sound is 340 m/s.

$$V_t = V_0 + 0.61\ t$$

$$\therefore\quad t = \frac{8}{0.61} = 131\ C$$

13. Find the length of a closed organ pipe which produces a fundamental frequency 480 c/s. Vel. of sound in air = 360 m/s.

We have $V = 4nl$

$$\therefore\quad \frac{V}{4n} = \frac{360 \times 100}{4 \times 480} = 18.75\ \text{cm.}$$

14. The velocity of sound in air at 16°C is 341 m/s. Calculate the vel. at 60° C.

$$\frac{V_2}{V_1} = \sqrt{\frac{T_2}{T_1}} = \sqrt{\frac{273 + 60}{273 + 16}} = \sqrt{\frac{333}{289}}$$

$$\therefore\quad V_2 = V_1\sqrt{\frac{333}{289}} = \frac{341\sqrt{333}}{17} = 366.0\ \frac{m}{s}$$

15. In a resonance air column apparatus, the 1st and the 2nd resonance positions were observed at 14.8 cm and 48 cm. Find the velocity of sound in air and the end correction.

$V = 2n(l_2 - l_1) = 2 \times 512 (48 - 14.8)$

$= 1024 \times 3.32$ cm/s $= 339.96$ m/s

End Correction $x = \frac{l_2 - 3l_1}{2} = \frac{48 - 3 \times 14.8}{2}$

$= \frac{48 - 44.4}{2} = 1.8$ cm.

Vibration of Strings

Exercise on Page 149

1. **What types of waves are produced in the stretched string ?**

Stationary waves are produced in a stretched string.

2. **What do you mean by nodes and antinodes ?**

Nodes are the positions where the particles are at their mean position having maximum strain and zero amplitude. Antinodes are the positions where the particles vibrate with maximum amplitude having minimum strain.

3. **What is amplitude of vibration ?**

The amplitude of vibration of a wave is the maximum displacement of the particle from its equilibrium position.

4. **Why is tension needed to make a wire vibrate ?**

When a wire vibrates, it assumes the shape of an are of a circle, which means the particles constituting the wire are moving round a circular arc with a constant speed for which a centripetal force is needed. To provide the necessary centripetal force, the wire must be stretched i.e. tension must be applied at its two ends.

5. **In the formula, $n = \frac{1}{2l}\sqrt{\frac{T}{m}}$. What are m and n ?**

This is the formula for the frequency of the note emitted by a vibrating string in a sonometer n represents the frequency of the fundamental note emitted by a vibrating, string m is the mass per unit length of the string.

6. **What do you mean by the fundamental mode of vibration ?**

A wire is stretched at its two ends. When it plucked at its mid point, it will vibrate in one loop or one segment. This is the simplest type or the fundamental mode of vibration and the note emitted is known as the fundamental note.

7. **State the laws of vibration of strings.**

The frequency of a note emitted by a vibrating string stretched at its ends is given by

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

where l is the length of the vibrating segment, T the tension applied and m is the mass per unit length of the string. From this, the laws of vibration of a string may be stated as:

(i) Law of length of the i.e. $n \propto \frac{1}{l}$

Fundamental note emitted by a vibrating string is inversely proportional to the length of its vibrating segment.

(ii) Law of Tension i.e. $n \propto \sqrt{T}$

The frequency fundamental note emitted by a vibrating string is directly proportional to the square root of the tension applied.

(iii) Law of amss i.e. $n \propto \sqrt{\frac{1}{m}}$

The frequency n is inversely proportional to the square root of its mass per unit length.

Here $m = \frac{\pi d^2}{4} \times 1.\rho$ where d is the diameter of the wire ρ its density

This maybe e written as

$$n \propto \frac{1}{\sqrt{\frac{\pi d^2}{4}\rho}} \text{ i.e. } \propto \frac{2}{d\sqrt{\pi\rho}}$$

∴ This law of mass may be subdivídes into

(a) Law of diameter $n \propto \frac{1}{d}$

i.e. the frequency of the fundamental note is inversely proportional to the diameter of the wire.

(b) Law of density i.e. $n \propto \frac{1}{\sqrt{\rho}}$

the frequency of the fundamental note is inversely proportional to the square root of its density of the material of the wire.

8. What is resonant vibration ?

When the stem of a vibrating tuning fork is pressed against the wooden board of a sonometer, the sonometer wire vibrates under forced vibration. When the length of the wire is adjusted properly, the sound emitted by plunking the wire and that emitted by the vibrating tuning fork will be heard as a single sound, then the wire is said to be in unision with the fork. i.e. in resonant vibration when the frequency of vibrating of the string will be the same as that of the tuning fork.

9. What do you mean by resonating length ?

When the length of the sonometer wire is vibration with the same frequency as that of the tuning fork, it is called resonating length.

10. What are overtones ?

These are notes of frequencies higher than the fundamental but which may not be the exact multiplies of fundamental frequency.

11. **What are stationary waves ?**

A stationary wave is that wave produced when two waves of equal amplitude and frequency travel in opposite direction in a medium.

12. **Using A.C. mains in a sonometer why does a wire vibrate without plucking it ?**

To determine A.C. main frequency by a sonometer a horse shoe type of magnet is placed near about the middle of the wire when a A.C. current is passed along the wire, there will be two magnetic fields at right angles to each other, which will interact and produces a resultant magnetic field at right angles to the plane of both. This causes the wire to vibrate with the same frequency as that of the A.C. mains when the length of the wire is properly adjusted. The wire is then said to be resonating with the same frequency as that of the A.C. mains.

13. **What is meant by A.C. ? How does it differ from D.C. ?**

The current from a battery flows continuously in one directiononly and its strength remain constant with time, whereas an alternating current reverses its direction of flow through of circuit many times a second. It is all the time either increasing or decreasing . The rotation of a coil in a magnetic field gives rise to an alternating e.m.*f*. and if an external circuit be joined suitably to the coil, an alternating current (A.C.) will circulate through it.

14. **Why do you need a step down transformer in this experiment ?**

The laboratory is provided with an A.C. mains of 220 volt. It is not proper to work with such a high voltage of 220 volt in a simple expt. It is too dangerous. It has to be stepped down to a voltage of maximum 12 volt. Usually it is sufficient to step it down to about 6 volt for this expt. Hence the use of a step-down transformer.

15. **A string 2.0 m long has a mass of 1.20×10^{-4} kg and is stretched by a force of 100N. What is the frequency of the fundamental vibration ?**

We have

$$\eta = \frac{1}{2l}\sqrt{\frac{T}{m.}} = \frac{1}{2 \times 2}\sqrt{\frac{100 \times 2}{120 \times 10^{-4}}}$$

$$= \frac{10}{2 \times 2 \times 10^{-2}}\sqrt{\frac{20}{12}} = \frac{1000}{4} \times 1.29 = 322.7 \text{ Hz.}$$

16. **Calculate the tension in a stretched string for which the frequency of the fundamental vibration equals the frequency of the second overtone when the tension is 4.96 ¥ 10^5 dyne.**

$$\eta_1 = 2\,\eta_2$$

or $$\frac{1}{2l}\sqrt{\frac{T_1}{m}} = 2 \times \frac{1}{2l}\sqrt{\frac{T_2}{m}}$$

or $$\sqrt{\frac{T_1}{m}} = 2\sqrt{\frac{4.96 \times 10^5}{m}}$$

or $$T_1 = 4 \times 4.96 \times 10^5 = 1.984 \times 10^6 \text{ dyne}$$

17. A sonometer wire of length 0.75 m is maintained under a tension of 4 kg. wt. and an A.C. is passed through the wire. A horse shoe magnet is placed with its poles above and below the wire at its mid point, and the resonating forces set the wire in resonant vibration. If the density of the material of the wire is 8800 kgm^{-3}, and the diameter of the wire is 1m. What is the frequency of the A.C. mains ?

Hence $T = 4$ kg. wt. $= 40$ N

$l = 0.75$ m

density $\rho = 8800$ kgm^{-3}.

$$m = \text{mass per unit length} = \frac{\pi d^2}{4} \times 1 \times \rho = \frac{22}{7 \times 4} \times (10^{-3})^2 \times 1 \times 8800 \ \frac{kg}{m}$$

$$\text{We have, } n = \frac{1}{2l}\sqrt{\frac{T}{m}} = \frac{1}{2 \times 0.75} \times \sqrt{\frac{40 \times 28}{22 \times 8800 \times (10^{-3})^2}}$$

$$= \frac{1}{1.5} \times \frac{33.47}{440 \times 10^{-3}} = \frac{33.47 \times 1000}{15 \times 440} = \frac{33470}{660} = 507 \text{ Hz}$$

Magnetism

Exercise on Page 172

1. **Define pole, unit poles, pole strength and magnetic moment.**

Pole: The region near the end of a magnet where the attraction is the strongest is called the pole of the magnet, the north seeking pole is called the north pole, the south seeking pole being called the south pole.

Unit Pole: A unit pole in c.g.s. unit is defined as a pole of that much strength which when placed at a distance of 1 cm. from a similar and equal pole repels it with a force of 1 dyne.

In M.K.S.unit a unit pole is defined as a pole of that much strength which when placed at a distance of one meter from a similar and equal poe in free space, repels it with a force of $\frac{10^7}{16\pi^2}$ Newton.

1 C.G.S. unit of pole strength $= 4\pi \times 10^{-8}$ mks. unit of pole strength.

2. **What is the difference between the real length and the effective length ? How are they related ?**

Real length of a magnet is the distance between its ends whereas the effective length is the distance between its poles. They are related as effective length $2l = 0.85 \times$ Real length.

3. **State Coulomb's law of magnetic forces.**

Coulomb's law states that.

The force of attraction or repulsion between two magnetic poles varies directly as the product of their pole strengths and inversely as the square of the distance between them. The latter part is also known as the law of Inverse squares.

4. **Define magnetic field. What is the intensity of magnetisation ?**

Susceptibility, Permeabiliy, magnetic induction, Retentivity, magnetic intensity (or intensity of magnetic field).

Magnetic field: The space around a magnet in which its magnetic influence extends is known as magnetic field.

Magnetic intensity (or intensity of the magnetic field): It id defined as the force exerted on a unit north pole placed at that point.

Intensity of magnetisation: It is defined as the magnetic moment per unit volume or the pole strength per unit area.

Permeability: It is the property possessed by a medium which will allow the influence of the magnet to be transmitted.

Relative Permeability: It is the ratio of the permeability of the material to that of empty space i.e.

$\mu_r = \frac{\mu}{\mu_u}$

Susceptibility: The magnetic susceptibility per unit volume is the intensity of magnetisation per unit magnetic field intensity. In symbol $\chi = \frac{1}{H}$.

Magnetic Induction: The strength of a magnetic field, due to a pole m_1 depends on the medium in which it is placed. It is necessary and convenient to have some quantity to describe the effect of a given pole at a given distance independently of the medium. That quantity is called the magnetic induction, denoted by B. It is μ times the magnetic field strength where $\mu = \mu_r\mu_0$.

$$B = \mu H$$

Retentivity: It is the value of the magnetic induction when the magnetizing field is zero. steel has more retentivity and soft iron.

5. **What is a line of force ?**

A line of force is a continuous curve in the field of a magnet such that the tangent at any point of which represents the resultant magnetic field at that point.

6. **Define a magnetic field and intensity of magnetic field. See Q. 4**

7. **What is a neutral point ?**

It is that point in a magnetic field where the resultant magnetic field is zero.

8. **Define magnetic flux and flux density ?**

The total no. of lines of force crossing any area normally is called the magnetic flux through that area.

The cgs unit of magnetic flux is Maxwell and the mks unit of flux is weber.

Magnetic flux density: This is the magnetic flux per unit area and is denoted by B. It is expressed in weber/m^2 or Tesla.

9. Explain why neutral points are obtained on the axis of the magnet produced when placed in the magnetic meridian with it n - pole pointing south and on the equatorial line when placed with its n -pole pointing north.

When the magnet is placed with its n-pole pointing south, the intensity of the magnetic field due to the earth and that due to the magnet will be along the line joining the n - s direction. So a point will be obtained on this line where the field due to the earth and the magnet will be equal and opposite so that a neutral point may be obtained.

But when placed with its n-pole pointing north such a point as described above will be somewhere along the equational line, not on the axis and hence a neutral point will be obtained.

10. What is meant by the horizontal component of the earth' field ?

The earth is supposed to be a huge magnet with its imaginary magnet lying approxmately along the line joining the north and south geographical point. At a point any where on the earth, there is a resultant magnetic field due to the north and south pole of this imaginary magnet. This resultant field is the total intensity I of the earth's field. The component of I along the horizontal line is called the horizontal component of the earth's magnetic field and that along the vertical direction the vertical component.

11. What is a Gauss ?

The c.g.s. unit of flux density is called a Gauss.

12. What is Tesla ?

The M.K.S. unit of flux density is Weber per $(\text{meter})^2$ and is also known as tesla.

13. Can you isolate a single pole of a magnet ? Give reasons for your answer.

No. according to the molecular theory of magnetism every molecule of a magnet is a complete magnet by itself with north and south poles at it ends. So if a magnet be broken into pieces each of the pieces will be a complete magnet with north pole at one end and south pole at the other. This will continue to be so even if we break it upto the molecular state. So it is not possible to isolate a single pole of a magnet.

14. While performing expt. on magnetism, why is it necessary to remove other magnets and magnetic substances from the working table ?

Other magnets or magnetic substances (which may be feebly magnetised) may produce their own field in addition to that produced by the main experimental magnet.hence they should be removed from the working table before starting the experiment with the experimental magnet.

15. Why shouldn't you heat or rough handle a magnet ?

The molecules of a magnet are all set or aligned in definite lines in a regular manner showing north pole at one end and south pole at the other. If we roughly handle it as dropping down the working table or heat it (when the molecules will have random motion due to heat) the molecular alignment gets disturbed and power of magnets may be lost altogether at least weakened.

16. State the Tangent law of magnetic forces.

The Tangent law states that the intensity magnetic field due to a magnet is directly proportional to the tangent of the angle it produces.

17. **What is a Deflection Magnetometer ? Why is it so called ?**

A deflection magnetometer is an instrument used for the measurement of magnetic quantities depending on the principle of the Tangent Law i.e. depending on the angle of deflection produced at the center of the pivoted magnetic needle. Hence it is called a Deflection magnetometer ?

18. **What is Null Deflection method ?**

It is the method of comparison of moments of two bar magnets, placing one magnet at some position on one arm of a Deflection magnetometer and placing the 2^{nd} magnet in the other arm and tistance adjusted. The distance of the magnet is so adjusted that the intensity of the field produced by the 1^{st} magnet is equal and opposite to that produced by the 2^{nd} magnet such that there is zero deflection of the needle. The effect due to the 1^{st} magnet produced is counter balanced by that due to the 2^{nd} so as to make zero deflection.

19. **What is an Oscillation Magnetometer ?**

It is also an instrumental used for the magnetic measurements. Its working principle depends on the oscillation of the magnet in the meridian. Hence its is called oscillation magnetometer.

Current Electricity

Exercise on Page 189

1. **State Ohm's law. Why does Ohm's law insist that temperature should be constant ?**

Ohm's law: At constant temperature the current I flowing through a conductor is directly proportional to the potential difference V at its ends.

i.e. $I \propto V$

i.e. $I = \frac{V}{R}$ or $\frac{V}{I} = R$ a constant depending on the nature of the material of the conductor.

The temperature must be constant otherwise R varies with temperature. The constant R is called the resistance of the conductor. Hence the temperature remaining constant must be mentioned.

2. **What is the unit of the current and Potential Difference ?**

The ampere is the mks unit of current. It is equivalent to the rate of flow of one coulomb of charge per sec. The unit of Potential difference is volt which is the amount of work done in joules when one coulomb of charge is flowing from one point to the other.

3. **What is an Ampere ? What is a Coulomb ?**

See Qn. 2. A coulomb is the unit of charge 1 electron carries a charge of 1.6×10^{-19} C. Thus one coulomb is the charge carried by 6.25×10^{18} electrons.

4. **What is an Ammeter ? What is a Voltmeter ? How do you connect them in a circuit?**

An ammeter is an instrument used for measuring current passing through a conductor. It is connected in series in the circuit.

A voltmeter is an instrument used for measuring the potential difference between two points. It is connected in parallel.

5. **What is the difference between an e.m.*f*. and p.d. ?**

The e.m.*f*. of the electromotive force which is the total amount of work done in joules when a unit charge i.e. one coulomb is flowing through the entire circuit including the internal resistance of the battery while P.D. is the potential difference between two points which means the amount of work done when one coulomb of charge flows between these points Both are expressed in volts.

6. What is the function of a Rheostat ?

It is a variable resistor used to vary the resistance in a circuit and thereby control the current.

7. Mention the factors on which the resistance of conductor depend.

The resistance of a conductor is

(i) directly proportional to its length.

(ii) inversely proportional to its area of cross section.

(iii) and also depends on the nature of the material and its temperature.

Thus, $R \propto \frac{l}{a}$ or $= \rho . \frac{l}{a}$

where ρ is a quantity characteristic of the material, called the resistivity of specific resistance and is numerically equal to the resistance of the resistor having unit cross section and unit length.

8. Name the common materials used as resistance wire.

Ureka or constantan, manganin nichrome, german silver, etc.

9. What are ohmic and non-ohmic conductors ?

The conductiors which obey ohm's law are called ohmic conduction. For such conductor, graph between current and potential difference is a straight line passing through the origin. for example, metallic conductors such as silver, copper aluminum managing are ohmic conductors.

There are other conductor such as vacuum tubes, crystal rectifiers, thermistors, transistors which do not obey Ohm's law. The graph between current and pot. diff. for such conductors does not come out a straight line. Circuits containing such conductors are called non-ohmic circuit.

10. What is a shunt ?

Shunt is a low resistance to be connected in parallel with a galvanometer so as to allow only a small fraction of the main current through it and hence protect it from damage due to heavy current.

11. Define resistivity. State its units.

The resistivity of the material of a wire is the resistance offered by a unit length of the wire of unit Cross section. Its unit is ohm-cm or ohm-m.

12. Why should a wire resist the flow of electrons through it ?

Electrons moving through the material of a wire have to overcome the electrical friction which therefore offers resistance to their flow.

13. What is a cell or a battery ?

A cell is a contrivance which by maintaining two different conductors positively or negatively charged keeps the charge flowing in a circuit by converting the chemical energy into electrical energy.

A combination of cells is called a battery.

14. Distinguish between a Primary cell and a Secondary cell.

In a primary cell the electrical energy is produced by the chemical reaction but the rate of production cannot be increased.

In the secondary cell the electrical energy is first stored in it during the process of charging in the form of chemical energy and then can be drawn at any desired rate.

The second essential difference lies in the working of two. The chemical reactions going on in a primary cell are irreversible while those in a secondary cell are reversible.

15. **What are the defects of a simple cell ? How are they removed in (i) a Leclanche cell (ii) a Daniel cell.**

There are two common defects of a simple cell. (i) Local action (ii) Polarisation.

(i) **Local action:** It is the useless consumption of zinc in a simple cell. Commercial zinc contain impurities such as iron, carbon, arsenic, lead etc. When one of these impurities comes in contact with the sulphuric acid a minute cell is formed consisting of this impurity and sulphuric acid and zinc uselessly. The main current is weakened. This way of weakening the main current is called Local action which may be eliminated amalgamating the zinc rod. The zinc mercury amalgam will prevent the impurities to come in contact with the acid and hence, local action is eliminated in Leclanche cell and Daniel cell.

(ii) **Polarisation:** It is a defect in the cells caused by the accumulation of hydrogen bubbles (produced by the action of zinc on sulphuric acid) on the positive plate. Hydrogen bubbles being a bad conductor of electricity, prevents the charges to come in direct contact with positive and hence weaken the main current. Polarization is eliminated mechanically by brushing off the layer of hydrogen. It is also removed by chemical means by using chemicals known as depolarisers. In a Leclanche cell, the depolariser used is Manganese Dioxide which being a good oxidising agent supplies oxygen to the hydrogen bubbles and forms water. Thus hydrogen bubbles are prevented from coming in contact with the positive plate carbon rod in a Leclanche cell and copper vessel in a Daniel cell.

16. **What is a standard cell ?**

The e.m.*f*. of ordinary cells like Leclanche or Daniel cells decreases with continuous use. The e.m.*f*. in the standard cells used are usually Weston or Cadmium cells which has got much temperature coefficient a longer life and greater capacity for recovery after drawing accidentally of an excessive current. Such cells are used not for supplying current but for initially calibrating the potentiometer wire.

17. **What is a Tangent Galvanometer ? Why is it so called ?**

It is a galvanometer use for measurement of current making use of the Tangent Law of magnetic force. The current flowing in the circuit is made to pass through tit adjusted properly in the magnetic meridian. The deflection produced in the needle is noted, making use of the Tangent Law. Current is calculated using the formula.

$$I = \frac{10\ Hr}{2\pi n} \tan\theta$$

where the symbols H stands for the earth's horizontal intensity, r, radius of the coil, n, the no. of turns of the coil.

18. **what is the Reduction factor of a Tangent Galvanometer ?**

$K = \frac{Hr}{2\pi n}$ is the Reduction factor of a Tangent Galvanometer which when multiplied by the tangent of the angle of deflection given the strength of the current in the circuit.

19. **State Faraday's laws of Electrolysis.**

Faraday's laws are stated as;

1st law: The mass of an ion liberated at an electrode is directly proportional to the strength of the current and the time for which it flows.

In symbol $W \propto IT$

2nd law: When the same current passes through different voltammeters in series, the masses of the ions liberates in them are directly proportion to their chemical equivalents.

20. What is the e.c.e. of an element ?

In the formula

$$W = ZIt$$

when I = 1 amp,

t = 1 sec. W = Z

Thus Z, the e.c.e. of an element is the mass of an ion liberated by the passes of 1 ampere current flowing for 1 sec.

21. What is the difference between a voltammeter and a voltameter ?

A voltmeter is an instrument used to measure the potential difference between two points in circuit or to measure the e.m.*f*. a cell.

A voltameter is a vessel in which the electrolysis of a substance in solution takes place on the action of a current flowing through it. eg. copper voltmeter, silver voltmeter.

Exercise on Page 206

1. What is an Ammeter ? What is a voltmeter ? How do they differ from a galvanometer ? Why is the resistance of a voltmeter kept high ?

An ammeter is an instrument used for measuring current in a circuit. It is a galvanometer with a low resistance connected in parallel as a shunt.

A voltmeter is an instrument used for measuring the pot. difference between two points in a circuit or measuring the e.m.*f*. of a cell. It is also a galvanometer but with a high resistance connected in series with its coil. The purpose of using a very high resistance is that it should draw a very little current form the circuit.

2. Define resistivity. State its unit.

Ref. earlier questions.

3. What do you mean by the resistance of a wire ?

It is a property possessed by a wire by virtue of which the flow of current in a circuit is reduced.

4. Why should the wire of a certain material resist the flow of electrons through it.

Ref. earlier question.

5. What is Wheatstone Bridge Principle ?

In a Wheatstone Bridge there are four resistance's P, Q, R, X joined so to form a closed circuit as shown in the fig.

A and C are joined with a cell with a key in between B and D are joined with a galvanometer and a key.

When B and D are at the same potential, there is no current in the galvanometer.

$\therefore$ for null Deflection $\frac{X}{R} = \frac{P}{Q}$ knowing P,Q and R the unknown resistance X can be found out. This principle is called Wheatstone Bridge Principle.

6. **What is a P.O.Box. ?**

It is just a resistance box working on the principle of Wheatstone Bridge. Originally it was intended to measure the resistance of the telegraph wires in post offices. Hence it is called Post Office Box.

7. **What is meant by the sensitivity of a galvanometer ?**

The sensitivity of a galvanometer is given by

$$\frac{d\theta}{dI} = \frac{nAH}{C}$$

It is the deflection produced in it per unit current passing through it. Hence the sensitivity is

(i) directly proportional to the number of turns of the galvanometer coil.

(ii) directly proportional to the intensity (H) of the magnetic field in the space between pole pieces.

(iii) directly proportional to the face area A of the coil.

(iv) inversely proportional to the torsion couple per unit twist of the suspension.

8. **Why does the pointer in a table galvanometer move ?**

The current flowing through the galvanometer produces a couple in its coil placed between the pole pieces of a string horse shoe type of magnet. The coil is suspended by a phosphor Bronze Bridge strip which in turn is attached to a pointer moving over a graduated scale calibrated in such a way as to be deflected proportional to the current passed through it.

9. **What is a potentiometer ? Why is it so call ?**

It is an electrical device used for measuring the potential developed across a certain length of the wire. Since it measures the potential difference between two points, it is called a potentiometer.

10. **What is a Potential Divider ?**

Suppose an electric circuit contains two or more than two resistor in series (r_1, r_2, r_3 etc.) the current in the circuit is

$$I = \frac{V}{r_1 + r_2 + r_3}$$

Now PD across r_2 is

$$V_2 = Ir_2 = \frac{V}{r_1 + r_2 + r_3} \cdot r_2$$

This method of obtaining a fraction of a certain P.D. in such a circuit is called Potential Devider arrangement.

11. **Why is the name dry cell given to the common battery used in flash lights and radio ?**

Because it does not contain any liquids as the exciting agent.

12. **Does a storage cell store up electricity ? Why is it properly called a Storage Cell ?**

A storage cell is a secondary cell. In it the electrical energy is stored during charging first into chemical energy and reconverted into electrical energy whenever desired.

13. One should never hold a lighted match near an open storage battery ? Explain it.

It may catch fire.

14. A steady current of 10 amp. is maintained in a metal conductor for 2 min. What charge in coulomb is transferred through it in that time.

We have $I = \frac{Q}{t}$

or $Q = It$

or $10 \times 2 \times 60 = 1200$ coulomb

15. A 6.24 volt battery is connected for 3.33 hr. to a Rheostat and a current of 1477 mt. is noted.

(a) What is the resistance of the rheostat ?

(b) What charge is taken from the battery ?

$= \frac{V}{R}$

or $\frac{147}{1000} = \frac{6.24}{R}$

or $R = \frac{6.24 \times 1000}{147} = 42.4\ \Omega$

or $I = \frac{Q}{t}$

$\therefore\ Q = It = \frac{147}{1000} \times 3.33 \times 3600 = 1762.2$ coulomb.

16. What is the use of a Potentiometer ?

Uses of a Potentiometer:

(i) determination of the e.m.*f*. of a cell.

(ii) comparison of e.m.*f*.s of two cells.

(iii) determination of the internal resistor of a cell.

(iv) calibration of an ammeter and a voltmeter.

17. State the principle of a potentiometer.

A stready current is maintained by connecting its two ends to a source of constant e.m.*f*. Because at null point, no current flows through the galvanometer, the cell is on open circuit, and therefore, the potential difference across the terminals will be equal to the e.m.*f*. of the cell. Hence the principle is to balance the e.m.*f*. of the cell with potential drop across the length of the potentiometer wire at null point.

18. What is the potential gradient ? On what factors does it depend ?

The potential gradient is the fall of potential per unit length of the potentiometer wire.

Thus $k = \frac{E}{l}\ \frac{\text{Volt}}{\text{m}}$

i.e. k depends on the e.m.*f*. of the driving battery and its total length.

19. **What do you mean by the sensitiveness of a potentiometer ? How can it be increased ?**

The smallest potential difference that can be measured with a potentiometer is called its sensitiveness. Thus the smaller the value of the potential gradient, the greater would be its sensitiveness. It can thus be increased with a ten wire type of stretched wire potentiometer.

20. **On what factors does the accuracy if the potentiometer depend ?**

It depends on its potential gradient, the constancy of the e.m.*f*. of the driving cell.

21. **Is it not better to measure the e.m.*f*. of a cell by a voltmeter ?**

In the balanced condition, the voltmeter draws the current whereas the potentiometer does no current. So it is better to use a voltmeter.

Because the voltmeter draws some current.

22. **What type of cell hold be used in the main circuit.**

A cell with a constant e.m.*f*.(freshly charged battery) or an alkali cell should be used in the main driving circuit. It must have an e.m.*f*. greater than that of the comparing cells.

23. **Will you prefer the null point in the first wire or the last wire ?**

Definitely on the last wire, because the potential gradient will be smaller and the sensitivity of the potentiometer will be high.

24. **Why are the readings given by a potentiometer more accurate than those of the voltmeter ?**

In the potentiometer, the adjustable wire is approaciability long so that the potential gradient is very small, thus increasing its sensitivily. So then e is a scope of measuring very small voltages.

COMMON LOGARITHMS $\log_{10} x$

x	0	1	2	3	4	5	6	7	8	9	Δ_m +	1	2	3	4	5	6	7	8	9
												ADD								
10	·0000	0043	0086	0128	0170	0212					42	4	8	13	17	21	25	29	34	38
						0212	0253	0294	0334	0374	40	4	8	12	16	20	24	28	32	36
11	·0414	0453	0492	0531	0569	0607					39	4	8	12	16	19	23	27	31	35
						0607	0645	0682	0719	0755	37	4	7	11	15	19	22	26	30	33
12	·0792	0828	0864	0899	0934	0969					35	4	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	34	3	7	10	14	17	20	24	27	31
13	·1139	1173	1206	1239	1271	1303					33	3	7	10	13	16	20	23	26	30
						1303	1335	1367	1399	1430	32	3	6	10	13	16	19	22	26	29
14	·1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	30	3	6	9	12	15	18	21	24	27
15	·1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	28	3	6	8	11	14	17	20	22	25
16	·2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	26	3	5	8	10	13	16	18	21	23
17	·2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	25	2	5	7	10	12	15	17	20	22
18	·2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	24	2	5	7	10	12	14	17	19	22
19	·2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	22	2	4	7	9	11	13	15	18	20
20	·3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	21	2	4	6	8	11	13	15	17	19
21	·3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	20	2	4	6	8	10	12	14	16	18
22	·3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	19	2	4	6	8	10	11	13	15	17
23	·3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	18	2	4	5	7	9	11	13	14	16
24	·3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	18	2	4	5	7	9	11	13	14	16
25	·3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	17	2	3	5	7	9	10	12	14	15
26	·4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	16	2	3	5	6	8	10	11	13	14
27	·4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	16	2	3	5	6	8	10	11	13	14
28	·4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	15	2	3	5	6	8	9	11	12	14
29	·4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	15	1	3	4	6	7	9	10	12	13
30	·4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	14	1	3	4	6	7	8	10	11	13
31	·4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	14	1	3	4	6	7	8	10	11	13
32	·5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	13	1	3	4	5	7	8	9	10	12
33	·5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	13	1	3	4	5	6	8	9	10	12
34	·5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	13	1	3	4	5	6	8	9	10	12
35	·5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	12	1	2	4	5	6	7	8	10	11
36	·5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	12	1	2	4	5	6	7	8	10	11
37	·5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	12	1	2	4	5	6	7	8	10	11
38	·5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	11	1	2	3	4	6	7	8	9	10
39	·5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	11	1	2	3	4	6	7	8	9	10
40	·6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	11	1	2	3	4	5	7	8	9	10
41	·6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	10	1	2	3	4	5	6	7	8	9
42	·6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	10	1	2	3	4	5	6	7	8	9
43	·6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	10	1	2	3	4	5	6	7	8	9
44	·6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	10	1	2	3	4	5	6	7	8	9
45	·6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	10	1	2	3	4	5	6	7	8	9
46	·6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	9	1	2	3	4	5	5	6	7	8
47	·6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	9	1	2	3	4	5	5	6	7	8
48	·6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	9	1	2	3	4	4	5	6	7	8
49	·6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	9	1	2	3	4	4	5	6	7	8

	No.	log
π =	3·14159	0·49715
e =	2·71828	0·43429

$\ln x = \log_e x = (1/M) \log_{10} x$

$\log x = \log_{10} x = M \log_e x$

	No.	log
$(1/M)$ =	2·30259	0·36222
M =	0·43429	$\bar{1}$·63778

p	1	2	3	4	5	6	7	8	9	10
$\log e^{p}$	0·4343	0·8686	1·3029	1·7372	2·1715	2·6058	3·0401	3·4744	3·9087	4·3429
$\log e^{-p}$	$\bar{1}$·5657	$\bar{1}$·1314	$\bar{2}$·6971	$\bar{2}$·2628	$\bar{3}$·8285	$\bar{3}$·3942	$\bar{4}$·9599	$\bar{4}$·5256	$\bar{4}$·0913	$\bar{5}$·6571

x	0	1	2	3	4	5	6	7	8	9	Δm +	1	2	3	4	5	6	7	8	9
												ADD								
50	·6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	9	1	2	3	4	4	5	6	7	8
51	·7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	8	1	2	2	3	4	5	6	6	7
52	·7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	8	1	2	2	3	4	5	6	6	7
53	·7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	8	1	2	2	3	4	5	6	6	7
54	·7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	8	1	2	2	3	4	5	6	6	7
55	·7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	8	1	2	2	3	4	5	6	6	7
56	·7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	8	1	2	2	3	4	5	6	6	7
57	·7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	8	1	2	2	3	4	5	6	6	7
58	·7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	8	1	2	2	3	4	5	6	6	7
59	·7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	7	1	1	2	3	4	4	5	6	6
60	·7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	7	1	1	2	3	4	4	5	6	6
61	·7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	7	1	1	2	3	4	4	5	6	6
62	·7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	7	1	1	2	3	3	4	5	6	6
63	·7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	7	1	1	2	3	3	4	5	6	6
64	·8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	7	1	1	2	3	3	4	5	6	6
65	·8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	7	1	1	2	3	3	4	5	6	6
66	·8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	7	1	1	2	3	3	4	5	6	6
67	·8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	6	1	1	2	2	3	4	4	5	5
68	·8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	6	1	1	2	2	3	4	4	5	5
69	·8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	6	1	1	2	2	3	4	4	5	5
70	·8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	6	1	1	2	2	3	4	4	5	5
71	·8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	6	1	1	2	2	3	4	4	5	5
72	·8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	6	1	1	2	2	3	4	4	5	5
73	·8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	6	1	1	2	2	3	4	4	5	5
74	·8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	6	1	1	2	2	3	4	4	5	5
75	·8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	6	1	1	2	2	3	4	4	5	5
76	·8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	6	1	1	2	2	3	4	4	5	5
77	·8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	6	1	1	2	2	3	4	4	5	5
78	·8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	6	1	1	2	2	3	4	4	5	5
79	·8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	6	1	1	2	2	3	4	4	5	5
80	·9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	5	1	1	2	2	3	3	4	4	5
81	·9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	5	1	1	2	2	3	3	4	4	5
82	·9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	5	1	1	2	2	3	3	4	4	5
83	·9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	5	1	1	2	2	3	3	4	4	5
84	·9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	5	1	1	2	2	3	3	4	4	5
85	·9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	5	1	1	2	2	3	3	4	4	5
86	·9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	5	1	1	2	2	3	3	4	4	5
87	·9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	5	0	1	1	2	2	3	3	4	4
88	·9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	5	0	1	1	2	2	3	3	4	4
89	·9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	5	0	1	1	2	2	3	3	4	4
90	·9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	5	0	1	1	2	2	3	3	4	4
91	·9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	5	0	1	1	2	2	3	3	4	4
92	·9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	5	0	1	1	2	2	3	3	4	4
93	·9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	5	0	1	1	2	2	3	3	4	4
94	·9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	5	0	1	1	2	2	3	3	4	4
95	·9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	5	0	1	1	2	2	3	3	4	4
96	·9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	4	0	1	1	2	2	2	3	3	4
97	·9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	4	0	1	1	2	2	2	3	3	4
98	·9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	4	0	1	1	2	2	2	3	3	4
99	·9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	4	0	1	1	2	2	2	3	3	4

ANTILOGARITHMS 10^x

x	0	1	2	3	4	5	6	7	8	9	Δm +	1	2	3	4	5	6	7	8	9
												ADD								
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	2	0	0	1	1	1	1	1	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	2	0	0	1	1	1	1	1	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	2	0	0	1	1	1	1	1	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	2	0	0	1	1	1	1	1	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	3	0	1	1	1	1	2	2	2	3
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	3	0	1	1	1	1	2	2	2	3
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	3	0	1	1	1	1	2	2	2	3
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	3	0	1	1	1	1	2	2	2	3
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	3	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	3	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	3	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	3	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	3	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	3	0	1	1	1	2	2	2	2	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	3	0	1	1	1	2	2	2	2	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	3	0	1	1	1	2	2	2	2	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	3	0	1	1	1	2	2	2	2	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	4	0	1	1	2	2	2	3	3	4
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	4	0	1	1	2	2	2	3	3	4
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	4	0	1	1	2	2	2	3	3	4
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	4	0	1	1	2	2	2	3	3	4
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	4	0	1	1	2	2	2	3	3	4
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	4	0	1	1	2	2	2	3	3	4
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	4	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	4	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	4	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	4	0	1	1	2	2	2	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	4	0	1	1	2	2	2	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	4	0	1	1	2	2	2	3	3	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	4	0	1	1	2	2	2	3	3	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	5	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	5	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	5	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	5	1	1	2	2	3	3	4	4	5
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	5	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	5	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	5	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	6	1	1	2	2	3	4	4	5	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	6	1	1	2	2	3	4	4	5	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	6	1	1	2	2	3	4	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	6	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	6	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	6	1	1	2	2	3	4	4	5	5
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	6	1	1	2	2	3	4	4	5	5
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	6	1	1	2	2	3	4	4	5	5
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	7	1	1	2	3	3	4	5	6	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	7	1	1	2	3	3	4	5	6	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	7	1	1	2	3	3	4	5	6	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	7	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	7	1	1	2	3	4	4	5	6	6

x	0	1	2	3	4	5	6	7	8	9	Δ_m +	1	2	3	4	5	6	7	8	9
															ADD					
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	7	1	1	2	3	4	4	5	6	6
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	8	1	2	2	3	4	5	6	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	8	1	2	2	3	4	5	6	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	8	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	8	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	8	1	2	2	3	4	5	6	6	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	8	1	2	2	3	4	5	6	6	7
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	9	1	2	3	4	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	9	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	9	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	9	1	2	3	4	5	5	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	10	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	10	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	10	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	10	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	10	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	11	1	2	3	4	5	7	8	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	11	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	11	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	11	1	2	3	4	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	12	1	2	4	5	6	7	8	10	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	12	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	12	1	2	4	5	6	7	8	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	12	1	2	4	5	6	7	8	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	13	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	13	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	13	1	3	4	5	7	8	9	10	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	14	1	3	4	6	7	8	10	11	13
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	14	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	14	1	3	4	6	7	8	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	15	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	15	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	15	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	16	2	3	5	6	8	10	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	16	2	3	5	6	8	10	11	13	14
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	16	2	3	5	6	8	10	11	13	14
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	17	2	3	5	7	8	10	12	14	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	17	2	3	5	7	9	10	12	14	15
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	18	2	4	5	7	9	11	13	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	18	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	18	2	4	5	7	9	11	13	14	16
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	19	2	4	6	8	10	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	19	2	4	6	8	10	11	13	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	20	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	20	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	21	2	4	6	8	10	13	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	21	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	22	2	4	7	9	11	13	15	18	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	22	2	4	7	9	11	13	15	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	23	2	5	7	9	11	14	16	18	21

NATURAL SINES $\sin x^\circ$

x°	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ_m +	1′ ADD*	2′	3′	4′	5′
0°	0·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	18‡	3	6	9	12	15
1	0·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	17‡	3	6	9	11	14
2	0·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	17‡	3	6	9	11	14
3	0·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	17‡	3	6	9	11	14
4	0·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	17‡	3	6	9	11	14
5	0·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	17‡	3	6	9	11	14
6	0·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	17	3	6	9	11	14
7	0·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	17	3	6	9	11	14
8	0·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	17	3	6	9	11	14
9	0·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	17	3	6	9	11	14
10	0·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	17	3	6	9	11	14
11	0·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	17	3	6	9	11	14
12	0·2079	2096	2113	2130	2147	2164	2181	2198	2215	2233	17	3	6	9	11	14
13	0·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	17	3	6	8	11	14
14	0·2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	17	3	6	8	11	14
15	0·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	17	3	6	8	11	14
16	0·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	17	3	6	8	11	14
17	0·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	17	3	6	8	11	14
18	0·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	17	3	6	8	11	14
19	0·3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	16	3	5	8	11	13
20	0·3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	16	3	5	8	11	13
21	0·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	16	3	5	8	11	13
22	0·3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	16	3	5	8	11	13
23	0·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	16	3	5	8	11	13
24	0·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	16	3	5	8	11	13
25	0·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	16	3	5	8	11	13
26	0·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	16	3	5	8	11	13
27	0·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	16	3	5	8	11	13
28	0·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	15	3	5	8	10	13
29	0·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	15	3	5	8	10	13
30	0·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	15	3	5	8	10	13
31	0·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	15	2	5	7	10	12
32	0·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	15	2	5	7	10	12
33	0·5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	15	2	5	7	10	12
34	0·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	14	2	5	7	9	12
35	0·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	14	2	5	7	9	12
36	0·5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	14	2	5	7	9	12
37	0·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	14	2	5	7	9	12
38	0·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	14	2	5	7	9	12
39	0·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	14	2	5	7	9	12
40	0·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	13	2	4	7	9	11
41	0·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	13	2	4	7	9	11
42	0·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	13	2	4	6	9	11
43	0·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	13	2	4	6	9	11
44	0·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	12	2	4	6	8	10
45	0·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	12	2	4	6	8	10
46	0·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	12	2	4	6	8	10
47	0·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	12	2	4	6	8	10
48	0·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	12	2	4	6	8	10
49	0·7547	7559	7570	7581	7593	7604	7615	7627	7638	7649	11	2	4	6	7	9

$\operatorname{cosec} x^\circ = 1/\sin x^\circ$

‡ For 4 significant figures, see footnote ‡ opposite.

NATURAL SINES $\sin x^\circ$

x°	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ_m +	1′ ADD*	2′	3′	4′	5′
50°	0·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	11	2	4	6	7	9
51	0·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	11	2	4	5	7	9
52	0·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	11	2	4	5	7	9
53	0·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	10	2	3	5	7	8
54	0·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	10	2	3	5	7	8
55	0·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	10	2	3	5	7	8
56	0·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	10	2	3	5	7	8
57	0·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	9	2	3	5	6	8
58	0·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	9	2	3	5	6	8
59	0·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	9	1	3	4	6	7
60	0·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	9	1	3	4	6	7
61	0·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	8	1	3	4	5	7
62	0·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	8	1	3	4	5	7
63	0·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	8	1	3	4	5	7
64	0·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	8	1	3	4	5	7
65	0·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	7	1	2	4	5	6
66	0·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	7	1	2	4	5	6
67	0·9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	7	1	2	3	5	6
68	0·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	6	1	2	3	4	5
69	0·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	6	1	2	3	4	5
70	0·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	6	1	2	3	4	5
71	0·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	6	1	2	3	4	5
72	0·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	5	1	2	3	3	4
73	0·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	5	1	2	3	3	4
74	0·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	5	1	2	2	3	4
75	0·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	4	1	1	2	3	3
76	0·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	4	1	1	2	3	3
77	0·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	4	1	1	2	3	3
78	0·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	4	1	1	2	3	3
79	0·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	3	1	1	2	2	3
80	0·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	3	0	1	1	2	2
81	0·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	3	0	1	1	2	2
82	0·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	2	0	1	1	1	2
83	0·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	2	0	1	1	1	2
84	0·9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	2	0	1	1	1	2
85	0·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974						
86	0·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985						
87	0·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993						
88	0·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998						
89	0·9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000						

$\operatorname{cosec} x^\circ = 1/\sin x^\circ$

x°	σ	$1/\sigma$	$\sin x^\circ$	$\operatorname{cosec} x^\circ$
0°	57·30	·017453	·00000	∞
1	57·30	·017452	·01745	57·30
2	57·31	·017450	·03490	28·65
3	57·32	·017445	·05234	19·11
4	57·34	·017439	·06976	14·34
5	57·37	·017431	·08716	11·474
6	57·40	·017421	·10453	9·567
7	57·44	·017410	·12187	8·206
8	57·48	·017397	·13917	7·185

* For interpolation to tenths (0°·01) use PPs on p. 45 for the difference Δ between successive tabular values.

‡ sin, cos, sec *and* cosec *of angles near* 0° *and* 90°

For angles $x^\circ = 90^\circ - y^\circ \leqslant 8^\circ$:

$$\cos y^\circ = \sin x^\circ = (1/\sigma)\,x$$

$$x = \sigma \sin x^\circ \qquad y = 90 - \sigma \cos y^\circ$$

$$\sec y^\circ = \operatorname{cosec} x^\circ = \sigma/x$$

$$x = \sigma/\operatorname{cosec} x^\circ \qquad y = 90 - \sigma/\sec y^\circ$$

If $x' \leqslant 60' = 1^\circ$: $\sin x' \doteqdot 0{\cdot}0002909\,x$

NATURAL COSINES $\cos x^{\circ}$

x°	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ_m −	1′ SUBTRACT	2′	3′	4′	5′
0°	1·0000	1·000	1·000	1·000	1·000	1·000	9999	9999	9999	9999						
1	0·9998	9998	9998	9997	9997	9997	9996	9996	9995	9995						
2	0·9994	9993	9993	9992	9991	9990	9990	9989	9988	9987						
3	0·9986	9985	9984	9983	9982	9981	9980	9979	9978	9977						
4	0·9976	9974	9973	9972	9971	9969	9968	9966	9965	9963	2	0	1	1	1	2
5	0·9962	9960	9959	9957	9956	9954	9952	9951	9949	9947	2	0	1	1	1	2
6	0·9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	2	0	1	1	1	2
7	0·9925	9923	9921	9919	9917	9914	9912	9910	9907	9905	2	0	1	1	1	2
8	0·9903	9900	9898	9895	9893	9890	9888	9885	9882	9880	3	0	1	1	2	2
9	0·9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	3	0	1	1	2	2
10	0·9848	9845	9842	9839	9836	9833	9829	9826	9823	9820	3	1	1	2	2	3
11	0·9816	9813	9810	9806	9803	9799	9796	9792	9789	9785	4	1	1	2	3	3
12	0·9781	9778	9774	9770	9767	9763	9759	9755	9751	9748	4	1	1	2	3	3
13	0·9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	4	1	1	2	3	3
14	0·9703	9699	9694	9690	9686	9681	9677	9673	9668	9664	4	1	1	2	3	3
15	0·9659	9655	9650	9646	9641	9636	9632	9627	9622	9617	5	1	2	2	3	4
16	0·9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	5	1	2	3	3	4
17	0·9563	9558	9553	9548	9542	9537	9532	9527	9521	9516	5	1	2	3	3	4
18	0·9511	9505	9500	9494	9489	9483	9478	9472	9466	9461	6	1	2	3	4	5
19	0·9455	9449	9444	9438	9432	9426	9421	9415	9409	9403	6	1	2	3	4	5
20	0·9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	6	1	2	3	4	5
21	0·9336	9330	9323	9317	9311	9304	9298	9291	9285	9278	6	1	2	3	4	5
22	0·9272	9265	9259	9252	9245	9239	9232	9225	9219	9212	7	1	2	3	5	6
23	0·9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	7	1	2	4	5	6
24	0·9135	9128	9121	9114	9107	9100	9092	9085	9078	9070	7	1	2	4	5	6
25	0·9063	9056	9048	9041	9033	9026	9018	9011	9003	8996	8	1	3	4	5	7
26	0·8988	8980	8973	8965	8957	8949	8942	8934	8926	8918	8	1	3	4	5	7
27	0·8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	8	1	3	4	5	7
28	0·8829	8821	8813	8805	8796	8788	8780	8771	8763	8755	8	1	3	4	5	7
29	0·8746	8738	8729	8721	8712	8704	8695	8686	8678	8669	9	1	3	4	6	7
30	0·8660	8652	8643	8634	8625	8616	8607	8599	8590	8581	9	1	3	4	6	7
31	0·8572	8563	8554	8545	8536	8526	8517	8508	8499	8490	9	2	3	5	6	8
32	0·8480	8471	8462	8453	8443	8434	8425	8415	8406	8396	9	2	3	5	6	8
33	0·8387	8377	8368	8358	8348	8339	8329	8320	8310	8300	10	2	3	5	7	8
34	0·8290	8281	8271	8261	8251	8241	8231	8221	8211	8202	10	2	3	5	7	8
35	0·8192	8181	8171	8161	8151	8141	8131	8121	8111	8100	10	2	3	5	7	8
36	0·8090	8080	8070	8059	8049	8039	8028	8018	8007	7997	10	2	3	5	7	8
37	0·7986	7976	7965	7955	7944	7934	7923	7912	7902	7891	11	2	4	5	7	9
38	0·7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	11	2	4	5	7	9
39	0·7771	7760	7749	7738	7727	7716	7705	7694	7683	7672	11	2	4	6	7	9
40	0·7660	7649	7638	7627	7615	7604	7593	7581	7570	7559	11	2	4	6	7	9
41	0·7547	7536	7524	7513	7501	7490	7478	7466	7455	7443	12	2	4	6	8	10
42	0·7431	7420	7408	7396	7385	7373	7361	7349	7337	7325	12	2	4	6	8	10
43	0·7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	12	2	4	6	8	10
44	0·7193	7181	7169	7157	7145	7133	7120	7108	7096	7083	12	2	4	6	8	10
45	0·7071	7059	7046	7034	7022	7009	6997	6984	6972	6959	12	2	4	6	8	10
46	0·6947	6934	6921	6909	6896	6884	6871	6858	6845	6833	13	2	4	6	9	11
47	0·6820	6807	6794	6782	6769	6756	6743	6730	6717	6704	13	2	4	6	9	11
48	0·6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	13	2	4	7	9	11
49	0·6561	6547	6534	6521	6508	6494	6481	6468	6455	6441	13	2	4	7	9	11

Bold type indicates that the integer changes to zero.

NATURAL COSINES

cos x°

x°	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δ_m	1′	2′	3′	4′	5′
											—	SUBTRACT*				
50°	0·6428	6414	6401	6388	6374	6361	6347	6334	6320	6307	14	2	5	7	9	12
51	0·6293	6280	6266	6252	6239	6225	6211	6198	6184	6170	14	2	5	7	9	12
52	0·6157	6143	6129	6115	6101	6088	6074	6060	6046	6032	14	2	5	7	9	12
53	0·6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	14	2	5	7	9	12
54	0·5878	5864	5850	5835	5821	5807	5793	5779	5764	5750	14	2	5	7	9	12
55	0·5736	5721	5707	5693	5678	5664	5650	5635	5621	5606	14	2	5	7	9	12
56	0·5592	5577	5563	5548	5534	5519	5505	5490	5476	5461	15	2	5	7	10	12
57	0·5446	5432	5417	5402	5388	5373	5358	5344	5329	5314	15	2	5	7	10	12
58	0·5299	5284	5270	5255	5240	5225	5210	5195	5180	5165	15	2	5	7	10	12
59	0·5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	15	3	5	8	10	13
60	0·5000	4985	4970	4955	4939	4924	4909	4894	4879	4863	15	3	5	8	10	13
61	0·4848	4833	4818	4802	4787	4772	4756	4741	4726	4710	15	3	5	8	10	13
62	0·4695	4679	4664	4648	4633	4617	4602	4586	4571	4555	16	3	5	8	11	13
63	0·4540	4524	4509	4493	4478	4462	4446	4431	4415	4399	16	3	5	8	11	13
64	0·4384	4368	4352	4337	4321	4305	4289	4274	4258	4242	16	3	5	8	11	13
65	0·4226	4210	4195	4179	4163	4147	4131	4115	4099	4083	16	3	5	8	11	13
66	0·4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	16	3	5	8	11	13
67	0·3907	3891	3875	3859	3843	3827	3811	3795	3778	3762	16	3	5	8	11	13
68	0·3746	3730	3714	3697	3681	3665	3649	3633	3616	3600	16	3	5	8	11	13
69	0·3584	3567	3551	3535	3518	3502	3486	3469	3453	3437	16	3	5	8	11	13
70	0·3420	3404	3387	3371	3355	3338	3322	3305	3289	3272	16	3	5	8	11	13
71	0·3256	3239	3223	3206	3190	3173	3156	3140	3123	3107	17	3	6	8	11	14
72	0·3090	3074	3057	3040	3024	3007	2990	2974	2957	2940	17	3	6	8	11	14
73	0·2924	2907	2890	2874	2857	2840	2823	2807	2790	2773	17	3	6	8	11	14
74	0·2756	2740	2723	2706	2689	2672	2656	2639	2622	2605	17	3	6	8	11	14
75	0·2588	2571	2554	2538	2521	2504	2487	2470	2453	2436	17	3	6	8	11	14
76	0·2419	2402	2385	2368	2351	2334	2317	2300	2284	2267	17	3	6	8	11	14
77	0·2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	17	3	6	9	11	14
78	0·2079	2062	2045	2028	2011	1994	1977	1959	1942	1925	17	3	6	9	11	14
79	0·1908	1891	1874	1857	1840	1822	1805	1788	1771	1754	17	3	6	9	11	14
80	0·1736	1719	1702	1685	1668	1650	1633	1616	1599	1582	17	3	6	9	11	14
81	0·1564	1547	1530	1513	1495	1478	1461	1444	1426	1409	17	3	6	9	11	14
82	0·1392	1374	1357	1340	1323	1305	1288	1271	1253	1236	17	3	6	9	11	14
83	0·1219	1201	1184	1167	1149	1132	1115	1097	1080	1063	17	3	6	9	11	14
84	0·1045	1028	1011	0993	0976	0958	0941	0924	0906	0889	17‡	3	6	9	11	14
85	0·0872	0854	0837	0819	0802	0785	0767	0750	0732	0715	17‡	3	6	9	11	14
86	0·0698	0680	0663	0645	0628	0610	0593	0576	0558	0541	17‡	3	6	9	11	14
87	0·0523	0506	0488	0471	0454	0436	0419	0401	0384	0366	17‡	3	6	9	11	14
88	0·0349	0332	0314	0297	0279	0262	0244	0227	0209	0192	17‡	3	6	9	11	14
89	0·0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	18‡	3	6	9	12	15

* For interpolation to tenths (0°·01) use PPs on p. 45 for the difference Δ between successive tabular values.

‡ For 4 significant figures see footnote ‡, p. 17.

§ tan *and* cot *of angles near* 0° *and* 90°

For angles $x^{\circ} = 90^{\circ} - y^{\circ} \leq 8^{\circ}$:

$$\cot y^{\circ} = \tan x^{\circ} = (1/\tau)\, x$$

$$x = \tau \tan x^{\circ} \qquad y = 90 - \tau \cot y^{\circ}$$

$$\tan y^{\circ} = \cot x^{\circ} = \tau / x$$

$$x = \tau / \cot x^{\circ} \qquad y = 90 - \tau / \tan y^{\circ}$$

If $x' \leq 60' = 1^{\circ}$: $\tan x' \doteqdot 0{\cdot}0002909x$

x°	τ	1/τ	tan x°	cot x°
0°	57·30	·017453	·00000	∞
1	57·29	·017455	·01746	57·29
2	57·27	·017460	·03492	28·64
3	57·24	·017469	·05241	19·08
4	57·20	·017482	·06993	14·30
5	57·15	·017498	·08749	11·430
6	57·09	·017517	·10510	9·514
7	57·01	·017541	·12278	8·144
8	56·92	·017568	·14054	7·115

NATURAL TANGENTS   tan x°

x°	0 $0^{\circ}\cdot0$	6' $0^{\circ}\cdot1$	12' $0^{\circ}\cdot2$	18' $0^{\circ}\cdot3$	24' $0^{\circ}\cdot4$	30' $0^{\circ}\cdot5$	36' $0^{\circ}\cdot6$	42' $0^{\circ}\cdot7$	48' $0^{\circ}\cdot8$	54' $0^{\circ}\cdot9$	Δ_m +	1'	2'	3'	4'	5'
												ADD*				
0°	0·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	17§	3	6	9	11	14
1	0·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	17§	3	6	9	11	14
2	0·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	18§	3	6	9	12	15
3	0·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	18§	3	6	9	12	15
4	0·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	18§	3	6	9	12	15
5	0·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	18§	3	6	9	12	15
6	0·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	18	3	6	9	12	15
7	0·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	18	3	6	9	12	15
8	0·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	18	3	6	9	12	15
9	0·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	18	3	6	9	12	15
10	0·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	18	3	6	9	12	15
11	0·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	18	3	6	9	12	15
12	0·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	18	3	6	9	12	15
13	0·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	18	3	6	9	12	15
14	0·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	19	3	6	9	13	16
15	0·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	19	3	6	9	13	16
16	0·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	19	3	6	9	13	16
17	0·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	19	3	6	10	13	16
18	0·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	19	3	6	10	13	16
19	0·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	20	3	7	10	13	17
20	0·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	20	3	7	10	13	17
21	0·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	20	3	7	10	13	17
22	0·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	20	3	7	10	13	17
23	0·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	21	3	7	10	14	17
24	0·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	21	4	7	11	14	18
25	0·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	21	4	7	11	14	18
26	0·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	22	4	7	11	15	18
27	0·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	22	4	7	11	15	18
28	0·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	23	4	8	11	15	19
29	0·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	23	4	8	12	15	19
30	0·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	24	4	8	12	16	20
31	0·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	24	4	8	12	16	20
32	0·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	25	4	8	12	17	21
33	0·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	25	4	8	13	17	21
34	0·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	26	4	9	13	17	22
35	0·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	26	4	9	13	17	22
36	0·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	27	5	9	14	18	23
37	0·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	28	5	9	14	19	23
38	0·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	28	5	9	14	19	23
39	0·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	29	5	10	15	19	24
40	0·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	30	5	10	15	20	25
41	0·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	31	5	10	16	21	26
42	0·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	32	5	11	16	21	27
43	0·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	33	6	11	17	22	28
44	0·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	34	6	11	17	23	28
45	1·0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	36	6	12	18	24	30
46	1·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	37	6	12	18	25	31
47	1·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	38	6	13	19	25	32
48	1·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	40	7	13	20	27	33
49	1·1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	41	7	14	21	27	34

$\cot x^{\circ} = 1/\tan x^{\circ} = \tan(90^{\circ} - x^{\circ})$

NATURAL TANGENTS   tan $x°$

$x°$	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Δm +	1′	2′	3′	4′	5′ ADD*
50°	1·192	196	200	205	209	213	217	222	226	230	4	1	1	2	3	3
51	1·235	239	244	248	253	257	262	266	271	275	4	1	1	2	3	3
52	1·280	285	289	294	299	303	308	313	317	322	5	1	2	2	3	4
53	1·327	332	337	342	347	351	356	361	366	371	5	1	2	2	3	4
54	1·376	381	387	392	397	402	407	412	418	423	5	1	2	3	3	4
55	1·428	433	439	444	450	455	460	466	471	477	6	1	2	3	4	5
56	1·483	488	494	499	505	511	517	522	528	534	6	1	2	3	4	5
57	1·540	546	552	558	564	570	576	582	588	594	6	1	2	3	4	5
58	1·600	607	613	619	625	632	638	645	651	658	6	1	2	3	4	5
59	1·664	671	678	684	691	698	704	711	718	725	7	1	2	3	5	6
60	1·732	739	746	753	760	767	775	782	789	797	7	1	2	4	5	6
61	1·804	811	819	827	834	842	849	857	865	873	8	1	3	4	5	7
62	1·881	889	897	905	913	921	929	937	946	954	8	1	3	4	5	7
63	1·963	971	980	988	1·997	**2·006**	**014**	**023**	**032**	**041**	9	[illegible]	3	4	6	7
64	2·050	059	069	078	087	097	106	116	125	135	10	2	3	5	7	8
65	2·145	154	164	174	184	194	204	215	225	236	10	2	3	5	7	8
66	2·246	257	267	278	289	300	311	322	333	344	11	2	4	6	7	9
67	2·356	367	379	391	402	414	426	438	450	463	12	2	4	6	8	10
68	2·475	488	500	513	526	539	552	565	578	592	13	2	4	7	9	11
69	2·605	619	633	646	660	675	689	703	718	733	14	2	5	7	9	12
70	2·747	762	778	793	808	824	840	856	872	888	16	3	5	8	11	13
71	2·904	921	937	954	971	2·989	**3·006**	**024**	**042**	**060**	17	3	6	9	11	14
72	3·078	096	115	133	152						19	3	6	9	13	16
					152	172	191	211	230	251	20	3	7	10	13	17
											21	3	7	10	14	17
73	3·271	291	312	333	354						22	4	7	11	15	18
					354	376	398	420	442	465						
					582	606	630				24	4	8	12	16	20
74	3·487	511	534	558			630	655	681	706	26	4	9	13	17	22
											27	4	9	13	18	22
					839											
75	3·732	758	785	812	839	867	895	923	952	981	29	5	10	14	19	24
						165					31	5	10	15	21	26
76	4·011	041	071	102	134	165	198	230	264	297	33	6	11	17	22	28
					474	511	548				36	6	12	18	24	30
77	4·331	366	402	437			548	586	625	665	39	7	13	20	26	33
					872	915	959				42*	7	14	21	28	35
78	4·705	745	787	829			4·959	**5·005**	**050**	**097**	46*	8	15	23	31	38
					343						50*	8	17	25	33	42
79	5·145	193	242	292	343	396	449	503	558	614	55*	9	18	27	37	46
80	5·67	5·73	5·79	5·85	5·91	5·98	6·04	6·11	6·17	6·24	6	1	2	3	4	5
81	6·31	6·39	6·46	6·54	6·61	6·69	6·77	6·85	6·94	7·03	8	1	3	4	5	7
82	7·12	7·21	7·30	7·40	7·49	7·60	7·70	7·81	7·92	8·03	10	2	3	5	7	8
83	8·14	8·26	8·39	8·51	8·64	8·78	8·92	9·06	9·21	9·36	14*	2	5	7	9	12
											18*	3	6	9	12	15
84	9·51	9·68	9·84	**·02**	10·20	10·39	10·58	10·78	10·99	11·20	21*	4	7	11	14	18
							10·58				*					
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95	*	For 4 figures see				
86	14·30	14·67	15·06	15·46	15·89	16·35	16·83	17·34	17·89	18·46	*	footnote §, p. 19,				
87	19·1	19·7	20·4	21·2	22·0	22·9	23·9	24·5	26·0	27·3	—	or footnote †,				
88	28·6	30·1	31·8	33·7	35·8	38·2	40·9	44·1	47·7	52·1	—	p. 13.				
89	57·3	63·7	71·6	81·8	95·5	114·6	143·2	191·0	286·5	573·0						

$\cot x° = 1/\tan x° = \tan(90° - x°)$

Bold type indicates that the integer increases.

* For interpolation to tenths (0°·01), and for more accurate interpolation to sixths (1′), for angles less than 88°, use PPs on pp 43 and 45 for the difference Δ between successive tabular values.

RECIPROCALS $1/x$ OR x^{-1}

x	0	1	2	3	4	5	6	7	8	9	Δm	1	2	3	4	5	6	7	8	9
											—	SUBTRACT								
10	10000	9901	9804 9804	9709	9615 9615	9524	9434	9346	9259 9259	9174	98 94 89* 84	10 9 9 8	20 19 18 17	29 28 27 25	39 38 36 34	49 47 44 42	59 56 53 50	69 66 62 59	78 75 71 67	88 85 80 76
11	9091	9009	8929	8850	8772 8772	8696	8621	8547 8547	8475	8403	80* 75 71 67*	8 8 7 7	16 15 14 13	24 23 21 20	32 30 28 27	40 38 36 33	48 45 43 40	56 53 50 47	64 60 57 54	72 68 64 60
12	8333	8264	8197	8130	8065	8000 8000	7937	7874	7812	7752	62* 57	6 6	12 11	19 17	25 23	31 28	37 34	43 40	50 46	56 51
13	7692	7634	7576	7519	7463	7407 7407	7353	7299	7246	7194	53*	5	11	16	21	26	32	37	42	48
14	7143	7092	7042	6993	6944	6897	6849 6849	6803	6757	6711	49* 45	5 5	10 9	15 14	20 18	24 23	29 27	34 32	39 36	44 41
15	6667	6623	6579	6536	6494	6452	6410 6410	6369	6329	6289	43 40	4 4	9 8	13 12	17 16	21 20	26 24	30 28	34 32	39 36
16	6250	6211	6173	6135	6098	6061	6024	5988	5952	5917	37*	4	7	11	15	18	22	26	30	33
17	5882	5848	5814	5780	5747	5714	5682	5650	5618	5587	33*	3	7	10	13	16	20	23	26	30
18	5556	5525	5495	5464	5435	5405	5376	5348	5319	5291	29*	3	6	9	12	15	17	20	23	26
19	5263	5236	5208	5181	5155	5128	5102	5076	5051	5025	26*	3	5	8	10	13	16	18	21	23
20	5000	4975	4950	4926	4902	4878	4854	4831	4808	4785	24	2	5	7	10	12	14	17	19	22
21	4762	4739	4717	4695	4673	4651	4630	4608	4587	4566	22	2	4	7	9	11	13	15	18	20
22	4545	4525	4505	4484	4464	4444	4425	4405	4386	4367	20	2	4	6	8	10	12	14	16	18
23	4348	4329	4310	4292	4274	4255	4237	4219	4202	4184	18	2	4	5	7	9	11	13	14	16
24	4167	4149	4132	4115	4098	4082	4065	4049	4032	4016	17	2	3	5	7	8	10	12	14	15
25	4000	3984	3968	3953	3937	3922	3906	3891	3876	3861	15	2	3	5	6	8	9	11	12	14
26	3846	3831	3817	3802	3788	3774	3759	3745	3731	3717	14	1	3	4	6	7	8	10	11	13
27	3704	3690	3676	3663	3650	3636	3623	3610	3597	3584	13	1	3	4	5	7	8	9	10	12
28	3571	3559	3546	3534	3521	3509	3497	3484	3472	3460	12	1	2	4	5	6	7	8	10	11
29	3448	3436	3425	3413	3401	3390	3378	3367	3356	3344	12	1	2	4	5	6	7	8	10	11
30	3333	3322	3311	3300	3289	3279	3268	3257	3247	3236	11	1	2	3	4	5	7	8	9	10
31	3226	3215	3205	3195	3185	3175	3165	3155	3145	3135	10	1	2	3	4	5	6	7	8	9
32	3125	3115	3106	3096	3086	3077	3067	3058	3049	3040	10	1	2	3	4	5	6	7	8	9
33	3030	3021	3012	3003	2994	2985	2976	2967	2959	2950	9	1	2	3	4	4	5	6	7	8
34	2941	2933	2924	2915	2907	2899	2890	2882	2874	2865	8	1	2	2	3	4	5	6	6	7
35	2857	2849	2841	2833	2825	2817	2809	2801	2793	2786	8	1	2	2	3	4	5	6	6	7
36	2778	2770	2762	2755	2747	2740	2732	2725	2717	2710	8	1	2	2	3	4	5	6	6	7
37	2703	2695	2688	2681	2674	2667	2660	2653	2646	2639	7	1	1	2	3	4	4	5	6	6
38	2632	2625	2618	2611	2604	2597	2591	2584	2577	2571	7	1	1	2	3	3	4	5	6	6
39	2564	2558	2551	2545	2538	2532	2525	2519	2513	2506	6	1	1	2	2	3	4	4	5	5
40	2500	2494	2488	2481	2475	2469	2463	2457	2451	2445	6	1	1	2	2	3	4	4	5	5
41	2439	2433	2427	2421	2415	2410	2404	2398	2392	2387	6	1	1	2	2	3	4	4	5	5
42	2381	2375	2370	2364	2358	2353	2347	2342	2336	2331	6	1	1	2	2	3	4	4	5	5
43	2326	2320	2315	2309	2304	2299	2294	2288	2283	2278	5	1	1	2	2	3	3	4	4	5
44	2273	2268	2262	2257	2252	2247	2242	2237	2232	2227	5	1	1	2	2	3	3	4	4	5
45	2222	2217	2212	2208	2203	2198	2193	2188	2183	2179	5	0	1	1	2	2	3	3	4	4
46	2174	2109	2165	2160	2155	2151	2146	2141	2137	2132	5	0	1	1	2	2	3	3	4	4
47	2128	2123	2119	2114	2110	2105	2101	2096	2092	2088	4	0	1	1	2	2	2	3	3	4
48	2083	2079	2075	2070	2066	2062	2058	2053	2049	2045	4	0	1	1	2	2	2	3	3	4
49	2041	2037	2033	2028	2024	2020	2016	2012	2008	2004	4	0	1	1	2	2	2	3	3	4

* For more accurate interpolation use PPs on p. 45 for the difference Δ between successive tabular values. It sometimes helps to use

$$1/x = \tfrac{1}{2} \times 1/(\tfrac{1}{2}x) \quad \text{or} \quad 1/x = 2 \times 1/(2x)$$

x	0	1	2	3	4	5	6	7	8	9	Δ_m	1	2	3	4	5	6	7	8	9
											−	SUBTRACT								
50	2000	1996	1992	1988	1984	1980	1976	1972	1969	1965	4	0	1	1	2	2	2	3	3	4
51	1961	1957	1953	1949	1946	1942	1938	1934	1931	1927	4	0	1	1	2	2	2	3	3	4
52	1923	1919	1916	1912	1908	1905	1901	1898	1894	1890	4	0	1	1	2	2	2	3	3	4
53	1887	1883	1880	1876	1873	1869	1866	1862	1859	1855	4	0	1	1	2	2	2	3	3	4
54	1852	1848	1845	1842	1838	1835	1832	1828	1825	1821	3	0	1	1	1	2	2	2	2	3
55	1818	1815	1812	1808	1805	1802	1799	1795	1792	1789	3	0	1	1	1	2	2	2	2	3
56	1786	1783	1779	1776	1773	1770	1767	1764	1761	1757	3	0	1	1	1	2	2	2	2	3
57	1754	1751	1748	1745	1742	1739	1736	1733	1730	1727	3	0	1	1	1	2	2	2	2	3
58	1724	1721	1718	1715	1712	1709	1706	1704	1701	1698	3	0	1	1	1	1	2	2	2	3
59	1695	1692	1689	1686	1684	1681	1678	1675	1672	1669	3	0	1	1	1	1	2	2	2	3
60	1667	1664	1661	1658	1656	1653	1650	1647	1645	1642	3	0	1	1	1	1	2	2	2	3
61	1639	1637	1634	1631	1629	1626	1623	1621	1618	1616	3	0	1	1	1	1	2	2	2	3
62	1613	1610	1608	1605	1603	1600	1597	1595	1592	1590	3	0	1	1	1	1	2	2	2	3
63	1587	1585	1582	1580	1577	1575	1572	1570	1567	1565	2	0	0	1	1	1	1	1	2	2
64	1562	1560	1558	1555	1553	1550	1548	1546	1543	1541	2	0	0	1	1	1	1	1	2	2
65	1538	1536	1534	1531	1529	1527	1524	1522	1520	1517	2	0	0	1	1	1	1	1	2	2
66	1515	1513	1511	1508	1506	1504	1502	1499	1497	1495	2	0	0	1	1	1	1	1	2	2
67	1493	1490	1488	1486	1484	1481	1479	1477	1475	1473	2	0	0	1	1	1	1	1	2	2
68	1471	1468	1466	1464	1462	1460	1458	1456	1453	1451	2	0	0	1	1	1	1	1	2	2
69	1449	1447	1445	1443	1441	1439	1437	1435	1433	1431	2	0	0	1	1	1	1	1	2	2
70	1429	1427	1425	1422	1420	1418	1416	1414	1412	1410	2	0	0	1	1	1	1	1	2	2
71	1408	1406	1404	1403	1401	1399	1397	1395	1393	1391	2	0	0	1	1	1	1	1	2	2
72	1389	1387	1385	1383	1381	1379	1377	1376	1374	1372	2	0	0	1	1	1	1	1	2	2
73	1370	1368	1366	1364	1362	1361	1359	1357	1355	1353	2	0	0	1	1	1	1	1	2	2
74	1351	1350	1348	1346	1344	1342	1340	1339	1337	1335	2	0	0	1	1	1	1	1	2	2
75	1333	1332	1330	1328	1326	1325	1323	1321	1319	1318	2	0	0	1	1	1	1	1	2	2
76	1316	1314	1312	1311	1309	1307	1305	1304	1302	1300	2	0	0	1	1	1	1	1	2	2
77	1299	1297	1295	1294	1292	1290	1289	1287	1285	1284	2	0	0	1	1	1	1	1	2	2
78	1282	1280	1279	1277	1276	1274	1272	1271	1269	1267	2	0	0	1	1	1	1	1	2	2
79	1266	1264	1263	1261	1259	1258	1256	1255	1253	1252	2	0	0	1	1	1	1	1	2	2
80	1250	1248	1247	1245	1244	1242	1241	1239	1238	1236	2	0	0	1	1	1	1	1	2	2
81	1235	1233	1232	1230	1229	1227	1225	1224	1222	1221										
82	1220	1218	1217	1215	1214	1212	1211	1209	1208	1206										
83	1205	1203	1202	1200	1199	1198	1196	1195	1193	1192										
84	1190	1189	1188	1186	1185	1183	1182	1181	1179	1178										
85	1176	1175	1174	1172	1171	1170	1168	1167	1166	1164										
86	1163	1161	1160	1159	1157	1156	1155	1153	1152	1151										
87	1149	1148	1147	1145	1144	1143	1142	1140	1139	1138										
88	1136	1135	1134	1133	1131	1130	1129	1127	1126	1125										
89	1124	1122	1121	1120	1119	1117	1116	1115	1114	1112										
90	1111	1110	1109	1107	1106	1105	1104	1103	1101	1100										
91	1099	1098	1096	1095	1094	1093	1092	1091	1089	1088										
92	1087	1086	1085	1083	1082	1081	1080	1079	1078	1076										
93	1075	1074	1073	1072	1071	1070	1068	1067	1066	1065										
94	1064	1063	1062	1060	1059	1058	1057	1056	1055	1054										
95	1053	1052	1050	1049	1048	1047	1046	1045	1044	1043										
96	1042	1041	1040	1038	1037	1036	1035	1034	1033	1032										
97	1031	1030	1029	1028	1027	1026	1025	1024	1022	1021										
98	1020	1019	1018	1017	1016	1015	1014	1013	1012	1011										
99	1010	1009	1008	1007	1006	1005	1004	1003	1002	1001										

x	0	1	2	3	4	5	6	7	8	9	Δm +	1	2	3	4	5	6	7	8	9
												ADD								
10	1000	1020	1040	1061	1082	1103	1124	1145	1166	1188	21	2	4	6	8	10	13	15	17	19
11	1210	1232	1254	1277	1300	1323	1346	1369	1392	1416	23	2	5	7	9	11	14	16	18	21
12	1440	1464	1488	1513	1538	1563	1588	1613	1638	1664	25	2	5	7	10	12	15	17	20	22
13	1690	1716	1742	1769	1796	1823	1850	1877	1904	1932	27	3	5	8	11	13	16	19	22	24
14	1960	1988	2016	2045	2074	2103	2132	2161	2190	2220	29	3	6	9	12	14	17	20	23	26
15	2250	2280	2310	2341	2372	2403	2434	2465	2496	2528	31	3	6	9	12	15	19	22	25	28
16	2560	2592	2624	2657	2690	2723	2756	2789	2822	2856	33	3	7	10	13	16	20	23	26	30
17	2890	2924	2958	2993	3028	3063	3098	3133	3168	3204	35	3	7	10	14	17	21	24	28	31
18	3240	3276	3312	3349	3386	3423	3460	3497	3534	3572	37	4	7	11	15	18	22	26	30	33
19	3610	3648	3686	3725	3764	3803	3842	3881	3920	3960	39	4	8	12	16	19	23	27	31	35
20	4000	4040	4080	4121	4162	4203	4244	4285	4326	4368	41	4	8	12	16	20	25	29	33	37
21	4410	4452	4494	4537	4580	4623	4666	4709	4752	4796	43	4	9	13	17	21	26	30	34	39
22	4840	4884	4928	4973	5018	5063	5108	5153	5198	5244	45	4	9	13	18	22	27	31	36	40
23	5290	5336	5382	5429	5476	5523	5570	5617	5664	5712	47	5	9	14	19	23	28	33	38	42
24	5760	5808	5856	5905	5954	6003	6052	6101	6150	6200	49	5	10	15	20	24	29	34	39	44
25	6250	6300	6350	6401	6452	6503	6554	6605	6656	6708	51	5	10	15	20	25	31	36	41	46
26	6760	6812	6864	6917	6970	7023	7076	7129	7182	7236	53	5	11	16	21	26	32	37	42	48
27	7290	7344	7398	7453	7508	7563	7618	7673	7728	7784	55	5	11	16	22	27	33	38	44	49
28	7840	7896	7952	8009	8066	8123	8180	8237	8294	8352	57	6	11	17	23	28	34	40	46	51
29	8410	8468	8526	8585	8644	8703	8762	8821	8880	8940	59	6	12	18	24	29	35	41	47	53
30	9000	9060	9120	9181	9242	9303	9364	9425	9486	9548	61	6	12	18	24	30	37	43	49	55
31	9610	9672	9734	9797	9860	9923	9986				63	6	13	19	25	31	38	44	50	57
							999	1005	1011	1018	6	1	1	2	2	3	4	4	5	5
32	1024	1030	1037	1043	1050	1056	1063	1069	1076	1082	6	1	1	2	2	3	4	4	5	5
33	1089	1096	1102	1109	1116	1122	1129	1136	1142	1149	7	1	1	2	3	3	4	5	6	6
34	1156	1163	1170	1176	1183	1190	1197	1204	1211	1218	7	1	1	2	3	3	4	5	6	6
35	1225	1232	1239	1246	1253	1260	1267	1274	1282	1289	7	1	1	2	3	4	4	5	6	6
36	1296	1303	1310	1318	1325	1332	1340	1347	1354	1362	7	1	1	2	3	4	4	5	6	6
37	1369	1376	1384	1391	1399	1406	1414	1421	1429	1436	8	1	2	2	3	4	5	6	6	7
38	1444	1452	1459	1467	1475	1482	1490	1498	1505	1513	8	1	2	2	3	4	5	6	6	7
39	1521	1529	1537	1544	1552	1560	1568	1576	1584	1592	8	1	2	2	3	4	5	6	6	7
40	1600	1608	1616	1624	1632	1640	1648	1656	1665	1673	8	1	2	2	3	4	5	6	6	7
41	1681	1689	1697	1706	1714	1722	1731	1739	1747	1756	8	1	2	2	3	4	5	6	6	7
42	1764	1772	1781	1789	1798	1806	1815	1823	1832	1840	8	1	2	2	3	4	5	6	6	7
43	1849	1858	1866	1875	1884	1892	1901	1910	1918	1927	9	1	2	3	4	4	5	6	7	8
44	1936	1945	1954	1962	1971	1980	1989	1998	2007	2016	9	1	2	3	4	4	5	6	7	8
45	2025	2034	2043	2052	2061	2070	2079	2088	2098	2107	9	1	2	3	4	5	5	6	7	8
46	2116	2125	2134	2144	2153	2162	2172	2181	2190	2200	9	1	2	3	4	5	5	6	7	8
47	2209	2218	2228	2237	2247	2256	2266	2275	2285	2294	10	1	2	3	4	5	6	7	8	9
48	2304	2314	2323	2333	2343	2352	2362	2372	2381	2391	10	1	2	3	4	5	6	7	8	9
49	2401	2411	2421	2430	2440	2450	2460	2470	2480	2490	10	1	2	3	4	5	6	7	8	9
50	2500	2510	2520	2530	2540	2550	2560	2570	2581	2591	10	1	2	3	4	5	6	7	8	9
51	2601	2611	2621	2632	2642	2652	2663	2673	2683	2694	10	1	2	3	4	5	6	7	8	9
52	2704	2714	2725	2735	2746	2756	2767	2777	2788	2798	10	1	2	3	4	5	6	7	8	9
53	2809	2820	2830	2841	2852	2862	2873	2884	2894	2905	11	1	2	3	4	5	7	8	9	10
54	2916	2927	2938	2948	2959	2970	2981	2992	3003	3014	11	1	2	3	4	5	7	8	9	10
55	3025	3036	3047	3058	3069	3080	3091	310[illegible]	3114	3125	11	1	2	3	4	6	7	8	9	10
56	3136	3147	3158	3170	3181	3192	3204	3215	3226	3238	11	1	2	3	4	6	7	8	9	10
57	3249	3260	3272	3283	3295	3306	3318	3329	3341	3352	12	1	2	4	5	6	7	8	10	11
58	3364	3376	3387	3399	3411	3422	3434	3446	3457	3469	12	1	2	4	5	6	7	8	10	11
59	3481	3493	3505	3516	3528	3540	3552	3564	3576	3588	12	1	2	4	5	6	7	8	10	11

x	0	1	2	3	4	5	6	7	8	9	Δ_m +	1	2	3	4	5	6	7	8	9
												ADD								
60	3600	3612	3624	3636	3648	3660	3672	3684	3697	3709	12	1	2	4	5	6	7	8	10	11
61	3721	3733	3745	3758	3770	3782	3795	3807	3819	3832	12	1	2	4	5	6	7	8	10	11
62	3844	3856	3869	3881	3894	3906	3919	3931	3944	3956	12	1	2	4	5	6	7	8	10	11
63	3969	3982	3994	4007	4020	4032	4045	4058	4070	4083	13	1	3	4	5	6	8	9	10	12
64	4096	4109	4122	4134	4147	4160	4173	4186	4199	4212	13	1	3	4	5	6	8	9	10	12
65	4225	4238	4251	4264	4277	4290	4303	4316	4330	4343	13	1	3	4	5	7	8	9	10	12
66	4356	4369	4382	4396	4409	4422	4436	4449	4462	4476	13	1	3	4	5	7	8	9	10	12
67	4489	4502	4516	4529	4543	4556	4570	4583	4597	4610	14	1	3	4	6	7	8	10	11	13
68	4624	4638	4651	4665	4679	4692	4706	4720	4733	4747	14	1	3	4	6	7	8	10	11	13
69	4761	4775	4789	4802	4816	4830	4844	4858	4872	4886	14	1	3	4	6	7	8	10	11	13
70	4900	4914	4928	4942	4956	4970	4984	4998	5013	5027	14	1	3	4	6	7	8	10	11	13
71	5041	5055	5069	5084	5098	5112	5127	5141	5155	5170	14	1	3	4	6	7	8	10	11	13
72	5184	5198	5213	5227	5242	5256	5271	5285	5300	5314	14	1	3	4	6	7	8	10	11	13
73	5329	5344	5358	5373	5388	5402	5417	5432	5446	5461	15	1	3	4	6	7	9	10	12	13
74	5476	5491	5506	5520	5535	5550	5565	5580	5595	5610	15	1	3	4	6	7	9	10	12	13
75	5625	5640	5655	5670	5685	5700	5715	5730	5746	5761	15	2	3	5	6	8	9	11	12	14
76	5776	5791	5806	5822	5837	5852	5868	5883	5898	5914	15	2	3	5	6	8	9	11	12	14
77	5929	5944	5960	5975	5991	6006	6022	6037	6053	6068	16	2	3	5	6	8	10	11	13	14
78	6084	6100	6115	6131	6147	6162	6178	6194	6209	6225	16	2	3	5	6	8	10	11	13	14
79	6241	6257	6273	6288	6304	6320	6336	6352	6368	6384	16	2	3	5	6	8	10	11	13	14
80	6400	6416	6432	6448	6464	6480	6496	6512	6529	6545	16	2	3	5	6	8	10	11	13	14
81	6561	6577	6593	6610	6626	6642	6659	6675	6691	6708	16	2	3	5	6	8	10	11	13	14
82	6724	6740	6757	6773	6790	6806	6823	6839	6856	6872	16	2	3	5	6	8	10	11	13	14
83	6889	6906	6922	6939	6956	6972	6989	7006	7022	7039	17	2	3	5	7	8	10	12	14	15
84	7056	7073	7090	7106	7123	7140	7157	7174	7191	7208	17	2	3	5	7	8	10	12	14	15
85	7225	7242	7259	7276	7293	7310	7327	7344	7362	7379	17	2	3	5	7	9	10	12	14	15
86	7396	7413	7430	7448	7465	7482	7500	7517	7534	7552	17	2	3	5	7	9	10	12	14	15
87	7569	7586	7604	7621	7639	7656	7674	7691	7709	7726	18	2	4	5	7	9	11	13	14	16
88	7744	7762	7779	7797	7815	7832	7850	7868	7885	7903	18	2	4	5	7	9	11	13	14	16
89	7921	7939	7957	7974	7992	8010	8028	8046	8064	8082	18	2	4	5	7	9	11	13	14	16
90	8100	8118	8136	8154	8172	8190	8208	8226	8245	8263	18	2	4	5	7	9	11	13	14	16
91	8281	8299	8317	8336	8354	8372	8391	8409	8427	8446	18	2	4	5	7	9	11	13	14	16
92	8464	8482	8501	8519	8538	8556	8575	8593	8612	8630	18	2	4	5	7	9	11	13	14	16
93	8649	8668	8686	8705	8724	8742	8761	8780	8798	8817	19	2	4	6	8	9	11	13	15	17
94	8836	8855	8874	8892	8911	8930	8949	8968	8987	9006	19	2	4	6	8	9	11	13	15	17
95	9025	9044	9063	9082	9101	9120	9139	9158	9178	9197	19	2	4	6	8	10	11	13	15	17
96	9216	9235	9254	9274	9293	9312	9332	9351	9370	9390	19	2	4	6	8	10	11	13	15	17
97	9409	9428	9448	9467	9487	9506	9526	9545	9565	9584	20	2	4	6	8	10	12	14	16	18
98	9604	9624	9643	9663	9683	9702	9722	9742	9761	9781	20	2	4	6	8	10	12	14	16	18
99	9801	9821	9841	9860	9880	9900	9920	9940	9960	9980	20	2	4	6	8	10	12	14	16	18

The decimal point must be inserted by inspection.

Examples:

$(1{\cdot}43)^2 \doteqdot 2{\cdot}045 \qquad (6{\cdot}935)^2 \doteqdot 48{\cdot}09$

$(232{\cdot}8)^2 = (2{\cdot}328 \times 10^2)^2 \doteqdot 5{\cdot}420 \times 10^4$

$(0{\cdot}007035)^2 = (7{\cdot}035 \times 10^{-3})^2 \doteqdot 49{\cdot}49 \times 10^{-6} = 0{\cdot}00004949$

SQUARE ROOTS $\sqrt{x}$ OR $x^{\frac{1}{2}}$

x	0	1	2	3	4	5	6	7	8	9	Δ_m	1	2	3	4	5	6	7	8	9
											+	ADD								
10	1000	1005	1010	1015	1020	1025	1030	1034	1039	1044	5	0	1	1	2	2	3	3	4	4
	3162	3178	3194	3209	3225	3240	3256	3271	3286	3302	16	2	3	5	6	8	10	11	13	14
11	1049	1054	1058	1063	1068	1072	1077	1082	1086	1091	5	0	1	1	2	2	3	3	4	4
	3317	3332	3347	3362	3376	3391	3406	3421	3435	3450	15	1	3	4	6	7	9	10	12	13
12	1095	1100	1105	1109	1114	1118	1122	1127	1131	1136	4	0	1	1	2	2	2	3	3	4
	3464	3479	3493	3507	3521	3536	3550	3564	3578	3592	14	1	3	4	6	7	8	10	11	13
13	1140	1145	1149	1153	1158	1162	1166	1170	1175	1179	4	0	1	1	2	2	2	3	3	4
	3606	3619	3633	3647	3661	3674	3688	3701	3715	3728	14	1	3	4	6	7	8	10	11	13
14	1183	1187	1192	1196	1200	1204	1208	1212	1217	1221	4	0	1	1	2	2	2	3	3	4
	3742	3755	3768	3782	3795	3808	3821	3834	3847	3860	13	1	3	4	5	7	8	9	10	12
15	1225	1229	1233	1237	1241	1245	1249	1253	1257	1261	4	0	1	1	2	2	2	3	3	4
	3873	3886	3899	3912	3924	3937	3950	3962	3975	3987	13	1	3	4	5	6	8	9	10	12
16	1265	1269	1273	1277	1281	1285	1288	1292	1296	1300	4	0	1	1	2	2	2	3	3	4
	4000	4012	4025	4037	4050	4062	4074	4087	4099	4111	12	1	2	4	5	6	7	8	10	11
17	1304	1308	1311	1315	1319	1323	1327	1330	1334	1338	4	0	1	1	2	2	2	3	3	4
	4123	4135	4147	4159	4171	4183	4195	4207	4219	4231	12	1	2	4	5	6	7	8	10	11
18	1342	1345	1349	1353	1356	1360	1364	1367	1371	1375	4	0	1	1	2	2	2	3	3	4
	4243	4254	4266	4278	4290	4301	4313	4324	4336	4347	12	1	2	4	5	6	7	8	10	11
19	1378	1382	1386	1389	1393	1396	1400	1404	1407	1411	4	0	1	1	2	2	2	3	3	4
	4359	4370	4382	4393	4405	4416	4427	4438	4450	4461	11	1	2	3	4	6	7	8	9	10
20	1414	1418	1421	1425	1428	1432	1435	1439	1442	1446	4	0	1	1	2	2	2	3	3	4
	4472	4483	4494	4506	4517	4528	4539	4550	4561	4572	11	1	2	3	4	6	7	8	9	10
21	1449	1453	1456	1459	1463	1466	1470	1473	1476	1480	3	0	1	1	1	2	2	2	2	3
	4583	4593	4604	4615	4626	4637	4648	4658	4669	4680	11	1	2	3	4	5	7	8	9	10
22	1483	1487	1490	1493	1497	1500	1503	1507	1510	1513	3	0	1	1	1	2	2	2	2	3
	4690	4701	4712	4722	4733	4743	4754	4764	4775	4785	11	1	2	3	4	5	7	8	9	10
23	1517	1520	1523	1526	1530	1533	1536	1539	1543	1546	3	0	1	1	1	2	2	2	2	3
	4796	4806	4817	4827	4837	4848	4858	4868	4879	4889	10	1	2	3	4	5	6	7	8	9
24	1549	1552	1556	1559	1562	1565	1568	1572	1575	1578	3	0	1	1	1	2	2	2	2	3
	4899	4909	4919	4930	4940	4950	4960	4970	4980	4990	10	1	2	3	4	5	6	7	8	9
25	1581	1584	1587	1591	1594	1597	1600	1603	1606	1609	3	0	1	1	1	2	2	2	2	3
	5000	5010	5020	5030	5040	5050	5060	5070	5079	5089	10	1	2	3	4	5	6	7	8	9
26	1612	1616	1619	1622	1625	1628	1631	1634	1637	1640	3	0	1	1	1	2	2	2	2	3
	5099	5109	5119	5128	5138	5148	5158	5167	5177	5187	10	1	2	3	4	5	6	7	8	9
27	1643	1646	1649	1652	1655	1658	1661	1664	1667	1670	3	0	1	1	1	2	2	2	2	3
	5196	5206	5215	5225	5235	5244	5254	5263	5273	5282	10	1	2	3	4	5	6	7	8	9
28	1673	1676	1679	1682	1685	1688	1691	1694	1697	1700	3	0	1	1	1	2	2	2	2	3
	5292	5301	5310	5320	5329	5339	5348	5357	5367	5376	9	1	2	3	4	5	5	6	7	8
29	1703	1706	1709	1712	1715	1718	1720	1723	1726	1729	3	0	1	1	1	1	2	2	2	3
	5385	5394	5404	5413	5422	5431	5441	5450	5459	5468	9	1	2	3	4	5	5	6	7	8
30	1732	1735	1738	1741	1744	1746	1749	1752	1755	1758	3	0	1	1	1	1	2	2	2	3
	5477	5486	5495	5505	5514	5523	5532	5541	5550	5559	9	1	2	3	4	5	5	6	7	8

The decimal point must be inserted by inspection.

Examples:

$\sqrt{1{\cdot}856} \doteqdot 1{\cdot}362$ $\quad$ $\sqrt{217{\cdot}3} \doteqdot 14{\cdot}74$

$\sqrt{27{\cdot}12} \doteqdot 5{\cdot}208$ $\quad$ $\sqrt{2930} \doteqdot 54{\cdot}13$

$\sqrt{0{\cdot}236} \doteqdot 0{\cdot}4858$ $\quad$ $\sqrt{0{\cdot}0306} \doteqdot 0{\cdot}1749$

SQUARE ROOTS $\sqrt{x}$ OR $x^{\frac{1}{2}}$

x	0	1	2	3	4	5	6	7	8	9	Δm +	1	2	3	4	5	6	7	8	9
												ADD								
31	1761	1764	1766	1769	1772	1775	1778	1780	1783	1786	3	0	1	1	1	1	2	2	2	3
	5568	5577	5586	5595	5604	5612	5621	5630	5639	5648	9	1	2	3	4	4	5	6	7	8
32	1789	1792	1794	1797	1800	1803	1806	1808	1811	1814	3	0	1	1	1	1	2	2	2	3
	5657	5666	5675	5683	5692	5701	5710	5718	5727	5736	9	1	2	3	4	4	5	6	7	8
33	1817	1819	1822	1825	1828	1830	1833	1836	1838	1841	3	0	1	1	1	1	2	2	2	3
	5745	5753	5762	5771	5779	5788	5797	5805	5814	5822	9	1	2	3	4	4	5	6	7	8
34	1844	1847	1849	1852	1855	1857	1860	1863	1865	1868	3	0	1	1	1	1	2	2	2	3
	5831	5840	5848	5857	5865	5874	5882	5891	5899	5908	9	1	2	3	4	4	5	6	7	8
35	1871	1873	1876	1879	1881	1884	1887	1889	1892	1895	3	0	1	1	1	1	2	2	2	3
	5916	5925	5933	5941	5950	5958	5967	5975	5983	5992	8	1	2	2	3	4	5	6	6	7
36	1897	1900	1903	1905	1908	1910	1913	1916	1918	1921	3	0	1	1	1	1	2	2	2	3
	6000	6008	6017	6025	6033	6042	6050	6058	6066	6075	8	1	2	2	3	4	5	6	6	7
37	1924	1926	1929	1931	1934	1936	1939	1942	1944	1947	3	0	1	1	1	1	2	2	2	3
	6083	6091	6099	6107	6116	6124	6132	6140	6148	6156	8	1	2	2	3	4	5	6	6	7
38	1949	1952	1954	1957	1960	1962	1965	1967	1970	1972	3	0	1	1	1	1	2	2	2	3
	6164	6173	6181	6189	6197	6205	6213	6221	6229	6237	8	1	2	2	3	4	5	6	6	7
39	1975	1977	1980	1982	1985	1987	1990	1992	1995	1997	2	0	0	1	1	1	1	1	2	2
	6245	6253	6261	6269	6277	6285	6293	6301	6309	6317	8	1	2	2	3	4	5	6	6	7
40	2000	2002	2005	2007	2010	2012	2015	2017	2020	2022	2	0	0	1	1	1	1	1	2	2
	6325	6332	6340	6348	6356	6364	6372	6380	6387	6395	8	1	2	2	3	4	5	6	6	7
41	2025	2027	2030	2032	2035	2037	2040	2042	2045	2047	2	0	0	1	1	1	1	1	2	2
	6403	6411	6419	6427	6434	6442	6450	6458	6465	6473	8	1	2	2	3	4	5	6	6	7
42	2049	2052	2054	2057	2059	2062	2064	2066	2069	2071	2	0	0	1	1	1	1	1	2	2
	6481	6488	6496	6504	6512	6519	6527	6535	6542	6550	8	1	2	2	3	4	5	6	6	7
43	2074	2076	2078	2081	2083	2086	2088	2090	2093	2095	2	0	0	1	1	1	1	1	2	2
	6557	6565	6573	6580	6588	6595	6603	6611	6618	6626	8	1	2	2	3	4	5	6	6	7
44	2098	2100	2102	2105	2107	2110	2112	2114	2117	2119	2	0	0	1	1	1	1	1	2	2
	6633	6641	6648	6656	6663	6671	6678	6686	6693	6701	8	1	2	2	3	4	5	6	6	7
45	2121	2124	2126	2128	2131	2133	2135	2138	2140	2142	2	0	0	1	1	1	1	1	2	2
	6708	6716	6723	6731	6738	6745	6753	6760	6768	6775	7	1	1	2	3	4	4	5	6	6
46	2145	2147	2149	2152	2154	2156	2159	2161	2163	2166	2	0	0	1	1	1	1	1	2	2
	6782	6790	6797	6804	6812	6819	6826	6834	6841	6848	7	1	1	2	3	4	4	5	6	6
47	2168	2170	2173	2175	2177	2179	2182	2184	2186	2189	2	0	0	1	1	1	1	1	2	2
	6856	6863	6870	6877	6885	6892	6899	6907	6914	6921	7	1	1	2	3	4	4	5	6	6
48	2191	2193	2195	2198	2200	2202	2205	2207	2209	2211	2	0	0	1	1	1	1	1	2	2
	6928	6935	6943	6950	6957	6964	6971	6979	6986	6993	7	1	1	2	3	4	4	5	6	6
49	2214	2216	2218	2220	2223	2225	2227	2229	2232	2234	2	0	0	1	1	1	1	1	2	2
	7000	7007	7014	7021	7029	7036	7043	7050	7057	7064	7	1	1	2	3	4	4	5	6	6
50	2236	2238	2241	2243	2245	2247	2249	2252	2254	2256	2	0	0	1	1	1	1	1	2	2
	7071	7078	7085	7092	7099	7106	7113	7120	7127	7134	7	1	1	2	3	4	4	5	6	6
51	2258	2261	2263	2265	2267	2269	2272	2274	2276	2278	2	0	0	1	1	1	1	1	2	2
	7141	7148	7155	7162	7169	7176	7183	7190	7197	7204	7	1	1	2	3	4	4	5	6	6
52	2280	2283	2285	2287	2289	2291	2293	2296	2298	2300	2	0	0	1	1	1	1	1	2	2
	7211	7218	7225	7232	7239	7246	7253	7259	7266	7273	7	1	1	2	3	3	4	5	6	6
53	2302	2304	2307	2309	2311	2313	2315	2317	2319	2322	2	0	0	1	1	1	1	1	2	2
	7280	7287	7294	7301	7308	7314	7321	7328	7335	7342	7	1	1	2	3	3	4	5	6	6

Examples: $\sqrt{37450000} = \sqrt{37{\cdot}45 \times 10^6} \doteqdot 6{\cdot}120 \times 10^3 = 6120$

$\sqrt{0{\cdot}0005328} = \sqrt{5{\cdot}328 \times 10^{-4}} \doteqdot 2{\cdot}309 \times 10^{-2} = 0{\cdot}02309$

Note that the power of 10 extracted under the root sign must always be even. If this leaves one figure before the decimal point, use the upper line of a pair: if it leaves two figures before the decimal point, use the lower line.

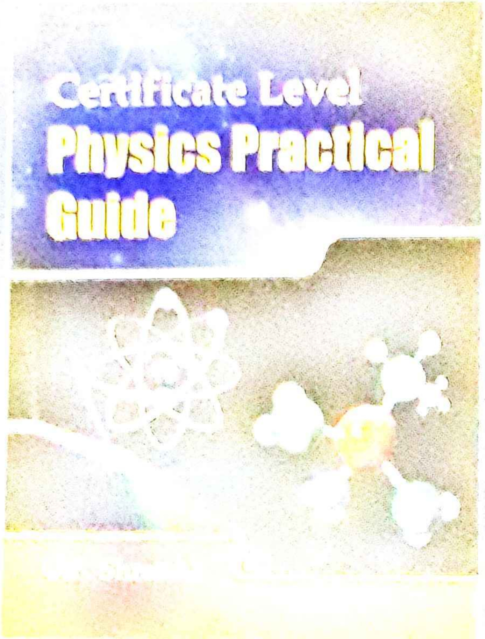
x	0	1	2	3	4	5	6	7	8	9	Δm +	1	2	3	4	5	6	7	8	9
												ADD								
54	2324	2326	2328	2330	2332	2335	2337	2339	2341	2343	2	0	0	1	1	1	1	1	2	2
	7348	7355	7362	7369	7376	7382	7389	7396	7403	7409	7	1	1	2	3	3	4	5	6	6
55	2345	2347	2349	2352	2354	2356	2358	2360	2362	2364	2	0	0	1	1	1	1	1	2	2
	7416	7423	7430	7436	7443	7450	7457	7463	7470	7477	7	1	1	2	3	3	4	5	6	6
56	2366	2369	2371	2373	2375	2377	2379	2381	2383	2385	2	0	0	1	1	1	1	1	2	2
	7483	7490	7497	7503	7510	7517	7523	7530	7537	7543	7	1	1	2	3	3	4	5	6	6
57	2387	2390	2392	2394	2396	2398	2400	2402	2404	2406	2	0	0	1	1	1	1	1	2	2
	7550	7556	7563	7570	7576	7583	7589	7596	7603	7609	7	1	1	2	3	3	4	5	6	6
58	2408	2410	2412	2415	2417	2419	2421	2423	2425	2427	2	0	0	1	1	1	1	1	2	2
	7616	7622	7629	7635	7642	7649	7655	7662	7668	7675	6	1	1	2	2	3	4	4	5	5
59	2429	2431	2433	2435	2437	2439	2441	2443	2445	2447	2	0	0	1	1	1	1	1	2	2
	7681	7688	7694	7701	7707	7714	7720	7727	7733	7740	6	1	1	2	2	3	4	4	5	5
60	2449	2452	2454	2456	2458	2460	2462	2464	2466	2468	2	0	0	1	1	1	1	1	2	2
	7746	7752	7759	7765	7772	7778	7785	7791	7797	7804	6	1	1	2	2	3	4	4	5	5
61	2470	2472	2474	2476	2478	2480	2482	2484	2486	2488	2	0	0	1	1	1	1	1	2	2
	7810	7817	7823	7829	7836	7842	7849	7855	7861	7868	6	1	1	2	2	3	4	4	5	5
62	2490	2492	2494	2496	2498	2500	2502	2504	2506	2508	2	0	0	1	1	1	1	1	2	2
	7874	7880	7887	7893	7899	7906	7912	7918	7925	7931	6	1	1	2	2	3	4	4	5	5
63	2510	2512	2514	2516	2518	2520	2522	2524	2526	2528	2	0	0	1	1	1	1	1	2	2
	7937	7944	7950	7956	7962	7969	7975	7981	7987	7994	6	1	1	2	2	3	4	4	5	5
64	2530	2532	2534	2536	2538	2540	2542	2544	2546	2548	2	0	0	1	1	1	1	1	2	2
	8000	8006	8012	8019	8025	8031	8037	8044	8050	8056	6	1	1	2	2	3	4	4	5	5
65	2550	2551	2553	2555	2557	2559	2561	2563	2565	2567	2	0	0	1	1	1	1	1	2	2
	8062	8068	8075	8081	8087	8093	8099	8106	8112	8118	6	1	1	2	2	3	4	4	5	5
66	2569	2571	2573	2575	2577	2579	2581	2583	2585	2587	2	0	0	1	1	1	1	1	2	2
	8124	8130	8136	8142	8149	8155	8161	8167	8173	8179	6	1	1	2	2	3	4	4	5	5
67	2588	2590	2592	2594	2596	2598	2600	2602	2604	2606	2	0	0	1	1	1	1	1	2	2
	8185	8191	8198	8204	8210	8216	8222	8228	8234	8240	6	1	1	2	2	3	4	4	5	5
68	2608	2610	2612	2613	2615	2617	2619	2621	2623	2625	2	0	0	1	1	1	1	1	2	2
	8246	8252	8258	8264	8270	8276	8283	8289	8295	8301	6	1	1	2	2	3	4	4	5	5
69	2627	2629	2631	2632	2634	2636	2638	2640	2642	2644	2	0	0	1	1	1	1	1	2	2
	8307	8313	8319	8325	8331	8337	8343	8349	8355	8361	6	1	1	2	2	3	4	4	5	5
70	2646	2648	2650	2651	2653	2655	2657	2659	2661	2663	2	0	0	1	1	1	1	1	2	2
	8367	8373	8379	8385	8390	8396	8402	8408	8414	8420	6	1	1	2	2	3	4	4	5	5
71	2665	2666	2668	2670	2672	2674	2676	2678	2680	2681	2	0	0	1	1	1	1	1	2	2
	8426	8432	8438	8444	8450	8456	8462	8468	8473	8479	6	1	1	2	2	3	4	4	5	5
72	2683	2685	2687	2689	2691	2693	2694	2696	2698	2700	2	0	0	1	1	1	1	1	2	2
	8485	8491	8497	8503	8509	8515	8521	8526	8532	8538	6	1	1	2	2	3	4	4	5	5
73	2702	2704	2706	2707	2709	2711	2713	2715	2717	2718	2	0	0	1	1	1	1	1	2	2
	8544	8550	8556	8562	8567	8573	8579	8585	8591	8597	6	1	1	2	2	3	4	4	5	5
74	2720	2722	2724	2726	2728	2729	2731	2733	2735	2737	2	0	0	1	1	1	1	1	2	2
	8602	8608	8614	8620	8626	8631	8637	8643	8649	8654	6	1	1	2	2	3	4	4	5	5
75	2739	2740	2742	2744	2746	2748	2750	2751	2753	2755	2	0	0	1	1	1	1	1	2	2
	8660	8666	8672	8678	8683	8689	8695	8701	8706	8712	6	1	1	2	2	3	4	4	5	5
76	2757	2759	2760	2762	2764	2766	2768	2769	2771	2773	2	0	0	1	1	1	1	1	2	2
	8718	8724	8729	8735	8741	8746	8752	8758	8764	8769	6	1	1	2	2	3	4	4	5	5

The decimal point must be inserted by inspection.

Examples:

$\sqrt{5.978} \doteqdot 2.445$ $\sqrt{67.42} \doteqdot 8.211$

$\sqrt{723.1} \doteqdot 26.89$ $\sqrt{0.7591} \doteqdot 0.8713$



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