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Units, Errors and Graphs

1.1. Units. Every physical experiment requires the *measurement* of one or more quantities. To express a quantity completely we must give the unit in which it is measured and the *number* of times this unit is contained in it. There are three *fundamental* units, namely, those of **length, mass** and **time.** The systems of fundamental units in common use are:

(*i*) **The M.K.S. system.** The units of length, mass and time on this system are *metre, kilogram* and *second* respectively.

The **metre** is the distance between the centres of two transverse lines engraved upon the polished surface of a platinum-iridium bar at the temperature of melting ice, kept at the International Bureau of Weights and Measures at Sevres near Paris.

The General Conference on Weights and Measures (1960) defines the metre as the length equal to 1,650,673.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $^2p_{10}$ and $^5d_5$ of krypton –86. The wavelength of radiation being 6057.802×10^{-10} metre.

The international **kilogram** is the mass of a cylinder of platinum-iridium kept at the International Bureau of Weights and Measures at Sevres near Paris.

The mean solar **second** is $\frac{1}{24 \times 60 \times 60} = \frac{1}{86400}$ th part of the mean solar day.

The General Conference on Weights and Measures (1960) defines a second as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of caesium-133 atom.

(*ii*) **The C.G.S. system.** The units of length, mass and time on this system are *centimetre, gram* and *second* respectively.

A **centimetre** is one hundredth $\left(\frac{1}{100}\right)$ part of a standard metre.

A **gram** is one thousandth $\left(\frac{1}{1000}\right)$ part of the international kilogram.

For all practical purposes one gram is the mass of 1 cc of pure water at 4°C.

(*iii*) **S.I. units.** The international system of units briefly written as **S.I.** has six fundamental units

(*i*) Unit of length	Metre (m)
(*ii*) Unit of mass	Kilogram (kg)
(*iii*) Unit of time	Second (s)
(*iv*) Unit of current	Ampere (A)
(*v*) Unit of thermodynamic temperature	Kelvin (K)
(*vi*) Unit of luminous intensity	Candela (Cd)

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The metre, kilogram and second have already been defined.

The **ampere** is the strength of that constant current which flowing through each of the two parallel and straight conductors of infinite length and negligible cross-section placed exactly one metre apart in vacuum exert a mutual force of 2×10^{-7} newton per metre of their length.

The **kelvin** is $\frac{1}{273.16}$ of thermodynamic temperature of the triple point of water.

The **candela** is the luminous intensity in a perpendicular direction of a surface 1/600,000 square metre of a black body at a temperature of freezing platinum under a pressure of 101.325 newton per sq. metre.

Most of the quantities are measured in units, the magnitude of which depends upon those of fundamental units of length, mass and time. These units are called *derived units*. As an example, the S.I. unit of area is a square metre which is the area of a square of side one metre in length. Some of the derived units are given special names. For example, the *S.I. unit* of force is called a newton and the *S.I.* unit of work a *Joule*. When no special name has been given to a unit it is expressed in terms of the fundamental units, *e.g.*, acceleration is stated as '*metre per second per second*'.

1.2. Errors. There is some error or the other in every measurement we make. The errors are of two kinds:

(*i*) Errors due to known causes (systematic errors).

(*ii*) Errors due to unknown causes (random errors).

(*i*) **Errors due to known causes.** Some important causes of such errors are given below :—

(*a*) Error due to the temperature of the measuring scale being different from that at which it was graduated.

(*b*) Error due to buoyancy of air which arises when a large body is weighed.

(*c*) Error in measuring time with a stop watch, the watch running either too slow or too fast.

(*d*) Error due to radiation loss or gain in calorimetric experiments.

(*e*) Zero error in various measuring instruments.

All such errors can be eliminated by suitable methods since we know the cause *e.g.*, the error due to buoyancy can be calculated from the density of the weights, density of the substance and the density of air; the error in a stop watch can be checked by comparison with a standard chronometer; the radiation error can be minimised by suitable means or calculated by the preliminary experiment and the zero error can also be measured.

(*ii*) **Errors due to unknown causes.** If an observation is repeated a number of times by the same person under similar conditions, it is found that every time a different reading is obtained, even though the instrument used is very sensitive and accurate and the observer is an experienced one. These errors are not due to any definite cause. We, therefore, cannot depend upon a single observation.

When a large number of observations are taken it is likely that some of them may have a value slightly greater than the correct value and an equal number may have a value slightly less than the correct value. This is why it is recommended that each observation must be repeated at least three times.

The effect of random error may, therefore be minimised by taking a number of measurements of the quantity to be determined and using the *arithmetic mean* of the measured values as the best estimate of the true value of the quantity.

Thus if n measurements of the quantity are made, all equally reliable and the measured values are $X_1, X_2, \ldots\ldots X_n$, then

$$\text{Arithmetic mean } \bar{X} = \frac{1}{n}(X_1 + X_2 + \ldots.. X_n) = \frac{1}{n}\sum_{i=1}^{n} X_i$$

The *true value* is defined as the mean value of an *infinite* set of measurements made under constant conditions and is denoted by μ. In practice, it is not possible to make an infinite number of observations. Hence when the number of observations is *sufficiently large*,

True value $\mu \cong$ Mean value $\overline{X}$

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 mean value $\overline{X}$. If the values are widely dispersed or the observed values have a large deviation from the true value, the precision is said to be *low*.

The deviation $\delta_i = X_i - \overline{X}$

Average deviation. The average value of the deviation of all the individual measurements from the arithmetic mean is known as *average deviation* and is denoted by $\overline{d}$

$$\therefore \quad \text{Average deviation} \quad \overline{d} = \frac{(X_1 - \overline{X}) + (X_2 - \overline{X}) \; \ldots\ldots + (X_n - \overline{X})}{n}$$

$$= \frac{\delta_1 + \delta_2 + \ldots\ldots \delta_n}{n}$$

$$= \frac{\Sigma \delta_i}{n}$$

Standard deviation. The square root of the mean square deviation for an infinite set of measurements is known as *standard deviation* (or root mean square deviation) and is denoted by σ.

When the number of observations n is sufficiently large

$$\sigma \cong \sqrt{\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 \ldots\ldots (X_n - \overline{X})^2}{n-1}}$$

$$= \sqrt{\frac{\delta_1^2 + \delta_2^2 + \ldots\ldots \delta_n^2}{n-1}} = \sqrt{\frac{S}{n-1}}$$

where

$$S = (X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 \ldots\ldots (X_n - \overline{X})^2$$

$$= \delta_1^2 + \delta_2^2 + \ldots\ldots \delta_n^2 = \sum_{i=1}^{n} \delta_i^2$$

For a fairly large sample of measurements which have a reasonably normal distribution about the mean value $\overline{X}$

$$\frac{\text{Average deviation}}{\text{Standard deviation}} = \frac{\overline{d}}{\sigma} \cong 0.80$$

Standard error. The quantity $\frac{\sigma}{\sqrt{n}}$ is known as *standard error* and is denoted by σ_m

$$\therefore \text{ Standard error} \quad \sigma_m = \sqrt{\frac{(X_1 - X)^2 + (X_2 - X)^2 \ldots\ldots (X_n - X)^2}{n\,(n-1)}}$$

$$= \sqrt{\frac{S}{n\,(n-1)}}$$

The normal law of errors predicts that the probability that the mean value obtained from a finite number of observations n may be in the interval $\mu \pm \sigma_m$ is 0.68, that it may lie between $\mu \pm 2\sigma_m$ is 0.95 and for it to lie between $\mu \pm 3\sigma_m$ is 0.99.

Probable error. The probable error is a quantity e such that it is an even chance whether true value of the quantity measured differs from the mean value by an amount greater or less than e. For example, if 5.45 is the mean of all the determinations of the density of the earth and 0.25 is the probable error, then it means that there is an even chance that the density of earth lies between 5.20 (5.45 – 0.25) and 5.70 (5.45 + 0.25). It also implies that the chance that the value of the mean density of the earth may differ from the mean value by more than 4 or 5 times the probable error is very remote.

On the basis of the theory of probability it can be shown that

$$\text{Probable error} = \pm\ 0.6745 \sqrt{\frac{S}{n\,(n-1)}}$$

$$= \pm\ 0.6745 \text{ standard error}$$

where 0.6745 is a natural constant.

Let us consider the following values for the radius of curvature of the surface of a convex lens with a spherometer.

No.	*Radius of curvature*	δ	δ^2
1	15.25	–.07	.0049
2	15.42	+.10	.0100
3	15.30	–.02	.0004
4	15.20	–.12	.0144
5	15.35	+.03	.0009
6	15.40	+.08	.0064

Mean radius of curvature = 15.32

$$S = \delta_1^2 + \delta_2^2 \ldots + \delta_n^2$$

$$= 0.0370$$

$$\text{Standard deviation } \sigma = \sqrt{\frac{S}{n-1}}$$

$$= \sqrt{\frac{0.0370}{5}} = 0.0860$$

$$\text{Standard error} \quad \sigma_m = \sqrt{\frac{S}{n\,(n-1)}}$$

$$= \sqrt{\frac{.0370}{6 \times 5}} = 0.03512$$

$$\text{Hence probable error } \pm\ 0.6745 \times \sigma_m = \pm\ .6745 \sqrt{\frac{0.0370}{6 \times 5}} = \pm\ 0.0237$$

$\therefore$ Radius of curvature = 15.32 ± 0.0237

1.3. Degree of accuracy. In an experiment all observations must be taken to the same "*degree of accuracy*". It is no use taking some observations to a much higher degree of accuracy than the rest of the observations because it will not make the result more accurate. The accuracy of the result is the same as that of the '*least accurate observation*'. It does not mean that the observations should not be taken accurately, but a *careful sense of proportion must be used*. For example, in the determination of specific heat by the method of mixtures it is useless to find the weight of the liquid in the calorimeter correct up to a fraction of a milligram. It is because apart from the errors due to the defects in the balance and the weights, it is not possible to measure the temperature to the desired accuracy. Great

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care, therefore, should be taken in reading the thermometer. To increase the accuracy practice should be made in estimating the temperature to at least 1/10th of a degree.

Percentage error. The students should have an idea of percentage error. For example, in the above experiment if the weight of the calorimeter is 50 gm an error of 5 mgm in the weight will mean only an error of .01%. The rise in the temperature is, however, only about 10°C and even if measured accurately up to one-tenth of a degree will cause an error of 1% which is 100 times as large as the error in the measurement of the weight.

1.4. Effect of combining errors. All observed values are subjected to mathematical treatment to find the results. *It is not possible to produce greater accuracy by mathematical manipulation*. The following are some of the important points:

(*i*) *Addition and subtraction*. Suppose the quantities having their *true values* a and b have *measured values* $a \pm \delta a$ and $b \pm \delta b$ respectively *where* δa *and* δb are their *absolute errors*. To find the error δQ in the *sum* $Q = a + b$, we have

$$Q \pm \delta Q = (a \pm \delta a) + (b \pm \delta b)$$
$$= (a + b) + (\pm \delta a \pm \delta b)$$

$$\therefore \quad \delta Q = \delta a + \delta b$$

To find the error in the difference $Q = a - b$, we have

$$Q \pm \delta Q = (a \pm \delta a) - (b \pm \delta b)$$
$$= (a - b) + (\pm \delta a \pm \delta b)$$

The maximum error in Q is again given by

$$\delta Q = \delta a + \delta b$$

Thus we find *that when two quantities are added or subtracted the absolute error in the final result is the sum of the absolute errors in the quantities*.

Example 1. Resistance $R_1 = 100 \pm 2$ ohm

Resistance $R_2 = 200 \pm 3$ ohm

Equivalent resistance when connected in series

$$R = (100 \pm 2) + (200 \pm 3)$$
$$= 300 \pm 5 \text{ ohm}$$

Example 2. Mass of a bulb with air $= 66.928 \pm .001$ gm

Mass of empty bulb $= 66.682 \pm .001$ gm

$\therefore$ Mass of air $= 0.246 \pm .002$ gm

Though the mass of air has been found by subtraction the errors are added.

(*ii*) *Multiplication and division*. Suppose the quantity $Q = ab$ and measured values of a and b are $a \pm \delta a$ and $b \pm \delta b$ respectively, then

$$Q \pm \delta Q = (a \pm \delta a)\ (b \pm \delta b) = ab \pm b\delta a \pm a\delta b \pm \delta a \delta b.$$

Dividing *L.H.S.* by Q and the *R.H.S.* by ab, as $Q = ab$, we have

$$1 \pm \frac{\delta Q}{Q} = 1 \pm \frac{\delta a}{a} \pm \frac{\delta b}{b}$$

neglecting $\pm \frac{\delta a}{a} \cdot \frac{\delta b}{b}$ which is the product of two very small quantities. Hence the *maximum* error in Q is given by

$$\frac{\delta Q}{Q} = \frac{\delta a}{a} + \frac{\delta b}{b}$$

and expressed as percentage error

$$\frac{\delta Q}{Q} \times 100 = \frac{\delta a}{a} \times 100 + \frac{\delta b}{b} \times 100$$

If the quantity $Q = a/b$, then also

$$Q \pm \delta Q = (a \pm \delta a)\ (b \pm \delta b)^{-1} = ab^{-1} + b^{-1}\,\delta a + ab^{-2}\,\delta b$$

Dividing L.H.S. by Q and R.H.S by ab^{-1} as

$$Q = a/b = ab^{-1} \text{ we have } 1 \pm \frac{\delta Q}{Q} = 1 \pm \frac{\delta a}{a} \pm \frac{\delta b}{b}$$

Hence the maximum error in Q

$$\frac{\delta Q}{Q} = \frac{\delta a}{a} + \frac{\delta b}{b}$$

and expressed as percentage

$$\frac{\delta Q}{Q} \times 100 = \frac{\delta a}{a} \times 100 + \frac{\delta b}{b} \times 100.$$

Thus *if the result Q is the product or quotient of two measured quantities a and b the fractional or percentage error in Q is the sum of the fractional or percentage errors in a and b.*

Example 1. Capacity of a capacitor $C = 2 \pm 0.1$ Farad

Applied voltage $V = 25 \pm 0.5$ Volt

$\therefore$ Charge on the capacitor $Q = CV = 2 \times 25 = 50$ coulomb

Percentage error in $C = \frac{0.1}{2} \times 100 = 5\%$

Percentage error in $V = \frac{0.5}{25} \times 100 = 2\%$

$\therefore$ Percentage error in $Q = 5 + 2 = 7\%$

or Error in $Q = 50 \times \frac{7}{100} = 3.5$ coulomb

Hence charge on the capacitor $Q = 50 \pm 3.5$ coulomb.

Example 2. Mass of an object $M = 345.1 \pm 0.1$ gm

Volume of the object $V = 41.55 \pm 0.05\ \text{cm}^3$

Density of the object $D = \frac{M}{V} = \frac{345.1}{41.55}$

$= 8.31\ \text{gm/cm}^3$

Percentage error in $M = \frac{0.1}{345.1} \times 100 = 0.03\%$

Percentage error in $V = \frac{0.05}{41.55} \times 100 = 0.12\%$

$\therefore$ Percentage error in $D = 0.03 + 0.12 = 0.15\%$

or Error in density $D = 8.31 \times \frac{0.15}{100} = 0.012\ \text{gm/cm}^3$

Hence density of the object $= 8.31 \pm .012\ \text{gm/cm}^3$

As a corollary, it follows that if the *result Q is some power n of a measured quantity a, then the fractional or percentage error in Q is n times the fractional or percentage error in a.*

(*iii*) *General case.* The final result of an experiment is generally calculated from a set of observations taken with a number of measuring instruments and connected by means of a formula, the process requiring the use of multiplication and division. It can be shown that all the quantities do not affect the result equally. Some affect more than others do. For example, consider a quantity Q which depends upon other quantities a, b and c connected by the relation

$$Q = ka^x b^y c^z$$

where k is a constant and x, y, z are numerical values, then

$$\frac{\delta Q}{Q} = x\frac{\delta a}{a} + y\frac{\delta b}{b} + z\frac{\delta c}{c}$$

or Percentage error in $Q = x$ times the % error in a plus y times the % error in b plus z times the % error in c.

Thus the effect on the final result is greater for the factor having higher power than that having smaller power. If in the above case x is the higher power the quantity a must be measured with the greatest possible accuracy to make δa as small as possible.

The area of a square is given by

$$A = l^2$$

$$\therefore \qquad \frac{\delta A}{A} = 2\frac{\delta l}{l}$$

In other words, if the length of the side of a square is measured and found to be 10 cm and this measurement has a possible percentage error of $\pm\ 0.5$, then the value of the area will have a possible error of $2 \times 0.5 = 1\%$.

To find the value of g by a simple pendulum, we have

$$g = 4\pi^2 \frac{l}{t^2}$$

$$\therefore \qquad \frac{\delta g}{g} = \frac{\delta l}{l} - 2\frac{\delta t}{t}$$

Hence a slight error in the measurement of the time period t will produce double the error in the result. The time period, therefore, should be measured very accurately.

To find the viscosity of a liquid by Poiseuille's formula, we have

$$\eta = \frac{\pi p r^4}{8lv}$$

$$\therefore \qquad \frac{\delta\eta}{\eta} = \frac{\delta p}{p} + 4\frac{\delta r}{r} - \frac{\delta l}{l} - \frac{\delta v}{v}.$$

In the case of random errors *i.e.* errors due to unknown causes the sign should be chosen in such a manner as to give maximum error.

$$\therefore \qquad \frac{\delta\eta}{\eta} = \frac{\delta p}{p} + 4\frac{\delta r}{r} + \frac{\delta l}{l} + \frac{\delta v}{v}.$$

It is to be noted that an error in the measurement of the radius of the capillary tube is magnified 4 times in the final result.

This is why in experiments where the quantities to be measured are raised to some power, *the quantity with the highest power should be measured with greatest possible accuracy.*

Significant figures. The number of significant figures to which the final result of an experiment should be stated depends upon the nature of the experiment and the accuracy with which the various measurements have been made. For example, in the measurements of the value of g at a place it is not desirable to write it as 980.432 cm/sec^2 because the length and the time period are not measured with the desired accuracy. Moreover, the various other sources of error, *e.g.*, friction due to air, amplitude not in one plane etc., cannot be removed.

In cases where the numbers dealt with are very large as 1053000000000 it may be written as 10.5×10^{11} if the accuracy is 1 in 100, and as 10.53×10^{11} if the accuracy is 1 in 1000.

Thus the number of significant figures automatically gives the accuracy of the result.

Result. Students often attach a great importance to the result of an experiment. They are usually alarmed when they find a large error in the result. But it is the *percentage error* that matters and not the *absolute error* as is clear from examples given below :

(*i*) In an experiment on the determination of 'g' the acceleration due to gravity, the result is 9.6 ms^{-2}. This result has an error of $9.8 - 9.6 = 0.2$ ms^{-2}.

(*ii*) In an experiment on the determination of specific gravity of common salt the result is 2.37 instead of 2.17. This result has an error of $2.37 - 2.17 = 0.20$.

It is clear that the absolute error in both the experiments is the same, but it does not mean that percentage accuracy is the same.

The percentage accuracy in the first case is $\frac{0.2}{9.8} \times 100 = 2\%$ (nearly)

and in the second case it is $\frac{0.20}{2.17} \times 100 = 9\%$ (nearly)

1.5. Graph. Physical laws express relationship between various physical quantities. These relationships can easily be expressed by means of graphs.

A graph is a pictorial representation of experimental data in the form of a curve which makes visible, at a glance, the main features of the relationship between two variables.

One of the two variable quantities is varied at will, generally in convenient equal steps and the corresponding values of the second variable quantity are observed experimentally. The corresponding values of the two quantities obtained are plotted on a squared paper and a graph is obtained. The quantity which is varied at will is called **independent variable** and the other which varies as a result of variation in the first is called **dependent variable.** As a general rule independent variable is plotted along the X-axis while the dependent variable is plotted along the Y-axis.

Plotting of a graph. The following rules must be observed to plot a good graph.

1. *Find the independent and the dependent variables. Represent the independent variable along the X-axis and the dependent variable along the Y-axis.*

Examples. (*i*) In an experiment with a simple pendulum the time period is measured for different lengths by changing the length. The *length* is the independent variable and *the time period* the dependent variable.

(*ii*) In the verification of Boyle's law where the volume is measured for various values of pressure, *the pressure* is the independent variable and *volume* (or $1/V$) the dependent variable.

(*iii*) In the experiment on the determination of Young's modulus where the extension of the wire is measured for various loads, *load* is the independent variable and extension the dependent variable.

2. *Determine the range of each of the variables* and count the number of big squares available for each along the two axes.

3. **Scale.** Choose a convenient scale for both the variables. It is not essential to have *the same scale for both*. The scale should neither be too narrow nor too wide. If the scales are too wide the irregularities due merely to experimental errors will become very much magnified and the shape of the graph will not be proper. If the scales are too narrow the points corresponding to accurate observations cannot be plotted with the same degree of accuracy. For convenience one big square should represent 1, 2, 10 or their multiples by any positive or negative power of 10.

A study of the specimen graph between P and $1/V$ for air in Fig. 0.1 shows that the pressure varies from 64.00 to 88.75 cm. Since pressure is the independent variable it is represented along the X-axis. The range of pressure lies roughly between 60 cm and 90 cm. There are seven big squares and the most convenient scale is to represent *one* big square by 5 cm thus utilising 6 squares.

Reciprocal of volume $1/V$ is the dependent variable and is represented along the Y-axis. The value of $1/V$ varies from .045 to .062. There are 10 big squares and the most convenient scale is to represent *one* big square by .002 thus utilising 9 squares.

Students sometimes unnecessarily trouble themselves in plotting and also make it less easy to read the values from the curves by selecting an inconvenient scale, *e.g.*, in the above case one big square equal to 4 will utilise more squares but will be an unwise choice.

4. **Origin.** If the relation between the two variables begins from zero or if it is desired to find the zero position on one of the variables where actual determination is not possible, then *zero must be taken at the origin on both the scales.*

In all other cases it is not necessary to take zero at the origin. When it is desired simply to test the proportionality of one quantity to the other the origin on both the axes should represent a **quantity a little less than the smallest value of the corresponding variable.**

In the specimen graph of Boyle's law the origin should be 60 along the X-axis and .044 along the Y-axis which represent pressure P and the reciprocal of volume $1/V$ respectively.

Of course, it will be more complicated to take the actual least value of the two variables at the origin.

5. The quantities to be plotted along X-axis and Y-axis should be given on the top of the graph in a tabular form.

6. Do not write all the values along the respective axes but only mark the ends of the thicker lines to indicate the values of the variables in round numbers. For example, in the graph Fig. 0.1 round values of pressure 60, 65, 70 etc. and those of $1/V$ .044, .046, .048 etc., are indicated along the respective axes.

7. Draw a small circle round each of the plotted points or put a cross mark neatly. Join the plotted points by a regular free hand curve and not by zig-zag lines from one point to the other. Maximum number of points should lie on the curve and the remaining points should be situated symmetrically on either side of it.

8. Take at least six observations (preferably more) whenever a graph is to be plotted. The range of observations should be as wide as possible.

Uses. 1. The graphs are used to extrapolate certain quantities beyond the limits of observations of the experiment, *e.g.* absolute zero can be determined by plotting a graph between pressure and temperature at constant volume. By extrapolating, the temperature at which pressure becomes zero is found and that gives the value of the absolute zero. In this case, it is evident that origin must be zero on both the axes.

2. Verification of certain laws can best be represented by graphs. There is always a mathematical relationship between the two variables. It may be simple or a complex relation. For the purpose of verification of a law the graphs may be divided into two groups.

(*i*) **Straight line graphs.** A straight line graph is very easy to interpret. The equation of a straight line is

$$y = mx + c$$

where y is the dependent variable, x the independent variable, m the slope or the gradient and c the intercept on the Y-axis.

If the graph plotted is a straight line, we can evaluate the constants m and c and thus we can find the relation that exists. For example, if we plot a graph between E the potential difference across the ends of a conductor and I the current through it the graph is a straight line passing through the origin. If the slope of the straight line is represented by a constant R (intercept c being zero) the relation can be put in the form

$$\frac{E}{I} = R \text{ (a constant)}$$

This is the statement of Ohm's law.

(*ii*) **Graphs which are not straight lines.** If the graph is not a straight line, there still may be a simple equation that gives the relation between the independent and the dependent variables. The relation can be converted into linear one by changing the variable, thus giving a straight line graph.

It should, however, be clearly understood that we do not at all change the *quantity* which is variable in the experiment. For example, in the experiment on verification of Boyle's law the independent variable is the *pressure* P and the dependent variable is the *volume* V. According to Boyle's law

$$PV = k \text{ (constant)}$$

The graph between P and V will not be a straight line. To get a straight line the relation is put in the form

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

which shows that a graph between P and $1/V$ will be a straight line. It is for this reason that the specimen graph has been plotted between P and $1/V$.

Similarly in the verification of Newton's law of cooling a straight line graph is obtained by plotting *log of excess of temperature* and *time* and thus the law is verified.

In practice the matters often are not as simple as given above particularly when we do not know the relation that exists and we are required to find it out. If y varies as some power of x, say

$$y \propto x^m$$

then the best method is to plot $\log y$ (dependent variable) against $\log x$ (independent variable). Slope of the straight line gives the power of x in the original relation. To understand the theory suppose the relation is

$$y \propto x^m$$

or
$$y = kx^m$$

then
$$\log y = m \log x + \log k$$

or
$$\log y = m \log x + c \qquad ...(i)$$

where c is another constant.

Hence a graph between $\log y$ *as dependent variable and* $\log x$ as an independent variable is a straight line.

Also consider the relation

$$y = b\, a^{kx}$$

where a, b and k are constants

$$\therefore \qquad \log y = \log b + kx \log a$$

or
$$\log y = \log b + (k \log a)\, x$$

Substituting $\log b = c$

and $k \log a = m$

where c and m are also constants, we get

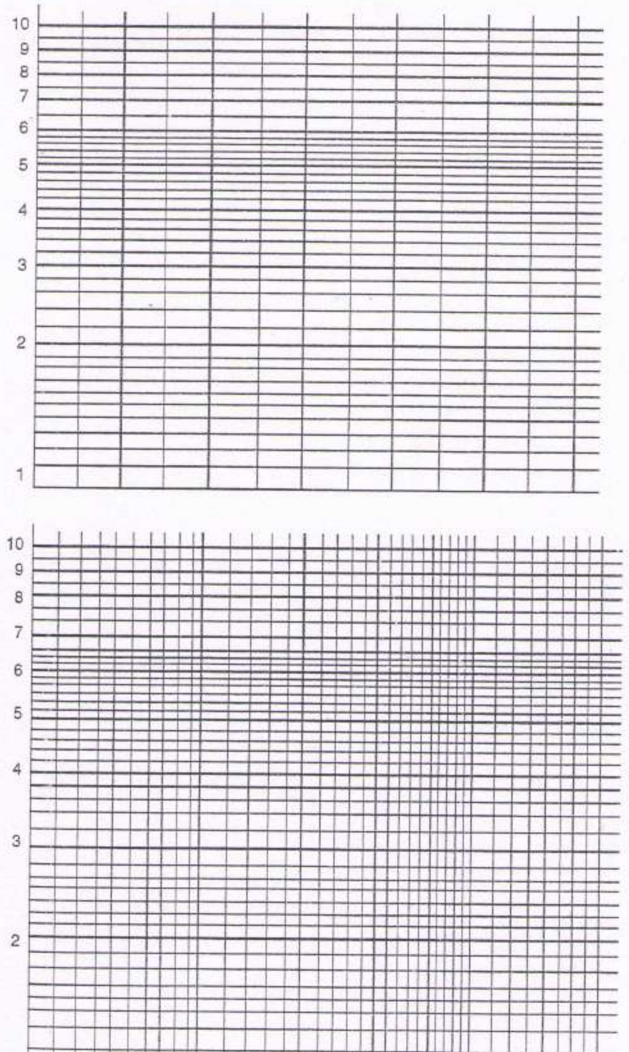
$$\log y = mx + c \qquad ...(ii)$$

Hence a graph between $\log y$ as dependent variable and x as independent variable is a straight line.

3. Graphs are used to calibrate or graduate a given instrument for ready calculations. For example, a graph is plotted between galvanometer deflection and temperature for a thermocouple to calibrate it and find any temperature from the graph.

4. A graph is used to find the mean value from a large number of observations. For example, in the experiment with a simple pendulum the mean value of l/t^2 is found from the graph and the value of g calculated from it. The method has the advantage that we can see at a glance whether the determination is likely to be a reliable one by noting how closely the plotted points lie with respect to the mean line. Any point which lies at a large distance may be ignored as it represents an observation which has some abnormal error. If time and conditions of the experiment allow, the observations may be repeated.

5. A graph is used to find the maximum and minimum values of the dependent variable. For example, we find the value of minimum deviation by plotting a graph between i the angle of incidence and D the corresponding angle of deviation.



Semi-log

Log-log

Fig. 1.1

Limitations of a graph. Although a graph is a good method of *visualising* the results of an experiment yet it is not the best method of finding the value of a constant. A graph enables us to see how closely the plotted points lie on a straight line and helps us to reject a point which lies a long way from the mean line.

Normally a great difficulty is experienced in drawing the *mean line* and also in deciding which points to lie on the line. Thus a number of lines having different slopes may be drawn which may appear equally good with respect to the plotted points but give different values of the constant to be calculated. Hence when the experiment is used to find the accurate value of a quantity graphical analysis should be supplemented by a calculation based on the most accurate set of observations yielding concordant results.

1.6. Special type of graph papers. Special type of graph papers are available which facilitate the plotting of logarithm of quantities. In such graph papers the distances of markings along the axes are not uniform but proportional to the logarithm of numbers. When one axis is marked logarithmically and the other axis is uniform the paper is called **semi-log** graph paper. It is used for plotting graphs of the type

$$\log y = mx + c$$

If both the axes are marked logarithmically it is called a **log-log** graph paper. It is used for plotting graphs of the type $\log y = m \log x + c$.

Both the types of graph papers are shown in Fig. 1.1.

Experiment 1.1. Fit the given data to a straight line graph and calculate from the given observations (*i*) Standard deviation (*ii*) Standard error and (*iii*) probable error.

Data The experimental data for the determination of acceleration due to gravity (g) by a simple pendulum is as under

Length l in cm	62.0	72.0	85.0	100.0	112.0	120.0	134.0	148.0
Time period t in sec.	1.58	1.71	1.85	2.01	2.12	2.20	2.32	2.44

(*i*) **Plotting of graph.** For a simple pendulum time period is given by the relation

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

$$\therefore \quad t^2 = \frac{4\pi^2}{g} l$$

This is an equation of the type $y = mx + c$ where $t^2 = y$, $\frac{4\pi^2}{g} = m$, $l = x$ and $c = 0$.

Thus a graph between l and t^2 will be a straight line. The slope of the line is $\frac{4\pi^2}{g}$.

To plot the graph between l and t^2 and to find the standard deviation and standard and probable error we tabulate the above data as under.

No.	*Length l in cm*	*Time period 't' in seconds*	t^2	$\frac{l}{t^2}$	$g = \frac{4\pi^2 l}{t^2}$ *in cm* s^{-2}
1.	62.0	1.58	2.496	24.84	$x_1 = 980.90$
2.	72.0	1.71	2.924	24.62	$x_2 = 972.21$
3.	85.0	1.85	3.422	24.84	$x_3 = 980.90$
4.	100.0	2.01	4.040	24.75	$x_4 = 977.34$
5.	112.0	2.12	4.494	24.92	$x_5 = 984.06$
6.	120.0	2.20	4.840	24.79	$x_6 = 978.82$
7.	134.0	2.32	5.382	24.90	$x_7 = 983.27$
8.	148.0	2.44	5.953	24.86	$x_8 = 981.69$

— Mean value of $g = 979.91$ cm s^{-2} —

To plot the graph:–

(*i*) As l is the independent variable it is taken along the X-axis. t^2 is the dependent variable it is taken along the Y-axis.

(*ii*) The scale along the X-axis is 1 small division = 2 cm and along Y-axis 1 small division is $t^2 = 0.1$ sec^2. The origin is taken as $l = 50$ and $t^2 = 2.0$.

(*iii*) Plotting various points and joining them we get a straight line as shown in Fig. 1.2.

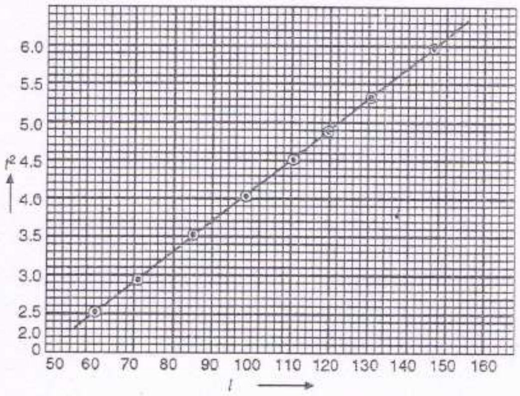


Fig. 1.2

(*ii*) **Determination of standard deviation.** To calculate the standard deviation we subtract the mean value of 'g' found in the above case from each of the individual calculated value *i.e.* X_1, X_2, X_3 etc.

Mean value of g, $\overline{X} = 979.91$ cm s^{-2}

No.	$X - \overline{X}$	δ	δ^2
1.	$\delta_1 = 980.90 - 979.91$	+ 0.99	0.98
2.	$\delta_2 = 972.21 - 979.91$	− 7.70	59.29
3.	$\delta_3 = 980.90 - 979.91$	+ 0.99	0.98
4.	$\delta_4 = 977.34 - 979.91$	− 2.57	6.60
5.	$\delta_5 = 984.06 - 979.91$	+ 4. 15	17.22
6.	$\delta_6 = 978.92 - 979.91$	− 0.99	0.98
7.	$\delta_7 = 983.27 - 979.91$	+ 3.36	11.29
8.	$\delta_8 = 981.69 - 979.91$	+ 1.78	3.17

$$\Sigma \delta^2 = \delta_1^2 + \delta_2^2 + \delta_3^2 + \delta_4^2 + \delta_5^2 + \delta_6^2 + \delta_7^2 + \delta_8^2 = 100.51$$

Number of observations $\quad n = 8$

Standard deviation $\sigma = \sqrt{\frac{\Sigma\,\delta^2}{n-1}} = \sqrt{\frac{100.51}{7}} = 3.7893$

Standard error. Standard error $\sigma_m = \sqrt{\frac{\Sigma\,\delta^2}{n\,(n-1)}}$

$$\therefore \qquad \sigma_m = \sqrt{\frac{100.51}{8 \times 7}} = 1.3397$$

Probable error. Probable error $= \pm\,0.6745\,\sqrt{\frac{\Sigma\,\delta^2}{n\,(n-1)}}$

$= \pm\,0.6745 \times$ standard error

$= \pm\,0.6745 \times 1.3397 = \pm\,0.9036$

$\therefore$ Value of $g = 979.91 \pm 0.9036\,\text{cm}\,s^{-2}$.

ACTVITIES

1.(i) AIM : TO FIND INTERNAL VOLUME, EXTERNAL VOLUME AND VOLUME OF MATERIAL OF A CALORIMETER USING VERNIER CALLIPERS

Apparatus Required. Vernier callipers, calorimeter.

Theory. This device was invented by Pierre Vernier, a Belgian mathematician. It consists of two scales, the main scale and the vernier scale. The least count of main scale is 1 mm and it is graduated in centimeters. Normally main scale can read upto 15 cm. The vernier scale can slide along the main scale and it has equally spaced ten divisions only.

(*i*) **Vernier constant (V.C.).** It is the least count of vernier callipers and can be defined as the minimum length, that can be measured accurately with the help of a vernier.

Vernier constant of vernier callipers is equal to the difference between the value of one main scale division and one vernier scale division.

$$\text{V.C.} = \text{Value of 1 MSD} - \text{Value of 1 VSD} \quad \text{...(1)}$$

Consider figure (1). Here 10 divisions on vernier scale coincide with 9 divisions on main scale. Since both scales are linear (*i.e.* evenly spaced divisions), so one VSD is proportional to one MSD. This is in fact the principle of working of vernier callipers, *i.e.* the least counts of two linear scales are directly proportional to each other. Thus from fig. (1), we can write

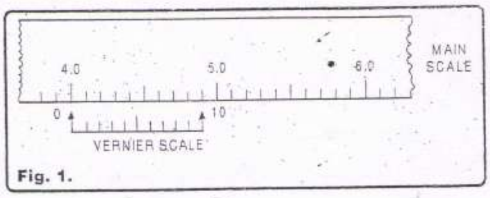


Fig. 1.

$$10\text{VSD} = 9\text{ MSD} = 9\text{ mm} \qquad (\because 1\text{ MSD} = 1\text{ mm})$$

$$\Rightarrow \quad 1\text{VSD} = \frac{9}{10}\text{mm} = 0{\cdot}9\text{ mm}$$

Put values in equation (1), we get

$$\text{V.C.} = 1\text{ mm} - 0{\cdot}9\text{ mm} = 0{\cdot}1\text{ mm} = 0{\cdot}01\text{ cm} \quad \text{...(2)}$$

Vernier constant of a vernier callipers is also equal to the ratio of value of 1 MSD to total no. of divisions on vernier scale.

$$\Rightarrow \quad V.C. = \frac{\text{Value of one MSD}}{\text{Total No. of divisions on vernier scale}} \quad ...(3)$$

Brief diagram of a vernier callipers is given below in fig. (2).

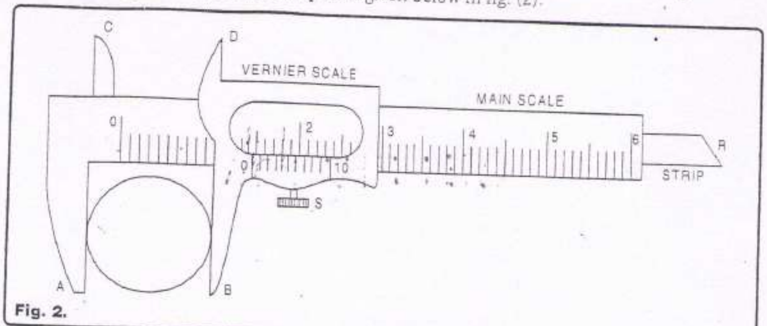


Fig. 2.

Its main scale is of steel graduated in centimeter on lower side and each small division on it is equal to one millimeter. The main scale is graduated in inches from upper side (not shown in figure). However, we shall consider only cm scale, same is applicable to inch scale. A vernier calliper has two jaws A and B at right angle to its length. Jaw A is fixed and jaw B carrying a vernier scale with it can move forward and backward. This jaw can be fixed at any position using screw S. There are two more jaws C and D in upper part of main scale. These jaws are used to find internal diameter of tubes or cylinders. On the other hand jaws A and B are used to find external diameters of tubes or cylinders or spherical bodies. There is a thin strip attached to the movable jaw B. This strip is used to find the internal depth of hollow cylinders. As an example above figure shows vernier callipers being used to determine external diameter of a cylinder. Here the zero of vernier scale is between 1·4 cm and 1·5 cm. The main scale reading is always the smaller of the two *i.e.* Main scale reading = 1·4 cm.

Now by carefully analyzing above fig., one can see that 4th vernier division is coinciding with some division on main side.

So vernier scale reading = (Number of vernier division coinciding) × V.C.

$= 4 \times 0{\cdot}01 \text{ cm} = 0{\cdot}04 \text{ cm}$

Thus total reading is always sum of main scale reading and vernier scale reading.

$\therefore$ Observed diameter $= MSR + VSR$

$= 1{\cdot}4 \text{ cm} + 0{\cdot}04 \text{ cm} = 1{\cdot}44 \text{ cm}$ ...(4)

(ii) **Zero error and zero correction.** In a correctly adjusted instrument, the zero of vernier scale coincides with the zero of main scale, when the movable jaw B is brought in contact with fixed jaw A. But in some instruments, both zeros may not be coinciding when jaws A and B are in contact with each other. In such a case, the instrument is said to possess zero error, which may either be positive or negative. This is demonstrated as follows :

In fig. (3) (*a*), the zero of vernier is to the right of zero of main scale. In this case instrument will always read the length of object more than its actual length. The zero error in such a case is said to be positive. In this figure one can see that the seventh vernier division is coincinding with some division on main scale.

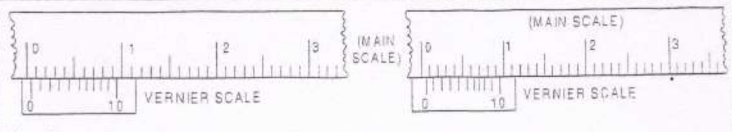


Fig. 3.

$\therefore$ Zero error = (No. of div. coinciding) × V.C.

$= 7 \times 0{\cdot}01 = 0{\cdot}07$ cm

Zero correction is defined as that value, which must be added to observed reading so as to obtain corrected reading. It is always equal in magnitude but opposite in sign to zero error.

$\therefore$ Zero correction = – (zero error)

$= -0{\cdot}07$ cm

Thus corrected reading = observed reading + zero correction ...(5)

Thus continuing the example considered earlier, to find diameter of a cylinder, the corrected diameter of cylinder will be given as

Corrected diameter $= 1{\cdot}44 \text{ cm} + (-0{\cdot}07 \text{ cm})$

$= 1{\cdot}37$ cm

In fig. (3) (*b*), the zero of vernier is to the left of zero of main scale. In this case the length of object recorded by the instrument is less than actual length. The zero error in such a case is said to be negative. From Fig., we can see that 7th vernier division coincides with a division on main scale.

$\therefore$ Zero error = (No. of div. coinciding – total no. of vernier div.) × V.C.

$= (7 - 10) \times 0{\cdot}01 \text{ cm} = -0{\cdot}03$ cm

$\therefore$ Zero correction = – (Zero error)

$= + 0{\cdot}03$ cm

Hence corrected diameter of cylinder in this case will be :

Corrected diameter = Observed diameter + Zero correction

$= 1{\cdot}44 \text{ cm} + 0{\cdot}03 \text{ cm} = 1{\cdot}47$ cm

Procedure. 1. Determine the value of one main scale division of given vernier callipers and count total no. of divisions on the vernier scale. From this data calculate the venier constant of given vernier callipers.

2. Find zero error, if any, in the given instrument with proper sign. If zero of vernier scale coincides with zero of main scale when jaws A and B are in contact, then write zero error as nil.

3. To measure external diameter of calorimeter. Put the calorimeter diameterwise between the jaws A and B as shown in fig. (2) and adjust the movable jaw so as to gently grip the calorimeter. Fix the screw S in this position. Note the main scale reading just before the zero of vernier scale. Then find the no. of vernier scale division which coincides with any of the main scale division. Multiply this number of

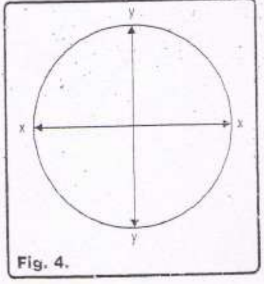


Fig. 4.

vernier divisions by the vernier constant and add it to the main scale reading to get the observed diameter. Apply zero correction and find correct diameter. The position at which calorimeter is held between the jaws of callipers is called XX position. Now loose the screw of movable jaw of vernier callipers and gently remove the calorimeter. Put it again diameterwise in a direction mutually perpendicular to the direction it was set previously (this position is called YY position) between jaws A and B. Measure the diameter of calorimeter in this position, similar to that for XX position. Find mean value of the diameter.

4. To measure the internal diameter of calorimeter. Insert the pair of jaws C and D (see Fig. (2)) inside the calorimeter and adjust the position of movable jaw, till the jaws C and D gently touch the wall of the calorimeter. Fix the screw S in this position. Now note the reading of main scale and the vernier division coinciding with some division on main scale and from this, calculate the observed value of internal diameter. Now measure the internal diameter in mutually perpendicular direction as described in point 3. Find mean value of internal diameter.

5. Measurement of internal depth. Put the edge of the main scale of vernier callipers on the hollow edge of the calorimeter so that strip R of vernier callipers is able to go inside the calorimeter. Slide the movable jaw of callipers, till the end of the strip just touches the bottom surface of the calorimeter. In this position, note the reading of main scale as well as vernier division coinciding with some division on the main scale and from this calculate the observed depth. Apply zero correction with its sign and find corrected value of internal depth.

6. Measurement of external depth/height of calorimeter. Hold the calorimeter lengthwise between jaws A and B of vernier callipers and find the external depth of calorimeter just as external diameter as described in point 3.

Formula used : Let D_i = Internal diameter

D_0 = External diameter

h_i = Internal depth

h_0 = External depth

Then (*i*) Internal volume $V_i = \frac{\pi D_i^2 h_i}{4}$

(*ii*) External volume $V_0 = \frac{\pi D_0^2 h_0}{4}$

(*iii*) Volume of material used in calorimeter is given by

$$V_m = \text{External volume} - \text{Internal volume}$$

$$= V_0 - V_i = \frac{\pi}{4}(D_0^2 h_0 - D_i^2 h_i)$$

Observations :

(*i*) Least count of vernier callipers =.........mm

=.........cm

(*ii*) Zero error =.........mm

=.........cm

(*iii*) Zero corrector (C) = − (Zero error)

=........cm

(*iv*) **Table for External Diameter :**

S. No.	XX Position				YY Position (Mutually perpendicular to XX position)				Mean Diameter
	Main Scale Reading a (cm)	No. of Vernier division coinciding n	Observed External Diameter $= a+n\times$L.C. (cm)	Corrected External Diameter = observed diameter + zero correction (cm) D_1 (say)	Main Scale reading a (cm)	No. of Vernier division coinciding n	Observed External diameter $= a+n\times$L.C. (cm)	Corrected External diameter = diameter + zero correction (cm) D_2 (say)	$\frac{D_1+D_2}{2}$ (cm)
1.									
2.									
3.									
4.									

Mean corrected external diameter D_0 =............cm.

(*v*) **Table for Internal Diameter :**

S. No.	XX Position				YY Position				Mean Diameter
	Main Scale Reading a (cm)	No. of Vernier division coinciding n	Observed External Diameter $= a+n\times$L.C. (cm)	Corrected External Diameter = observed diameter + zero correction (cm) D_1 (say)	Main Scale reading a (cm)	No. of Vernier division coinciding n	Observed External diameter $= a+n\times$L.C. (cm)	Corrected External diameter = diameter + zero correction (cm) D_2 (say)	$\frac{D_1+D_2}{2}$ (cm)
1.									
2.									
3.									
4.									

Mean corrected internal diameter D_i =..........cm.

(*vi*) **Table for Internal Depth :**

S. No.	Main Scale Reading a (cm)	No. of Vernier division coinciding n	Observed internal depth $= a + n \times$ L.C. (cm)	Corrected internal depth = observed depth + zero correction (cm)

Mean internal depth h_i =..........cm

(*vii*) **Table for External Depth :**

S. No.	Main Scale Reading a (cm)	No. of Vernier division coinciding (n)	Observed external depth $= a + n \times$ L.C. (cm)	Corrected external depth = Observed depth + zero correction (cm)

Mean external depth h_0 =..........cm.

Calculations :

(*i*) Internal volume of calorimeter is given as

$$V_i = \frac{\pi D_i^2 h_i}{4} = \text{.........cm}^3$$

(*ii*) External volume of calorimeter is given as

$$V_0 = \frac{\pi D_0^2 h_0}{4} = \text{.........cm}^3$$

(*iii*) Volume of material of calorimeter is given as

$$V_m = V_0 - V_i = \text{.........cm}^3$$

Precautions.

(*i*) The zero error with its proper sign must be noted carefully.

(*ii*) The jaws should not be pressed too hard.

(*iii*) Calorimeter should be held gently between the jaws of vernier callipers.

(*iv*) The dimension (*i.e.* length or diameter) to be measured should be held parallel to the main scale.

(*v*) For measurement of diameter we should take each reading in two mutually perpendicular directions.

Sources of Error.

(*i*) The movable jaw of vernier may be loosely fitted.

(*ii*) The jaws may not be at right angles to the main scale.

Result. (*i*) Internal volume of given calorimeter =..........cm^3

(*ii*) External volume of given calorimeter =.........cm^3

(*iii*) Volume of material of calorimeter =.........cm^3

1.(ii) AIM : TO FIND VOLUME OF A WIRE USING SCREW GAUZE

Apparatus Required. Screw Gauze, scale, wire.

Theory. A screw gauze consists of a U-shaped or semicircular metal frame F. One end of the frame has fixed steel stud. Opposite to stud A, there is another stud C attached to a screw M;

which passes through frame F. The screw M passes through a nut which is fixed inside cylindrical portion S. This cylindrical portion is also called stem. A line P is engraved on the cylinder S. This line is parallel to axis of the screw and is called reference line. The stem carries a scale in millimetres or half millimetres and this scale is called main scale (or pitch scale). The end H of screw is divided into 50 or 100 equal parts and is called circular scale. The screw M is turned by the milled head R. In improved instruments, it is not rigidly fixed to the end of the screw but has a 'ratched', which prevents the screw from being over tightened. The screw should always be rotated using this ratchet.

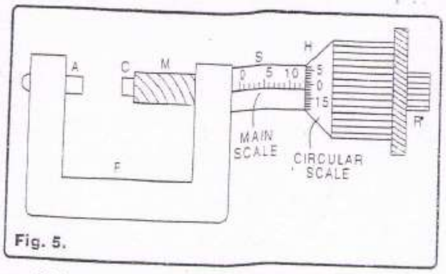


Fig. 5.

Screw gauze works on the principle of screw *i.e.* when a screw is rotated in a nut, then screw covers linear distance parallel to its axis and the linear distance covered by screw is directly proportional to the number of rotations given to the screw.

The linear distance covered by screw in one complete rotation is called pitch. It can also be defined as perpendicular distance between two consecutive threads on the screw. It is also equal to the least count of main scale.

To find pitch of screw, rotate it by a few complete rotations (say 10 rotations) and note down linear distance moved by screw. Then pitch is given as :

$$\text{Pitch} = \frac{\text{Linear distance moved by screw}}{\text{Number of rotations given}}$$

Least count of screw gauze is defined as the least distance that can be measured accurately with that screw gauze. It is equal to linear distance moved by screw when circular scale is turned through one division only. The least count of screw gauze can be found as :

$$\text{Least count} = \frac{\text{Pitch}}{\text{Total number of divisions on circular side}} \qquad \frac{0.5}{100} \quad \frac{0.5}{50}$$

Example. Consider a screw gauze having 100 circular scale divisions. Let when screw is turned through 10 complete rotations, then linear distance moved by screw is 10 mm.

$$\therefore \quad \text{Pitch} = \frac{\text{linear distance}}{\text{rotations given}} = \frac{10\text{ mm}}{10} = 1\text{ mm}$$

$$\therefore \quad \text{L.C.} = \frac{\text{Pitch}}{\text{Total no. of C.S.D.}} = \frac{1\text{ mm}}{100} = 0.01\text{ mm}$$

Zero error. Usually, it is found that zero of circular scale H does not concide with the zero of the linear scale P, when studs A and C are brought in contact. In this case, instrument is said to be suffering from zero error. To find zero error we consider the example given in fig. (6) :

In fig. (6) (*a*) zero of both main scale and circular scale exactly coincide each other when studs A and C are in contact. In this case zero error in the instrument is Nil. Note in this case the zero of main scale is just visible to us.

In fig. (6) (*b*) the zero of main scale is coinciding with eleventh division on circular scale. The rotation from zero of circular scale towards increasing reading (*i.e.* 0, 1, 2, 3, 4, ..., etc.) is considered positive. Hence in this case zero error is said to be +ve and our instrument will give

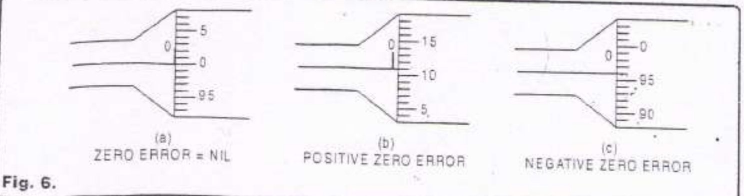


Fig. 6.

length of object more than its actual length. Note that in this case, zero of main scale is distinctly visible to us. The zero error in this case is found using following expression :

$$\text{Zero error} = \begin{pmatrix} \text{No. of circular scale division} \\ \text{coinciding with reference line} \end{pmatrix} \times (\text{Least count})$$

e.g. According to fig. (6) (*b*) Zero error in instrument is given as zero error

$$= (11) \times (0{\cdot}01) = 0{\cdot}11 \text{ mm}.$$

In fig. (6) (*c*), the zero of main scale is coinciding with 96 division on circular scale, when studs A and C are in contact with each other. The rotation of screw in the order (0, 99, 98, 97, 96, ... etc.) is considered as negative. Hence in this case zero error is said to be negative and our instrument will give length of object less than actual length. Note that in this case zero of main scale is not visible at all. The zero error in this case is found using following expression.

$$\text{Zero error} = \left\{ \begin{pmatrix} \text{No. of circular scale divisions} \\ \text{coinciding with referenceline} \end{pmatrix} - \begin{pmatrix} \text{Total No. of circular} \\ \text{scale divisions} \end{pmatrix} \right\} \times (\text{Least count})$$

e.g. According to fig. (6) (*c*), zero error in the instrument is given as zero error

$$= (96 - 100) \times (0{\cdot}01) = -0{\cdot}04 \text{ mm}$$

Zero correction. It is always equal to negative of zero error. It is added to observed reading in order to get corrected reading.

Backlash error. The error due to lag between rotatory motion given to the head screw and the linear motion along the reference line is known as backlash error. Generally, either due to imperfect construction or the constant use of the instrument, there may be looseness in the fitting of screw in the nut. In such condition, if the screw is first adjusted by rotating the screw head in one direction and then direction of rotation is suddenly reversed, the screw does not begin to move in the reverse direction untill the head has been rotated through an appreciable angle (*i.e.* finite number of circular scale divisions). The error due to this cause is called backlash error. This error can be avoided by rotating the screw always in one direction while taking an observation.

Procedure. (*i*) Determine the pitch of screw and then least count of the instrument as explained earlier.

(*ii*) Bring the studs A and C of screw gauze in contact and note zero error.

(*iii*) To measure the diameter of the wire, turn the screw back and insert the given wire between two studs. Turn the screw with the help of ratchet R till the wire is just held between the two studs. Note the main scale reading. Also note the reading of circular scale coinciding with refernce line. Multiply it by least count of screw gauze and add it to the main scale reading, so as to obtain observed diameter of wire. Add zero correction to it, so as to obtain corrected diameter. Turn the wire through right angle at the same point and note the diameter again. Take three or four such observations.

(*iv*) Remove the kinks (if any) in the wire and measure its length using a scale. Repeat the process three times and find mean length of the wire.

Formula used. Let length of wire = L

Diameter of wire = D

Then volume of wire is given as $V = \left(\frac{\pi D^2}{4}\right) L$

Observations : (*i*) Pitch of screw = $\frac{\text{distance moved}}{\text{rotations given}}$

= ....mm

(*ii*) L.C. = $\frac{\text{Pitch}}{\text{Total No. of C.S.D.}}$ = ...mm

(*iii*) Zero error = ...mm

(*iv*) Zero correction = C = − (zero error)

= ....mm

(*v*) Length of wire L (*a*) ....cm (*b*) ....cm (*c*) ....cm

Mean length L = ...cm

= ....mm

(*vi*) **Table for measurement of diameter of wire :**

S. No.	In one direction (XX)				In mutually perpendicular direction (YY)				Corrected diameter
	Main Scale Reading a (mm)	No. of circular scale division coinciding with refrence line (n)	Observed diameter $= a + n \times$ L.C. (mm)	Corrected diameter = observed diameter + zero correction A (mm)	Main Scale reading a (mm)	No. of circular scale division coinciding with refrence line (n)	Observed diameter $= a + n \times$ L.C. (mm)	Corrected diameter = observed diameter + zero correction B (mm)	$D = \left(\frac{A+B}{2}\right)$ (mm)
1.									
2.									
3.									
4.									

Mean corrected diameter D = ...mm

Calculations. The volume of given wire is calculated as $V = \frac{\pi D^2 L}{4}$

= ....mm^3

Precautions. (*i*) Pitch and least count of screw gauze should be noted precisely.

(*ii*) The screw should not be pressed too hard against the object but should touch the given object gently.

(*iii*) The screw should move freely without any friction.

(*iv*) The screw should be moved in one direction only so as to avoid backlash error.

(*v*) Diameter of wire should always be noted in two mutually perpendicular directions.

(*vi*) Zero correction must be applied with proper sign.

Result. The volume of given wire is V = ...mm^3

EXPERIMENTS

2. AIM: TO MEASURE THE DIVERGENCE OF THE LASER BEAM

Apparatus Required. He–Ne laser, stand, screen, measuring tape, graph paper etc.

Theory. Divergence is defined as the spread of the laser beam *i.e.* how much angle is subtended by the laser spot at the point of origin. It is measured in radian. In an optical resonator if single-pass gain is more than cavity loss (including diffraction) then TEM_{00} mode is developed whose intensity distribution has Gaussian shape in a direction transverse to the direction of propagation of beam. A Gaussian beam has following property. If a beam has Gaussian transverse profile at one location, then it will have Gaussian transverse profile at all locations elsewhere (except when optical elements introduce a distortion, that is non-uniform across the wave front of the beam). Such a Gaussian beam can be characterized completely at any spatial location by defining both its "beam waist" and radius of curvature of wave front at specific location of the beam. Moreover, an unaltered Gaussian beam always has a minimum waist size W_0 at one location in space as shown in fig. (20).

In this figure, Z-axis is chosen as direction of propagation of laser beam and origin is chosen at the point where waist size is minimum (ray). Since Gaussian beam remains Gaussian at all locations, thus the waist size of the beam at a distance Z is given by the relation

$$W^2(Z) = W_0^2 + \theta_0^2 Z^2 \qquad \text{...}(i)$$

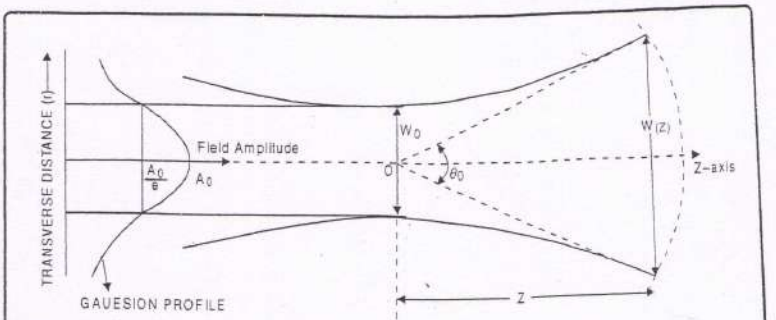


Fig. 20.

This result is a standard result and follows from property of Gaussian beam. Here W_0 = minimum waste size, θ_0 is angle of divergence, W (Z) is waste side at distance Z.

To find angle of divergence θ_0, we set up three equations. For this purpose, the waist or spot size (W) is measured at three arbitrary planes at Z, Z + D, Z + 2 D distance from the reference plane (see fig. (21)).

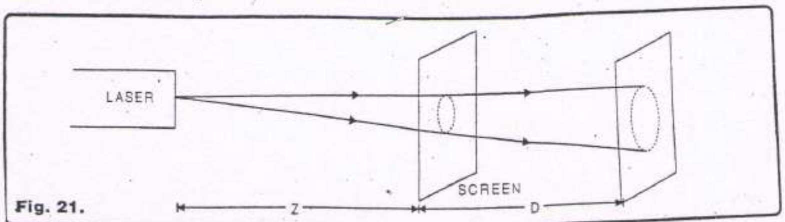


Fig. 21.

Let W_1, W_2, W_3 be spot size at distance Z, Z + D, Z + 2 D from laser, then using equation (*i*), we have

$$W_1^2 = W_0^2 + \theta_0^2 Z^2 \qquad \text{...}(ii)$$

$$W_2^2 = W_0^2 + \theta_0^2 (Z+D)^2 = W_0^2 + \theta_0^2 Z^2 + \theta_0^2 D^2 + 2Z\theta_0^2 \qquad \text{...}(iii)$$

and

$$W_3^2 = W_0^2 + \theta_0^2 (Z+2D)^2$$

$$= W_0^2 + \theta_0^2 Z^2 + \theta_0^2 (4D^2) + 4ZD\theta_0^2 \qquad \text{....}(iv)$$

From (*ii*), (*iii*), (*iv*), we have

$$W_1^2 - 2W_2^2 + W_3^2 = 2\theta_0^2 D^2$$

$$\therefore \quad \theta_0 = \frac{1}{D}\sqrt{\frac{W_1^2 - 2W_2^2 + W_3^2}{2}} \quad \ldots(v)$$

Procedure. (*i*) Arrange the apparatus as shown in figure (22).

(*ii*) Fix a graph paper on the screen and place it at some distance Z (roughly 2 m) from aser. Using a pencil and scale draw horizontal and vertical tangents on both sides of spot so as to form a square shape on graph paper. Using scale measure mean diameter (distance between opposite sides) *i.e.* waist size W_1.

(*iii*) Now distance screen in the direction of beam propagation by a known distance D (*i.e.* total distance from laser is Z + D) and measure spot size W_2 at this place, as described in step (*ii*). Now displace screen further away by same value D (approximately 2 m or more) so that new distance of screen from laser is (Z + 2 D). Measure spot size W_3 at this position as described in step (*ii*).

(*iv*) Put values in formula and find laser divergence.

Formula used. Let D = displacement of screen W_1, W_2, W_3 are spot size at distance Z, Z + D and Z + 2 D from laser, W_0 is minimum waist/spot size, then angular divergence is given by

$$\theta_0 = \frac{1}{D}\sqrt{\frac{W_1^2 - 2W_2^2 + W_3^2}{2}}$$

Observation. (*i*) Initial distance between laser and screen Z =.........m.

(*ii*) Displacement of screen D =.........m.

(*iii*) Table for spot size :–

S. No.	Distance (cm)	Spot size (cm)
1.	Z =	W_1 =
2.	Z + D =	W_2 =
3.	Z + 2 D =	W_3 =

Calculations. Angle of divergence is given by

$$\therefore \quad \theta_0 = \frac{1}{D}\sqrt{\frac{W_1^2 - 2W_2^2 + W_3^2}{2}} = \ldots\ldots\text{radian}$$

Precautions. (*i*) Experiment should be performed in dark room.

(*ii*) Spot size should be measured accurately.

(*iii*) Screen should be placed normally to the path of laser beam.

(*iv*) Laser light should not fall directly into the eyes of observer.

(*v*) Spot size and other distances must be recorded in same units.

Result. The angle of divergence of He–Ne laser is given by θ_0 =........radian. Since this angle is very small (≈ 1 milli radian), we conclude that laser beam is highly directional as compared to ordinary light source.

3. TO STUDY DIFFRACTION USING LASER BEAM AND THUS TO DETERMINE GRATING ELEMENT

Apparatus Required. A He–Ne laser, transmission grating, measuring tape or steel scale, screen, graph paper.

Theory. A diffraction grating is extremely useful device to study diffraction. It consists a large number of slits placed side by side. All these slits lie in a single plane. Due to this it is also called plane diffraction grating. These slits are separated from each other by opaque spaces. When a wavefront is incident on a grating surface, light is transmitted through transparent portion and obstructed by opaque parts of grating. This causes diffraction of light and hence bright and dark fringes are obtained on screen. The intensity of bright fringes goes on decreasing in higher orders.

In fig. (18) beam of parallel rays is incident on a plane diffraction grating. The undiffracted rays are converged to its focus by convex lens and these rays form central (primary) maxima. However, diffracted rays are converged to different points on the focal plane by the convex lens. These diffracted rays (secondary waves) can interfere to form maximum as well as a minimum depending upon value of path difference. From fig. (25), we see that path difference between two secondary waves originating from corresponding points A and C of two neighbouring slits is CD.

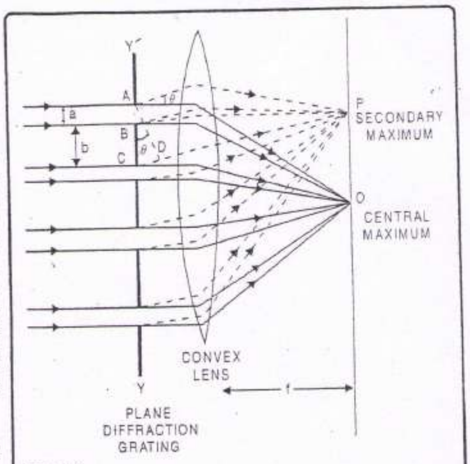


Fig. 16.

Let θ = angle of diffraction

a = AB = width of transparent part

b = BC = width of opaque part

Let $$d = a + b \qquad ...(i)$$

d is called slit width or grating element and is equal to sum of widths of transparent and opaque parts.

In ΔACD, we have $$\frac{CD}{AC} = \sin\theta$$

$\therefore$ $$CD = AC\sin\theta = (AB + BC)\sin\theta$$

$\therefore$ $$CD = d\sin\theta \qquad ...(ii)$$

The point P on screen will be a secondary maxima when path difference CD is integral multiple of wavelength of light

i.e. $$CD = n\lambda; \qquad n = 1, 2, 3, ...$$

$\Rightarrow$ $$d\sin\theta_n = n\lambda \qquad ...(iii)$$

The equation (*iii*) is called grating equation and gives the condition for formation of secondary maxima from diffraction grating. Here θ is replaced by θ_n which simply shows that angle of diffraction is different for different orders.

Let there are N slit widths in a unit length of diffraction grating. It is related to 'd'. To find relation between N and d we note that

one slit width = d distance = grating element

$\therefore$ Number of slit widths in unit distance $= \dfrac{1}{d}$

or $$N = \frac{1}{d} \qquad ...(iv)$$

We can find N using (*iii*) in (*iv*) as follows :

$$N = \frac{\sin\theta_n}{n\lambda} \qquad ...(v)$$

It should be noted that diffraction of light waves can be observed only if slit width d is suitably chosen. To find the limit on value of d, we note that for all values of θ_n, $\sin\theta_n \le 1$.

$$\Rightarrow \qquad \frac{n\lambda}{d} \le 1 \qquad \text{using } (iii)$$

$$\therefore \qquad d \ge n\lambda$$

Since minimum value of n is one for diffraction to be observed. Hence $d_{min} \ge \lambda$.

Thus diffraction can be observed only if size of slit is comparable to the wavelength of light used.

Procedure. (*i*) Arrange the apparatus as shown in fig. (19).

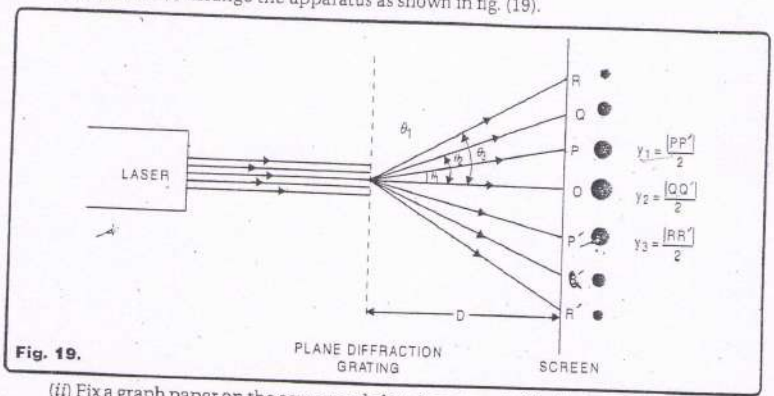


Fig. 19.

(*ii*) Fix a graph paper on the screen and place it at appreciable distance D from grating so that distinct maxima are seen.

(*iii*) Mark the centre of central spot (brightest) and first three maxima on both sides of central maximum.

(*iv*) Using a scale find distance between first maxima on either side of central spot. Then mean distance of first maximum from centre of screen is half of this separation *i.e.* $y_1 = \frac{|PP'|}{2}$. Find angle of diffraction θ_1 using the result $\tan\theta_1 = \frac{y_1}{D}$. Then use this value in grating equation to find d and hence grating element.

(*v*) Repeat the procedure of step (*iv*) for 2nd and 3rd maxima. Then find mean value of N.

Formula used. Let d = grating element

θ_n = angle of diffraction

n = order of diffraction

λ = wavelength of laser beam

Then (*i*) $d = \frac{n\lambda}{\sin\theta_n}$ (*ii*) $\theta_n = \tan^{-1}\left(\frac{y_n}{D}\right)$

where y_n = mean distance between nth maxima and central maximum

D = distance between diffraction grating and screen.

Observations and calculations :

(*i*) wavelength of He–Ne laser $\lambda = 6{\cdot}328 \times 10^{-7}$ m $= 6{\cdot}328 \times 10^{-5}$ cm,

(*ii*) distance between diffraction grating and screen D =........cm.

(*iii*) Table for grating element :

S. No.	Order of Diffraction (n)	Separation between corresponding maxima on either side of central maximum	Position of nth maximum y_n (cm)	Angle of diffraction $\theta_n = \tan^{-1}\left(\frac{Y_n}{D}\right)$ (degree)	Grating element $d = \frac{n\lambda}{\sin\theta_n}$ (cm)
1.	1	$\lvert PP' \rvert =$	$y_1 = \frac{\lvert PP' \rvert}{2} =$	$\theta_1 =$	
2.	2	$\lvert QQ' \rvert =$	$y_2 = \frac{\lvert QQ' \rvert}{2} =$	$\theta_2 =$	
3.	3	$\lvert RR' \rvert =$	$y_3 = \frac{\lvert RR' \rvert}{2} =$	$\theta_3 =$	

Mean value of grating element d =.......cm.

Precautions. (*i*) Experiment must be performed in dark room.

(*ii*) Laser light should not fall on eyes of observer directly.

(*iii*) All lengths should be measured in same unit.

(*iv*) Light should fall normally on diffraction grating and screen should be placed normal to the path of incident laser beam.

(*v*) Distance between spots should be measured accurately.

Result. Grating element of given diffraction grating is d =........cm.

4. TO DETERMINE THE WAVELENGTH OF MONOCHROMATIC LIGHT SOURCE i.e. He–Ne LASER SOURCE USING MICHELSON INTERFEROMETER.

Apparatus. Michelson interferometer, He-Ne Laser, screen, stand.

Formula used. Wavelength of monochromatic light is calculated by the relation

$$\lambda = \frac{2d}{m}$$

Where, d is the distance moved by the sliding mirror for the shift of 'm' number of fringes.

Theory. The Michelson interferometer is a device that produces interference between two beams of light. A diagram of the apparatus is shown in figure 22.

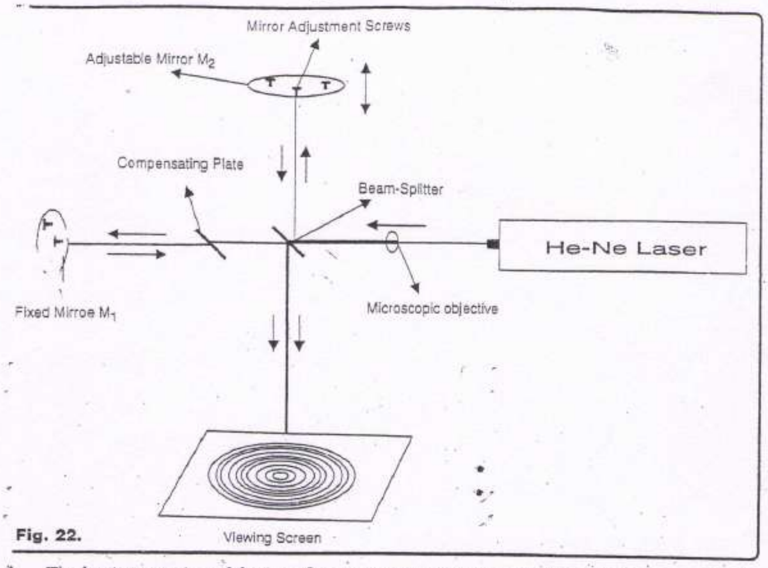


Fig. 22.

The basic operation of the interferometer is as follows: Light from a light source is split into two parts. One part of the light travels a different path length than the other. After traversing these different path lengths, the two parts of the light are brought together to interfere with each other. The interference pattern can be seen on a screen.

Light fromthe source strikes the beam splitter (BS). The beam splitter allows 50% of the radiation to be transmitted to the fixed mirror MI. The other 50% of the radiation is reflected to the translatable mirror M2. The compensator plate C is introduced along this path to make each path have the same optical path length when M1 and M2 are the same distance from the beam splitter. After returning from M1, 50% of the light is reflected toward the frosted glass screen. Likewise, 50% of the light returning from M2 is transmitted to the glass screen. At the screen, the two beams are superposed and one can observe the interference between them.

Optical paths. The rays falling on mirrors M1 and M2 are derived from the same wave source) originally incident at center point on beam splitter 'BS'. The wave reflected from M1 and entering the viewing screen crosses the compensating plate C twice. However the path of the wave falling on the mirror M1, in the absence of compensating plate 'C' travels totally in air. Thus an extra optical path $2(\mu - 1)t$ is introduced where, 't' is the thickness of the compensating plate C and 'μ' is the refractive index of the medium. It is immaterial if we produce fringes with monochromatic light, but it produces a serious problem when white light is used. Thus, it becomes necessary to compensate for the extra optical path $2(\mu - 1)t$ for all wavelengths. This is done by introducing another glass plate C (compensating plate) of same thickness as that of

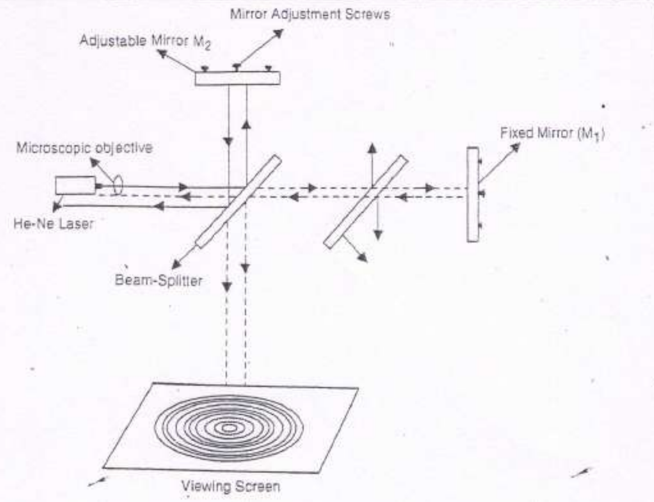


Fig. 23.

Beam Splitter parallel to it. Light reflected from M1 passes through plate twice and an extra optical path $2(\mu - 1)t$ produced in plate BS is compensated by the plate C.

Change in phase. A phase change of p occurs on reflection at M1 and M2. The exact phase change at the plate G will depend on the nature of the semi reflecting film deposited on the plate G. The optical path difference between the two rays is due to the different paths traveled in air before reaching the eye. The two waves will interfere constructively or destructively according as the path difference,

$$\Delta = 2m\lambda/2 = m\lambda \quad \text{(for maxima) and}$$

$$\Delta = (2m+1)\lambda/2 \quad \text{(for minima)}$$

The path difference between two two rays can be varied by moving M1.

The plates G and C are inclined at 450 to the incident and reflected beams. Hence, M2 is imaged virtually in the plate G. Thus, one of the interfering beams from M1 and other from M2 (or as if it had come from M2). The virtual image M2 and the mirror M1 may be supposed as two surfaces of an air film. The air film may be wedge shaped or parallel depending upon whether M2 and M1 are parallel or not.

Types of fringes. The fringes formed in Michelson interferometer may be straight, circular, parabolas or hyperbola depending upon the distance d between M1, M2 and angle θ between these surface.

1. **Circular fringes.** To obtain circular fringes, the planes of M1 and M2 must be perpendicular.
2. **Localized fringes or fringes of equal optical thickness.** When the mirror M1 and virtual image M2 are inclined to each other, the film enclosed is wedge shaped.

3. **With Light Fringes.** When M2 and M1 intersect, the path difference along the line of intersection is zero and therefore, is same for all the wavelengths. When a source of white light is used we get central achromatic bright fringe. On either side of central fringe, three or four colored straight fringes are observed.

Procedure

(*a*) How to Get Circular Fringes

1. Set the Michelson Interferometer on lab table with coarse adjustable knob pointing towards you.
2. Set the lab jack in front of microscopic objective holder and set the height using lifting knob.
3. Place the He-Ne Laser source on lab jack, pointing the source towards the centre of fixed mirro.
4. Plug-in the laser cord on AC 220V, 50Hz socket.
5. Turn the laser on and ajust the laser beam height using lab jack lifting knob until the beam is approximately parallel with the top of the interferometer and strikes the fixed mirror in the centre. (To check that the beam is parallel with the base, place a piece of paper in the beam path, with the edge of the the paper flush against the base. Mark the height of the beam on the paper. Using the piece of paper to check that, the beam height is the same at both ends of the interferometer.
6. Set the viewing screen just opposite of the adjustable mirror M2 to get the laser beam field view. (Note : Viewing screen should be placed at 1-2 meter from the adjustable mirror to get better resolution.)
7. To get circular fringes, M1 should be exactly perpendicular to M2. In this position, Michelson interferometer is said to be in normal adjustment. The setting needs that

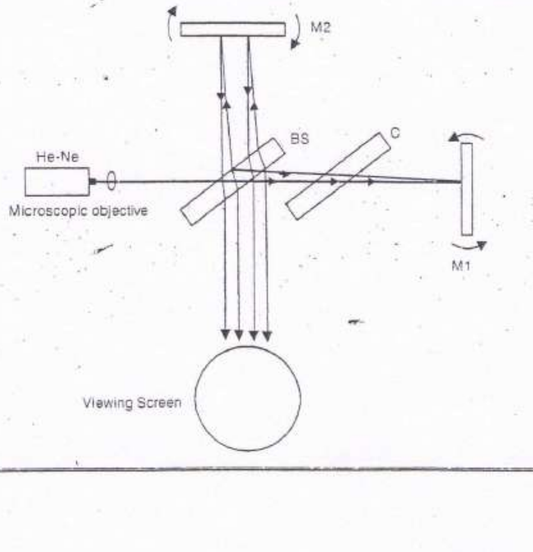


Fig. 24.

the plane of BS exactly bisects the angle (45°) between the polished surfaces of M1 and M2.

8. Using coarse adjustment knob makes the distance of M1 and M2 from BS nearly equal. (The distance of M1 and M2 from BS should not be exactly equal; otherwise the field of view on viewing screen will be dark).
9. When laser beam will be passing through beam splitter (BS) at 45° and observed in the direction M2, four spots of the He-Ne Laser beam are seen on the viewing screen; two of which are faint and two are intense as shown in figure. The faint spots are due to reflection from unsilvered surface of BS and then from M1 and M2 respectively. The intense spots are due to reflection from silvered surface of BS and M1, M2. (Note. Two spots of He-Ne laser beam also been seen on the viewing screen other than four spots, which are ignorable. Because these two spots are formed through compensating plate).
10. The tilting screws at the back of M1 and M2 as shown in fig. are adjusted to obtain only two images as shown in fig. 25. This happens only when the mirrors M1 and M2 are exactly perpendicular to each other.

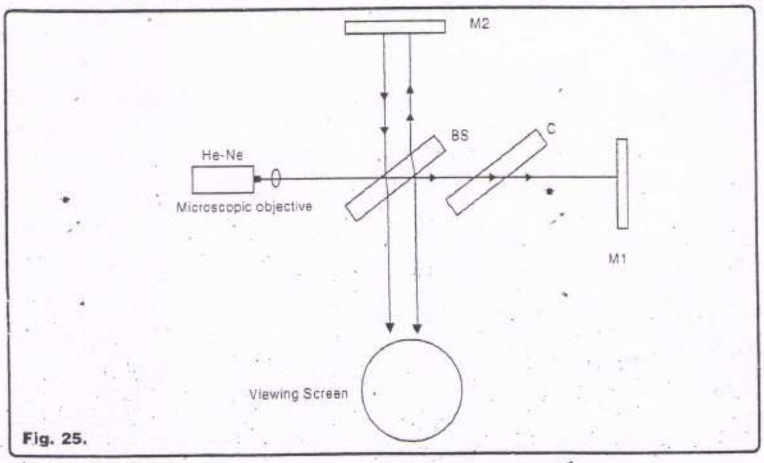


Fig. 25.

11. Now place the Microscope Objective in Microscopic objective holder.
12. Adjust the height of the microscope objective so that clear circular fringes are obtained on viewing screen.
13. Make fine adjustments of mirrors M1 and M2 using top tilting screws to obtain concenric circular fringes in the viewing screen.

Determination of wavelength of He-Ne laser light source: The circular fringes are obtained as already explained.

1. Move the mirror M2 using fine adjustment knob. The fringes appear or disappear in the field of view. (Always move the knob in one direction for precise measurement).

2. Note down the reading of coarse adjustment knob. Let it be 'm'. Multiply this reading with least count 0.01mm.
3. Take the reading of fine adjustment knob. Let it be 'n'. Multiply this reading with least count 0.0001 mm.
4. Now add the above two readings of coarse and fine adjustment knobs. Let it be L1.
5. Rotate the fine adjustment knob to count the number of fringes appearing or disappearing. Let it be N.
6. Note the observations as already explained in (c) and (d). Let it be L2.
7. Subtract L1 from L2 to get the value of 'd' for 'm' fringes.
8. Use the formula to calculate the value of d.

Note. Experiment can also be performed using a Sodium light source.

Observations. Wavelength of He-Ne laser light.

S.No.	Initial Reading 'L1' (Cm)	No. of fringes shifted 'm'	Final Reading 'L2' (Cm)	Distance moved (d = L2–L1)	$\lambda = 2d/m$ (cm)
1					
2					

Calculations

(*i*) Mean value of λ = ... cm

= .... nm

(*ii*) Exact value of λ = 632.8 nm

$$\text{Percentage error} = \frac{(\text{calculated value} - \text{exact value})}{\text{Exact value}} \times 100$$

Sources of Error

1. **Mirror Movement.** The amount of adjustable mirror M2 movement per fine adjustment knob is constant to with 1%. Most of error occurs at extreme end of the mirror's total possible movements.
2. **Movement of fine adjustment knob.** The rotation of fine adjustment knob should be either clock-wise or anti-clock-wise during the experiment to reduce any distortion on the fringes.
3. **Backlash.** The effect of backlash should be practically eliminated by using proper technique when counting fringes.
4. The fixed Mirror M1 should be exactly perpendicular to movable mirror M2 and nearly equal distance so that the fringes will be formed in circular pattern.
5. Distance of M1 and M2 from the back surface of beam splitter BS must not be exactly equal so as to get circular fringes.
6. The fine adjustment knob should be moved in one direction.

5. TO DETERMINE NUMERICAL APERTURE OF AN OPTICAL FIBRE

Apparatus Required. He–Ne laser, 20 X microscopic objective, fibre optic chuck, optical fibre, screen, graph paper, measuring tape etc.

Theory. Numerical aperture is a basic descriptive characteristic of specific fibres. It can be thought of as representing the size or degree of openness of the input acceptance cone. Mathematically, numerical aperture is defined as the sine of angle of acceptance. The light gathering power or flux carrying capacity of a fibre is numerically equal to the sequence of the aperture, which is the ratio between the area of a unit sphere with acceptance cone area of the hemisphere (2π solid angle). A fibre with a numerical aperture of 0·66 has 43% as much as flux carrying capacity as a fibre with numerical aperture of 1·0.

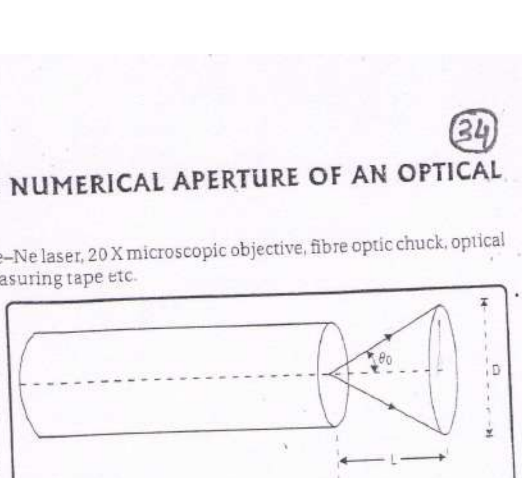


Fig. 26.

i.e. $(0{\cdot}66)^2/(1{\cdot}0)^2 = 0{\cdot}43.$

Let n_1 = refractive index of core

n_2 = refractive index of clad

Then numerical aperture of optical fibre (with air as surrounding medium) is given as

$$\text{NA} = \sin\theta_0 = \sqrt{n_1^2 - n_2^2} \qquad ...(i)$$

Proof of this relation can be seen in chapter of fibre optics of the book.

If a ray of light is incident at acceptance angle then, on entering the fibre, ray is incident on core clad interface at angle of incidence equal to critical angle. Hence it just suffers total internal reflection inside the fibre. All light rays entering in the fibre with angle of incidence less than acceptance angle are accepted, while light rays entering in the fibre at angle of incidence more than acceptance angle are leaked into the clad.

- To measure the numerical aperture experimentally, we consider figure (26). Here light comes out of optical fibre and makes same acceptance cone at output end, as at the input end. Let this light cone coming out from optical fibre is made to fall on a screen at a distance L from output end of fibre. Let D is diameter of circular spot formed on the screen. Then from fig. (26), we can write

$$\tan\theta_0 = \frac{D}{2L}$$

$$\therefore \quad \theta_0 = \tan^{-1}\left(\frac{D}{2L}\right) \qquad ...(ii)$$

Knowing D, L, we can find angle of acceptance using equation (*ii*). Then NA can be found as

$$\text{NA} = \sin\theta_0 = \sin\left(\tan^{-1}\left(\frac{D}{2L}\right)\right) \qquad ...(iii)$$

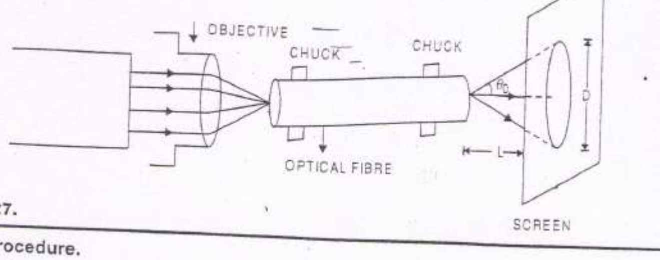


Fig. 27.

Procedure.

(*i*) Arrange the apparatus as shown in fig. (27). Mount both ends of optical fibre on the fibre optic chucks.

(*ii*) Couple the light from the He–Ne laser onto one of the fibre ends using a 20 X microscopic objective.

(*iii*) Place the screen at some distance from the output end (end other than at which light is coupled) of the fibre such that it is perpendicular to the axis of the fibre.

(*iv*) Now move the screen towards or away from the output end of optical fibre, sch that a circular spot is formed on the screen as shown in fig. (28).

(*v*) Measure the distance between the output end of optical fibre and screen. Let it is L. Also measure the diameter of the circular spot formed on the screen. Let it is D.

(*vi*) Use formula to find numerical aperture of optical fibre. Repeat the above procedure for different values of L and D and calculate average value of NA.

Formula used. (*i*) $\theta_0 = \tan^{-1}\left(\frac{D}{2L}\right)$ (*ii*) $NA = \sin\theta_0$

where D = diameter of spot

L = distance between screen and output end of optical fibre

Observations and Calculations :

S. No.	Distance between screen and output end of fibre L (cm)	Diameter of spot D (cm)	Angle of acceptance $\theta_0 = \tan^{-1}\left(\frac{D}{2L}\right)$ (degree)	Numerical Aperture $NA = \sin\theta_0$
1.				
2.				
3.				

Mean value of NA = ...

Precautions. (*i*) Spot formed on graph paper should be sharply defined.

(*ii*) Experiment should be performed in a dark room.

(*iii*) Coupling of light to optical fibre should be adequate.

(*iv*) Diameter of spot and distance between screen and output end of optical fibre should be measured carefully.

Result. Numerical aperture of optical fibre is = ...

6. TO DETERMINE ATTENUATION AND PROPAGATION LOSSES IN OPTICAL FIBRES

Apparatus Required. He–Ne laser, 20 X microscopic objective, fibre chuck, two optical fibres of same type but of different length, digital multimeter or digital microvoltmeter, photodetector.

Theory. As light travels along a fibre, its power decreases exponentially with distance. Let P_0 is optical power in a fibre at the origin (input end), then the power P at a distance z inside the fibre is given as

$$P = P_0 e^{-\alpha_p z} \qquad \text{...(i)}$$

where α_p is called fibre attenuation coefficient. It is given in units of $(\text{km})^{-1}$. The units of $2Z\alpha_p$ can also be designated as nepers. For simplicity in calculating the optical signal attenuation in a fibre, the common procedure is to express attenuation coefficient in units of decibels per kilometer. For accomplishing this task we define a new parameter α called "fibre loss" or "fibre attenuation" as follows :–

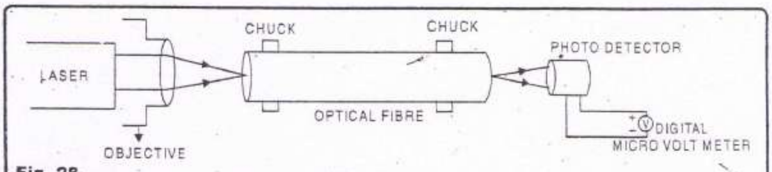


Fig. 28.

$$\alpha = \frac{10}{z}\log_{10}\left(\frac{P_0}{P}\right) \qquad \text{...(ii)}$$

To find relation between α and α_p we note that

$$\log_{10}(x) = \frac{1}{2\cdot303}\ln x$$

Hence (*ii*) gives

$$\alpha = \frac{10}{(2\cdot303)z}\ln\left(\frac{P_0}{P}\right) = \frac{4\cdot343}{z}\ln\left(\frac{P_0}{P}\right)$$

$$\Rightarrow \quad \frac{\alpha z}{4\cdot343} = \ln\left(\frac{P_0}{P}\right)$$

$$\Rightarrow \quad e^{\frac{\alpha z}{4\cdot343}} = \frac{P_0}{P}$$

$$\Rightarrow \quad P = P_0 e^{-\frac{\alpha z}{4\cdot343}} \qquad \text{...(iii)}$$

Comparing (*i*) and (*iii*), we get

$$\frac{\alpha}{4{\cdot}343} = \alpha_p$$

or

$$\alpha = 4{\cdot}343\,\alpha_p \qquad \ldots(iv)$$

Fibre loss or fibre attenuation is a function of several parameters, like bonds in the fibre wavelength of light, temperature etc.

In order to measure fibre loss experimentally, we will further modify equation (*ii*). Let P_1 is optical power at distance z and P_2 is optical power at distance $z + L$ from the input end of optical fibre, then

$$\alpha = \frac{10}{z}\log_{10}\left(\frac{P_0}{P_1}\right)$$

$\Rightarrow$

$$z = \frac{10}{\alpha}\log_{10}\left(\frac{P_0}{P_1}\right) \qquad \ldots(v)$$

and

$$\alpha = \frac{10}{z+L}\log_{10}\left(\frac{P_0}{P_2}\right)$$

or

$$z + L = \frac{10}{\alpha}\log_{10}\left(\frac{P_0}{P_2}\right) \qquad \ldots(vi)$$

Subtract (*v*) from (*vi*), we get

$$L = \frac{10}{\alpha}\left[\log_{10}\left(\frac{P_0}{P_2}\right) - \log_{10}\left(\frac{P_0}{P_1}\right)\right] = \frac{10}{\alpha}\log_{10}\left(\frac{P_1}{P_2}\right)$$

$\therefore$

$$\alpha = \frac{10}{L}\log_{10}\left(\frac{P_1}{P_2}\right) \qquad \ldots(vii)$$

However, P_1, P_2 are optical powers and are not easy to be measured directly. To overcome this problem, the optical power is converted into electrical power using photodetector. The photodetector generates a voltage pulse V_1 corresponding to power P_1 and voltage pulse V_2 corresponding to power P_2. If r is resistance of photodetector circuit, then electrical power is given as

$$P_1 = \frac{V_1^2}{r} \qquad \text{and} \qquad P_2 = \frac{V_2^2}{r}$$

$\Rightarrow$

$$\frac{P_1}{P_2} = \left(\frac{V_1}{V_2}\right)^2$$

Put this value in equation (*vii*), we get

$$\alpha = \frac{10}{L}\log_{10}\left(\frac{V_1}{V_2}\right)^2$$

or

$$\alpha = \frac{20}{L}\log_{10}\left(\frac{V_1}{V_2}\right) \qquad \ldots(viii)$$

Since voltage can be directly measured using sensitive digital voltmeter, so equation (*viii*) can be used to calculate fibre loss.

Procedure. (*i*) Couple the laser output to a 20 X microscopic objective [see fig. (28)]. Then hold both ends of optical fibre of length L_1 in chucks.

(*ii*) Couple one end of optical fibre to objective and other end to photodetector. The photodetector itself is connected to a digital voltmeter. Measure the voltage reading V_1.

(*iii*) Now remove the optical fibre and replace it by a similar optical fibre but of longer length L_2. Measure the output voltage reading for this fibre.

(*iv*) Find $L = L_2 - L_1$ as difference of the two lengths. Put the observed values in the formula to find fibre loss.

(*v*) Perform the experiment with glass as well as plastic fibres.

Formula used. Let V_1 = voltage at the output of fibre of length L_1

V_2 = voltage at output of fibre of length L_2

α = fibre loss

α_p = attenuation coefficient

Then (*i*) $\alpha = \frac{20}{L}\log_{10}\left(\frac{V_1}{V_2}\right)$ where $L = L_2 - L_1$

(*ii*) $\alpha_p = \frac{\alpha}{4.343}$

Observations and calculations :

(*i*) Length of smaller piece of fibre L_1 =..........cm =.........km

(*ii*) Length of longer piece of fibre L_2 =.........cm =.........km

Voltage reading at output of smaller fibre V_1 =..........μV

Voltage reading at output of longer fibre V_2 =.........μV

Difference in two lengths $L = L_2 - L_1$ =.........km

Fibre loss $\alpha = \frac{20}{L}\log_{10}\left(\frac{V_1}{V_2}\right)$ =.........dB/km

Attenuation coefficient $\alpha_p = \frac{\alpha}{4.343}$ =.........(km)$^{-1}$

Precautions. (*i*) Coupling of light into the fibre and into the photodetector should be almost perfect.

(*ii*) The two fibres should be exactly similar. Only their length should be different.

(*iii*) When first fibre is being replaced by second fibre, then light coupling between laser and 20 X microscopic objective should not get disturbed.

(*iv*) Since we are not calculating additional bending loss, so there should not be sharp bends in the fibre while taking observations.

(*v*) Experiment should be performed in dark room.

(*vi*) Light from output end of fibre should only be allowed to fall on photodetector. Care should be taken that laser light or a part of it is not falling directly on photodetector.

Result. (*i*) Fibre loss is given by α =.........dB/km.

(*ii*) Attenuation coefficient α_p =.........(km)$^{-1}$.

(*iii*) The fibre loss is several hundred decibels per kilometer of plastic fibres and a few decibel per kilometer in case of glass fibres. So we conclude that there is more power loss in plastic fibres as compared to glass fibres.

7. Aim. To find the refractive index of a prism material using spectrometer.

Apparatus Required. Spectrometer, magnifying glass, spirit level, prism, sodium vapour lamp etc.

Formula Used. If A is angle of prism, δm is angle of minimum deviation, then refractive index μ is given as

$$\mu = \frac{\sin\left(\frac{A + \delta m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Theory. A spectrometer is a device used to study pure spectrum. Its brief diagram is shown in figure 32. It has following main parts.

(a) Collimator. It contains a slit of adjustable width fitted at outer end of a telescopic tube, while inner end has a convex lens. The distance between slit and lens of collimater is so adjusted that it is equal to the focal length of the lens. A source of light is placed in front of this slit and light coming out from this slit is converted into a parallel beam by the lens and this light is then made incident on a prism, which is placed on prism table.

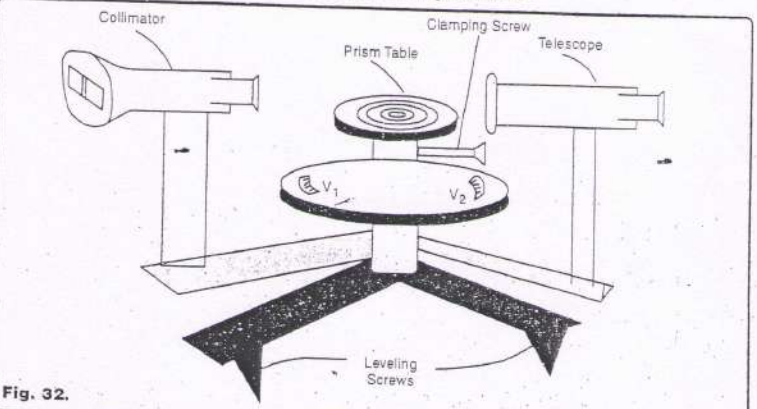


Fig. 32.

(b) Prism Table. It is a circular table used for keeping prism on it. It is provided with screws underneath it so as to make the table hoirzontal. The height of table can be adjusted by a clamping screw. The table can be rotated about a vertical axis. Concentric circular lines on the table help to place the prism correctly on the table.

(c) Telescope. It is an astronomical telescope containing achromatic objective and Ramsden's eye piece with a cross wire. The length of tube can be adjusted with rack and pinion arrangement. The telescope can be rotated freely in a circular path. The angle described by telescope can be noted from two vernier scales V_1 and V_2 as shown in the figure.

Procedure. 1. First of all the telescope is adjusted in normal mode so as to view objects at infinity. For that a very distant object like building or a tree is focussed by taking telescope to an open area, or by looking through an open window of the room. Thereafter it is not disturbed from this setting while doing experiment. It should be noted that cross wire should also be clearly visible in this adjustment.

2. Keep the spirit level on the base of spectrometer and using levelling screws make it in horizontal plane. When it happens then bubble of level is in the centre.

3. Place the slit of collimator facing a sodium lamp source and view the light coming out of collimator using telescope directly (*i.e.* without placing prism on the table). Now adjust the slit width of the collimator so that a fine slit image is seen. Find the vernier constant of the spectrometer. (For details see experiment no. 1).

4. (*a*) **To find angle of prism.** Place prism ABC on the prism table such that light from collimator is falling on the refracting faces AB and AC of the prism *i.e.* non refracting face BC (or base) is away from collimator and refracting edge passing through A is facing the collimator. This is shown in figure 33.

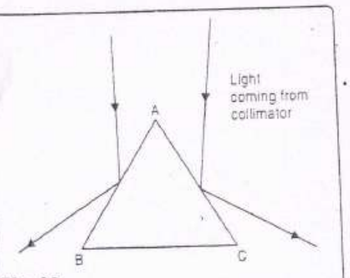


Fig. 33.

(*b*) Now rotate the telescope so as to collect light reflected from face AB of prism. Coincide vertical line of crosswire with slit image in the telescope. Now lock telescope at this position and use fine adjustment screws for proper matching once this is done, note down readings of both verniers V_1 and V_2. Note that it is good to locate the image with naked eye first and then bring telescope at that position.

(*c*) Now repeat procedure (*b*) for face AC and note down new readings of both verniers V_1' and V_2' (say).

(d) Repeat procedure (*b*) and (*c*) three times and find angle of prism A from following observation table :-

Vernier constant of Spectrometer = ...

Table for Measuring angle of prism

S.No.	Vernier V_1			Vernier V_2		
	Position of Telescope		Difference	Position of Telescope		Difference $\theta = \lvert V_2' - V_2 \rvert$
	Face AB (V_1)	Face AC (V_1')	$\theta = \lvert V_1' - V_1 \rvert$	Face AB (V_2)	Face AC V_2'	

Mean value of θ = ...

$$\text{Angle of prism} = A = \frac{\theta}{2}$$

6. To find Angle of Minimum Deviation. (*a*) Place the prism on prism table with its centre exactly coinciding with the centre of prism table. Rotate the table in such a way that light enters in prism from one refracting face AB and comes out from second refracting face AC as shown in figure 34.

Now collect the light coming from second face AC with the help of telescope. Now very carefully rotate prism table by small margin in one direction. The image of slit will also move. Adjust the telescope position again so that slit image remains in the field of view. Continue to repeat this process again and again. It will be found that as the prism is continuously rotated in one direction, the image moves across the field of view, pauses and then moves in reverse direction again. At the moment when slit image just reveses its direction the prism table is fixed and slit image is coincided with the vertical portion of cross wire. Note the readings of both verniers V_1 and V_2 at this position by locking the telescope. This is the position of prism at minimum deviation.

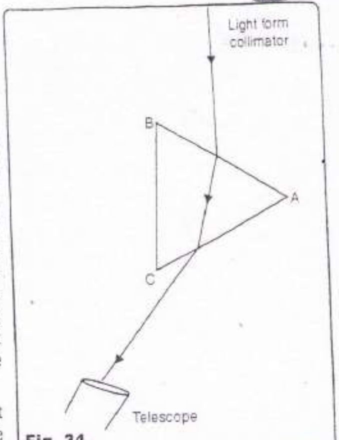


Fig. 34.

(*b*) Now remove the prism from table so that light from collimator goes undeviated. Now move the telescope so as to collect direct light and coincide slit image again with vertical part of cross wire. Lock telescope at this position and note new readings of both verniers V_1' and V_2' (say) Repeat the procedure three times to find angle of minimum deviation δm according to following table.

Table for measurement of angle of minimum deviation

Sr. No.	Reading at Minimum deviation position		Direct Reading		Angle of Minimum deviation	
	Vernier V_1	Vernier V_2	Vernier V_1'	Vernier V_2'	$\delta m = \lvert V_1' - V_1 \rvert$	$\delta m = \lvert V_2' - V_2 \rvert$
1.						
2.						
3.						

Mean value of δm = ...

Now find refractive index of prism using formula

$$\mu = \frac{\sin\left(\frac{A + \delta m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Result. Refractive index of prism material is found to be μ = ...

Precautions of Sources of Error :

1. Position of eye piece should be so adjusted that cross wires are distinctly seen.

2. The plane of prism table should be horizontal

3. Axis of collimator and telescope should be horizontal.

4. The telescope must be focussed at infinity and there should be no parallex between cross wire and image of distant object.

5. Slit size should be narrow.

6. While measuring angle of minimum deviation, the centre of prism table should coincide with centre of prism.

7. Experiment must be performed in a dark room.

8. To find refractive index of a liquid using spectrometer

Apparatus. Spectrometer, hollow prism, given liquid, spirit level, magnifying glass.

Formula used. Same as in experiment no. 7.

Theory. Same as in experiment no. 7.

Procedure. 1. Set the appratus as described in experiment no. 13.

2. Fill the hollow prism with given liquid and measure angle of prism (A) and angle of minimum deviation (δm) as described in experiment no. 13.

3. Find the refractive index of liquid using formula

$$\mu = \frac{\sin\left(\frac{A + \delta m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Result. Refractive index of given liquid is $\mu = \ldots\ldots$

9. Cathode Ray Oscilloscope

... **Cathode ray oscilloscope.** The cathode ray oscilloscope is an instrument which can record instantaneous values of rapidly varying voltages. It is used to observe various alternating current wave forms. There is no mechanical moving part in the oscilloscope but the '*moving*' is done by a beam of electrons. There is no inertia and the electron beam serves as an ideal indicator for any rapidly changing voltage. The electron beam is focused on a fluorescent screen where it produces a fine, bright spot of light. By applying an electrostatic (or magnetic) field in the vicinity of the beam it can be deflected and the spot of light made to move over the face of the screen tracing out a visible pattern which is determined by the potential producing the electrostatic field (or the current producing the magnetic field).

A cathode ray oscilloscope (C.R.O.) essentially consists of a cathode ray tube (C.R.T), a sweep circuit or time base circuit, a synchronisation circuit, high and low voltage supplies, and horizontal and vertical amplifiers.

1. **Cathode ray tube.** The cathode ray tube is an evacuated tube of the shape shown in Fig. 42.1 (*a*). Its main parts are an *electron emitter* called the *cathode* (K), a device to control the intensity called the *grid* (G); accelerating and focusing electrodes (A_1, A_2, A_3) known as *anodes; deflecting plates* vertical (Y_1, Y_2) and horizontal (X_1 X_2) and a *screen* which fluoresces when electrons impinge on it.

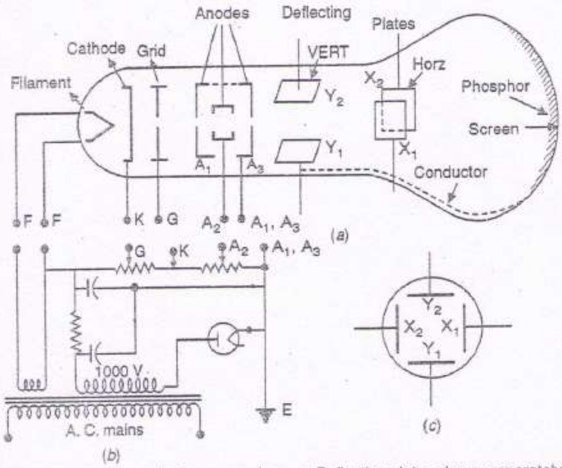
(*i*) *Electron emitter.* The method of obtaining electrons is similar to that used in a thermionic valve. The *cathode K* is indirectly heated by passing a suitable current through the *filament FF*. It is electrically insulated but thermally connected to the filament. The cathode is oxide coated type (with a material like MgO) and when heated gives out a copious supply of electrons.

(*ii*) *Intensity control.* The cathode is surrounded by a metal shield in the form of a cylinder with a hole at the end farther from the cathode. The cylinder is given a negative potential with respect to the cathode so that the electrons are repelled from it and any off axis electrons join the axial stream to form a fine beam which passes through the hole. This electrode is called the *grid* (or shield or *modulator*). By varying the *negative* potential of the grid, the emission of electrons from the cathode can be controlled and thus the *brightness* of the spot on the screen can be varied. This control is usually labelled '*brightness.*' '*brilliance*' or '*intensity*' on the C.R.O. panel board.

(*iii*) *Focus.* The beam of electrons from the grid passes through a series of electrodes known as the first, second or third anode (A_1, A_2 and A_3) all of which are at positive potentials with respect to the cathode. These electrodes act like an electron lens system and bring about a sharp focusing of the electron beam on the fluorescent screen. Generally, the anodes A_1 and A_3 are connected together and have the *highest positive potential* with respect to the cathode while the anode A_2 has a potential lower than that of A_1 and A_3 but higher than that of the cathode. The potential of the anode A_2 can be varied and thus the spot of light brought to a fine focus on the screen. The potentiometer knob controlling the potential of A_2 is usually labelled '*focus*'.

The whole system consisting of the cathode, the grid and the anode shoots out a fine pencil of fast moving electrons and is therefore, called an **electron gun.**

(*ii*) *Deflection of electron beam.* The common form of a cathode ray tube uses electrostatic deflection arrangement. For this purpose two sets of plates X_1 X_2 and Y_1 Y_2 are mounted between the final anode A_3 and the screen. As shown in Fig. 42.1. (*a*) the plates Y_1 Y_2 are horizontal and represent a parallel plate capacitor in which an electric field in the *vertical* (Y) direction is set up when a potential difference is applied to the plates thereby causing the electron beam to move *up* or *down* according to the polarity of the plates. The plates X_1 and X_2 are vertical and an electric field in the *horizontal* (X) direction is set up when the potential difference is applied to these plates thereby causing the electron beam to move from left to right or right to left according to the polarity of the plates. If electric fields are simultaneously set up between the vertical and the horizontal deflecting plates, the resultant displacement of the electron will be in accordance with the vector sum of the vertical and horizontal displacements.



a Cathode ray tube b. Power supply c. Deflecting plates shown separately

Fig. 42.1

The vertical and horizontal plates though shown separately are at the same place.

The position of the spot on the screen can, therefore, be adjusted to a pre-determined position by applying suitable *D.C.* potentials to each of the two sets of deflecting plates. The variable *D.C.* potential for this purpose is regulated by control knobs labelled '*Horizontal positioning* (*Hor. Pos*) and '*Vertical positioning* (*Vert. Pos.*)

One plate of each pair (X_1 and Y_1) is connected to the anode A_3 so that there is no electric field between the plates and the electron gun. Finally the anode A_3 is earth connected so that the deflector plates are not in the vicinity of high potentials which would cause the spot to behave in an erratic manner and may also be dangerous. Thus the cathode and the other electrodes are at a negative potential with respect to the earth.

Caution. *It is dangerous to handle the cathode, the filament (heater) and the focusing anode A_2 when the tube is working.*

(*v*) *Screen.* The screen is coated with a fluorescent material such as zinc orthosilicate and a brilliant spot is visible on the screen due to fluorescence where the electron beam strikes. The inside of the neck of the tube is coated with *aquadag* or some other conducting material thereby connecting the screen to the final plate A_3 which keeps the electron beam from A_3 to the screen in free flight as the space through which the electron beam passes is free from all electrostatic (or magnetic) fields except those set up between the deflecting plates. As the electrons strike the screen these '*leak off*' to the anode A_3 and finally through the power supply to the cathode.

2. **Time base.** One of the great advantages of a cathode ray oscillograph is its ability to indicate very short time intervals and to record variations of voltage with time. If an alternating potential difference is applied to the plates $Y_1\,Y_2$, the spot on the screen will trace out a vertical line proportional to the peak value of the applied voltage. If the wave form of the alternating voltage is to be obtained the spot must be made to move horizontally along the X-direction as well as move up and down along the Y-axis so that the pattern may spread out on the screen. This is done by connecting the horizontal deflecting plates $X_1\,X_2$ to a source of voltage that rises gradually at a constant rate to a maximum value and then suddenly drops back to zero. Such a voltage is said to have a *saw tooth* shape. It causes the beam to move horizontally across the screen at a uniform speed and then snaps back to its starting point. The electronic circuit producing the saw tooth voltage is called the '*sweep circuit*' or '*time base circuit*'. A time base is said to be *linear* if it produces a uniform movement of the spot. The sweep circuit or time base enables us to obtain a pattern on the screen which is exactly the same as a curve of varying voltage applied across the vertical deflecting plates $Y_1\,Y_2$ as a function of time. The only condition that has to be fulfilled is that the period of the saw tooth voltage must be equal to or an exact multiple of the period of the applied voltage to be studied. For example, suppose the frequency of the alternating voltage applied to the Y-plates is 50 c.p.s., then if the time period of the saw tooth voltage is also 1/50 sec (frequency 50 c.p.s.), then *one* complete cycle of the applied voltage will appear on the screen. If the time period of the saw tooth voltage is double *i.e.* 1/25 sec (frequency 25 c.p.s.), then *two* complete cycles of the applied voltage will appear and so on.

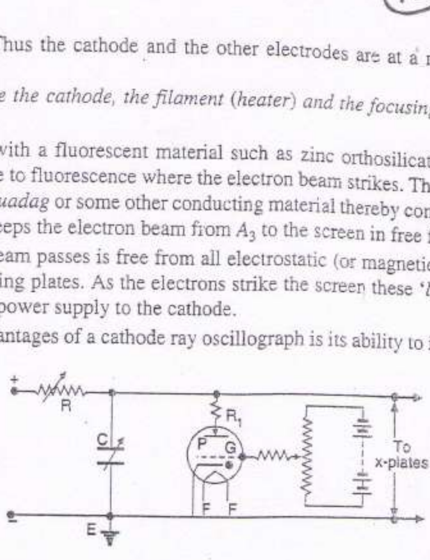


Fig. 42.2

A simple form of '*time base*' makes use of a *gas filled triode* known as *thyratron*. The circuit is shown in Fig. 42.2. The capacitor C is charged through a high resistance R by connecting it to a $D.C.$ source of constant *e.m.f.* V_0. With the thyratron connected in parallel with the capacitor, the voltage V_c builds up from zero to V_c according to the equation.

$$V_c = V_0\,(1 - e^{-t/RC})$$

The curve for the voltage V_c plotted against time is shown in Fig. 42.3. The quantity RC is called the *time constant* and is defined as the time during which the voltage rises to

$$\left(1 - \frac{1}{e}\right) = \left(1 - \frac{1}{2.7}\right) = 0.63$$

of the maximum value. When the voltage across C is sufficient to '*fire*' the thyratron the capacitor discharges rapidly through the valve. (The current being limited to a safe value by the resistance R_1) till the capacitor potential falls to '*extinction value*' at which it is unable to maintain the discharge. At this stage the discharge stops and the capacitor commences to recharge. The process repeats itself and the resulting potential variation across C is shown in Fig. 42.4. The pattern is similar to the edge of a saw and hence the name '*saw tooth*'. If the X-plates are connected across the capacitor, then during the charging period the spot moves across the screen at a nearly uniform rate and suddenly '*flies back*' to the starting point during the discharge period. The time required for a complete cycle of build up of the charge and then discharge of the capacitor *i.e.*, the frequency of oscillations of the sweep circuit can be adjusted by changing the value of time constant RC. The length of the sweep depends upon the value of the '*firing voltage*' and '*extinction voltage*'. The capacitor charge curve is exponential but a sufficiently small section of it, as ab in Fig. 42.3 can be regarded as almost linear. The circuit is made to operate between these two points by adjusting the *firing* and '*extinction*' voltages corresponding to V_a and V_b respectively. For greater linearity the resistance R is replaced by a pentode valve.

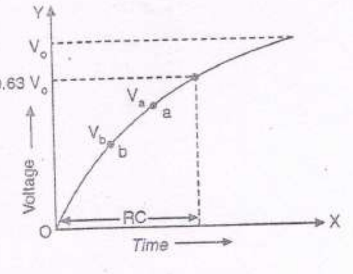


Fig. 42.3

In order to study the wave forms of different frequencies, the sweep frequency can be suitably adjusted with the help of two controls–a '*Range switch*' giving different ranges of frequencies in coarse steps by changing the capacitance C and marked '*frequency selector*' and a '*frequency control switch*' marked '*frequency vernier*' which by gradually varying the resistance R permits fine adjustment of sweep frequency within the limits of any one setting on the range switch.

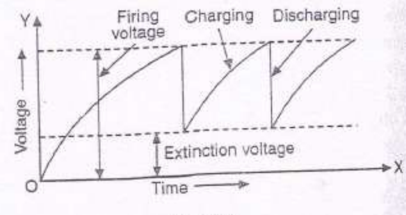


Fig. 42.4

3. **Synchronisation.** When two events occur simulatneously they are said to be synchronised. The input signal applied to the Y-plates, if it is periodic is synchronised with the sweep signal and will appear *stationary* or '*locked in step*' when the beginning of a pulse of the signal wave train is caused to appear at the beginning of the sweep trace. If there is a slight lack of synchronisation the wave pattern will move across the screen either left to right or right to left. To keep the trace steady without frequent recourse to fine frequency control a portion of the incoming signal is fed to the saw tooth generator and serves to '*lock*' the generator in step with the vertical input frequency. The '*synch*' control varies the signal fed to the sweep oscillator and a slight adjustment of fine '*synch*' control knob helps to '*freeze*' (or *lock*') the pattern on the screen. When synchronisation has been achieved the trace is repeated again and again in the same position and thus appears stationary on the screen.

4. **Power supply.** The power supply provides the high voltage for the cathode ray tube (1–15 *KV*), filament voltages for vacuum tubes and low voltages (1–150V) for other valves in the circuit. A simple form is shown in Fig. 42.1 (b).

5. **Amplifiers.** To amplify weak signals to increase the deflection in the vertical and horizontal directions without distortion of the incoming signals, the X-and Y-plates producing the horizontal and vertical deflections are connected to suitable amplifiers. Regulating knobs provided on the C.R.O.

panel are respectively labelled '*Horizontal gain*' (HOR. GAIN) and '*Vertical gain*' (VERT. GAIN). With the help of these the gain or amplification of the signal may be varied for the horizontal and vertical plates. The horizontal amplifier can also amplify the sweep circuit oscillations and is provided with a switch so that it can be connected to the internal sweep circuit or the external signal.

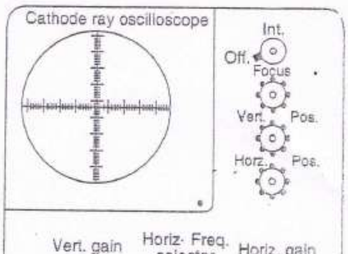


Fig. 42.5

Experiment 9 (*a*) **To obtain the wave form of a given oscillator using a cathode ray oscilloscope.**

9(*b*) **To obtain the wave form of A.C. mains supply using a cathode ray oscilloscope.**

Apparatus. Cathode ray oscilloscope, audio oscillator (signal generator), a step down transformer.

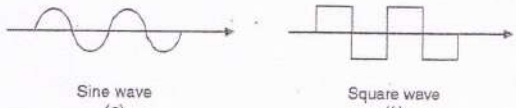
Procedure (*a*) 1. Connect the output terminal marked '*ground*' (GND) or '*earth*' of the oscillator to the terminal marked '*ground* or '*earth*' of the vertical input of the C.R.O.

2. Connect the C.R.O. to the A.C. mains and switch on the '*intensity*' control (or *power switch*). Note the position of the '*spot*' as it appears on the screen and adjust the '*intensity*' and '*focus*' controls to get a sharp and fine spot. Now adjust the bias on the X and Y deflecting plates by using the '*horizontal*' and *vertical positioning*' (centering) controls so that the spot is in the centre of the screen.

CAUTION. *See that the bright spot does not remain on the screen for any length of time otherwise that area of the tube will be burnt.*

3. Switch on the '*time base*' or '*sweep circuit*' so that the spot sweeps across the screen in rapid successions. See that the time axis is straight horizontal and clearly defined.

4. Connect the oscillator to A.C. mains and switch it on. Set the oscillator frequency at 1000 cycles/sec. Now set the '*coarse*' frequency control of the sweep circuit of the C.R.O. with the help of '*frequency selector*' control to a step with 1000 c.p.s. and adjust the '*vernier frequency*' control carefully to '*stop*' the wave pattern obtained. Adjust the oscillator gain as well as the vertical and horizontal gains of the C.R.O. to get a proper amplitude of the wave form on a large part of the screen. When the hand is taken off the '*vernier frequency*' control the pattern will, probably, begin to *walk* along the sweep. If it does, adjust the '*synch. amp*' control to '*freeze*' the pattern. You will get *one* complete wave form of the oscillator with this adjustment. Trace the wave form.



Sine wave (*a*) Square wave (*b*)

Fig. 42.6

5. Now set the 'COARSE' FREQUENCY CONTROL to a step with 500 c.p.s. and again adjust the '*vernier frequency*' control to '*stop*' the pattern. '*Freeze*' the pattern with the help of '*synch amp*' control, if necessary. You should now get *two* similar patterns. Similarly get 4, 5, and 10 patterns. Note the type of wave pattern *i.e.* sinusoidal, square wave, triangular wave or any other form. Trace the wave form an a tracing paper. A sine wave and a square wave is shown in Fig. 42.6 (*a*) and (*b*).

6. Switch off the oscillator and the C.R.O. and disconnect from A.C. mains. Disconnect the oscillator from the C.R.O.

(*b*) 1. To study the wave form of *A.C.* supply, the secondary terminals of a step-down transformer are connected to the 'vertical input' terminals of the *C.R.O.*

The *A.C.* mains frequency is 50 cycles/sec and is usually held to a very small tolerance.

2. Connect the *C.R.O.* to the *A.C.* mains and obtain a sharp and fine spot on the centre of the screen as explained in **step 2.** Adjust the '*coarse frequency*' control of the sweep circuit to a step with 50 c.p.s. and proceed as in **step 4** to get *one* complete *A.C.* wave form '*locked in*' on the screen. Trace the pattern obtained.

3. Repeat with time base frequency set at 25 c.p.s. and 100 c.p.s.

Precautions. 1. Do not allow the spot of light to remain on the screen for a long time, otherwise the area will be burnt.

2. Adjust the horizontal and vertical gain controls of the *C.R.O.* to obtain proper amplitude of the wave pattern on a large part of the screen.

Calibration of an oscilloscope. If one plate of a pair of deflecting plates of a C.R.O. is maintained at a positive potential with respect to the other, then electron beam will be attracted towards the positive plate and the spot of light will move across the screen.

If *D.C.* potential is applied to the X -plates the spot will move from the '*centre*' position to a point either on the left or right of the centre depending upon the polarity of the plates. If the potential is applied to the Y-plates, the spot will move up or down for the same reason. The deflection of the spot will be proportional to the difference of potential between the plates.

If alternating voltages are applied, *the spot will be drawn out into a line*. The length of the line is a measure of the *peak to peak* voltage applied. The *D.C.* voltage corresponding to the length of the line *i.e.* the sum of the deflections on either side of the centre will be equal to $2\sqrt{2}$ times the r.m.s. voltage.

The calibration of an oscilloscope is generally done with *A.C.* voltage to avoid the possibility of burning of the screen due to the electron spot having remained in one particular position for a long time. For calibration purposes some oscilloscopes are provided with an in built standard 1 volt *A.C.* signal. The usual circuit for calibration is shown in Fig. 42.9. (*a*). T is a step-down transformer, the voltage across its secondary is measured by an *A.C.* voltmeter V. This voltage is applied to a potential dividing arrangement consisting of two resistance boxes R_1 and R_2. To find the vertical sensitivity the potential difference across R_2 is applied to the plate Y_2 of the vertical deflecting plates and the plate X_2 of the horizontal deflecting plates is earthed by connecting it to the terminal marked '*ground*'. The deflecting plates X_1 X_2 and Y_1 Y_2 are shown separately in Fig. 42.9 (*b*). To find the horizontal sensitivity the potential difference across R_2 is applied to the plate X_2 and plate Y_2 is earthed by connecting it to the terminal marked '*ground*'. If V is the voltmeter reading, then

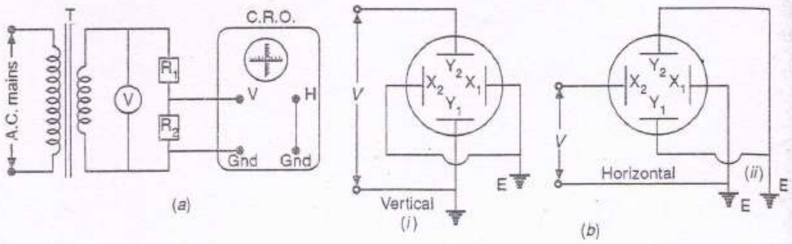


Fig. 42.9

$P.D.$ across $$R_2 = V\,\frac{R_2}{R_1 + R_2}$$

If L_v is the total length of the line traced on the screen, then since it is proportional to peak to peak voltage, we have

Peak to peak voltage $2\sqrt{2}\,V\,\dfrac{R_2}{R_1 + R_2} \propto L_v$

or $$2\sqrt{2}\,V\,\frac{R_2}{R_1 + R_2} = k_v\,L_v$$

where k_v is the vertical sensitivity.

$$\therefore \qquad k_v = \frac{2\sqrt{2}\,V R_2}{L_v\,(R_1 + R_2)}$$

Similarly If L_h is the total length of the line traced on the screen in the horizontal direction, then horizontal sensitivity

$$k_h = \frac{2\sqrt{2}\,V R_2}{L_h\,(R_1 + R_2)}$$

The vertical and horizontal sensitivity of a cathode ray oscilloscope depends upon the gain from the respective amplifiers. The sensitivity is *minimum* for *no gain* position, *maximum* for *full* gain position and has an intermediate value for any other gain position. For example, the sensitivity of a C.R.O. may be 1 volt per cm for no gain position and 0.1 volt per cm for full gain. The vertical and horizontal sensitivities may also be different. In general, the sensitivity of a C.R.O. is required to be determined in a *particular* gain position which may have been used in an *experiment*. In such a case the gain position should not be disturbed after the experiment. In other words, the vertical and horizontal gain control knobs *should be kept fixed in position*.

Experiment 9(C) To find the vertical and horizontal sensitivity of a cathode ray oscilloscope (*i*) with no amplifier gain and (*ii*) with full amplifier gain.

Apparatus. A cathode ray oscilloscope, two resistance boxes, an *A.C.* voltmeter, a step down transformer etc.

Procedure. 1. Draw a diagram showing the scneme of connections as in Fig. 42.9 (*a*) and connect accordingly.

2. (*a*) **Vertical sensitivity.** Connect the '*hor. input*' terminal to the '*ground*' terminal. Set the '*hor. freq. select*' control knob to the '*ext. input*' position. Set the '*vert. gain*' control knob to the *no* (zero) gain position.

3. Connect the C.R.O. to the A.C. mains. Put off the time base circuit and obtain a sharp, bright spot on the screen. Switch on the A.C. mains supply to the step down transformer T and adjust the value of R_1 and R_2 so that a vertical trace of a suitable length is obtained on the C.R.O. screen. Note the reading of the voltmeter, values of R_1 and R_2 and trace the line displayed on the screen on a *ransparent paper*. Measure the length L_v of the line

Take six such readings by changing the values of R_1 and R_2 and getting the line trace from a minimum to the maximum length.

4. Now set the '*vert. gain*' control knob to the *maximum* (full) gain position and repeat the experiment.

5. (*b*) **Horizontal sensitivity.** Connect the '*vert. input*' terminal to its '*Ground*' terminal. Set the '*hor. freq. select*' control knob to the *no* (zero) gain position. Take at least six observations as explained in step 3 by tracing the horizontal line displayed on the screen.

6. Now set the '*hor. gain*' control knob to the *maximum* (full) gain position and repeat the experiment.

Record. (*a*) **Vertical sensitivity**

No gain					*Full gain*				
Voltmeter-Reading (V)	R_1	R_2	L_v	$k_v = \frac{2\sqrt{2}\,VR_2}{(R_1+R_2)\,L_v}$	*Voltmeter-Reading (V)*	R_1	R_2	L_v	$k_v = \frac{2\sqrt{2}\,VR_2}{(R_1+R_2)\,L_v}$

Mean sensitivity = volt/cm　　Mean sensitivity = volt/cm

(*b*) **Horizontal sensitivity**

No gain					*Full gain*				
Voltmeter-Reading (V)	R_1	R_2	L_h	$k_h = \frac{2\sqrt{2}\,VR_2}{(R_1+R_2)\,L_h}$	*Voltmeter-Reading (V)*	R_1	R_2	L_h	$k_h = \frac{2\sqrt{2}\,VR_2}{(R_1+R_2)\,L_h}$

Mean sensitivity = volt/cm　　Mean sensitivity = volt/cm

Precautions. 1. While finding the vertical sensitivity both the horizontal deflecting plates must be earthed and vice versa.

2. The sensitivity depends upon the amplifier gain. The gain control knob should not be disturbed during the experiment.

3. The A.C. voltmeter must be connected in parallel with the secondary of the step down transformer.

Exercise. *Find the vertical and horizontal sensitivity of a C.R.O. at half gain.*

Hint. In each case set the '*gain control*' knob midway between the *zero* and *full* gain markings and proceed as in **Expt.**

Experiment 9(d) To measure A.C. voltages using a C.R.O. and to calculate the deflection sensitivity in m.m. per r.m.s. volt.

Apparatus. Same as in **Expt.** 42.3.

Theory. When an A.C. voltage is applied to the Y-Y plates of a C.R.O. keeping X-X plates earthed, the spot remains moving up and down due to the variation of potential. However, due to *persistence of vision* a *line* is traced on the screen. The length of the line corresponds to peak to peak value of the A.C. voltage applied and thus measures $2\sqrt{2}$ *r.m.s.* voltage. If V *is the r.m.s.* voltage, then

$$V \propto L$$

where L is the length of the line traced.

Procedure 1. Draw a diagram showing the scheme of connections as shown in Fig. 42.10 and make connections accordingly. The variable resistance R is a wire potentiometer type with a variable knob having resistance in the range 2-5 KΩ.

2. Switch on the C.R.O putting off the time base circuit and get a sharp and bright, stationary spot at O the centre of the screen. Using the *Brightens control* make the brightness of the spot minimum.

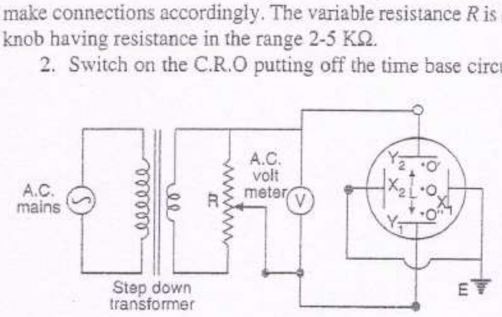


Fig. 42.10

3. Now apply a suitable A.C. voltage to the Y-Y plates by adjusting the variable knob of the resistance R. Note the voltmeter reading. Measure the length of the line $O'O''$ traced by the spot of light on the screen by tracing it on a butter paper.

4. Go on changing the voltage and note the voltage as well as the corresponding length of the line traced by the spot of light on the screen. Take 6-7 readings first by increasing the voltage and then decreasing it.

5. Now apply the unknown A.C. voltage E_v to the Y-Y plates of the C.R.O and note the length of the line on the screen traced by the spot of light.

Observations.

S. No.	*Applied voltage (V)*	*Length of the line*		
		Voltage increasing Length $L_1 = O'O''$	*Voltage decreasing Length* $L_2 = O'O''$	Mean $L = \frac{L_1 + L_2}{2}$
1				
2				
3				
4				
5.				
6				
7				

6. Plot a graph taking the voltage V (*r.m.s.* value) along the X-axis and the mean length L of the line traced by the spot of light (in m.m.) along Y-axis. The graph is a straight line. [NOTE: The deflection $O'O''$ measures the peak to peak voltage whereas the voltage measured by the voltmeter is the *r.m.s.* value].

Deflection sensitivity v = slope of the graph = $\frac{AC}{BC}$ = mm per *r.m.s.* volt.

Unknown voltage. Length of the line for the unknown A.C. voltage = l = mm

Unknown voltage $E_v = v \times l$ = volts (*r.m.s.*)

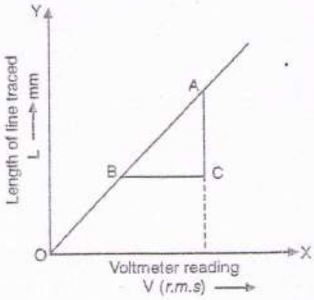


Fig. 42.11

Preacations. Same as in Expt.

Experiment 9(e) To measure a d.c. voltage with the help of a C.R.O.

Apparatus. A *d.c.* source, A variable resistance of the order of 20-50 kΩ, a *d.c.* voltmeter (of suitable range) a key, connecting wires.

Theory. When the X-X plates of a C.R.O are earthed, its time base-circuit switched off and no voltage is applied to the Y-Y plates we get a sharp, bright spot of light at O the centre of the screen. If a *d.c.* voltage is now applied by connecting Y_2 to the positive and Y_1 to the negative of the *d.c.* source the spot of light is displaced towards the positive plate Y_2 and appears at O' instead of O. The displacement of the spot OO' is directly proportional to the applied voltage as indicated by the voltmeter V connected in parallel with Y-Y plates.

Procedure. 1. Draw a diagram showing the scheme of connections as shown in Fig. 42.12 and

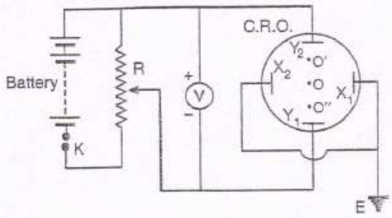


Fig. 42.12

make connections accordingly. The resistance R is of the order of 20-50 kΩ. It is a wire potentiometer type with a variable knob.

2. Switch on the C.R.O. putting off the time base circuit and get a sharp, bright and stationary spot at O the centre of the screen. Rotate the brightness control to the *left* to reduce the brightness of the spot temporarily.

3. Now apply a known suitable *d.c.* voltage to the Y_1 Y_2 plates by inserting the key K in the battery circuit. Rotate the brightness control to the *right* so as to increase the brightness. The spot of light is now displaced to the point O' towards the Y_2 plate. Note the displacement OO' in m.m. either by tracing the position of the spot on a tracing paper fixed to the screen or on the screen itself if it is already graduated.

Note the corresponding voltage from the voltmeter connected in parallel with Y-Y plates.

4. Now change the value of the voltage applied to the Y-Y plates and go on noting the voltage as well as the corresponding displacement of the spot of light on the screen.

NOTE The spot should not be allowed to stay at one point for a long time. Always bring the brightness control to minimum before taking the next reading.

5. Now interchange the polarities of Y_1 and Y_2 plates connecting Y_1 to the *positive* and Y_2 to the *negative* of the battery and repeat the observation. The displacement of O is now in the downward direction from O to O'' towards the plate Y_1. Note the reading of the voltmeter and corresponding displacement of the spot of light.

6. Now apply the unknown *d.c.* voltage to the Y_1 Y_2 plates of the C.R.O. and note the displacement first with Y_2 positive and then with Y_1 positive.

Observations

No.	*Applied voltage in volts*	*Displacement OO′ in mm. Y_2 (+ve)*	*Displacement OO″ in mm. Y_1 (+ve)*	*Mean displacement d*
1				
2				
3				
4				
5				
6				
7				

Graph. 7. Plot a graph taking voltage v in volts along the X-axis and the mean displacement of the spot of light d along the Y-axis. The graph is a straight line.

Voltage per m.m. from the graph $v =$

$$\frac{AC}{BC} = \quad \text{volts/mm.}$$

Displacement for unknown voltage

Y_2 (+ve) = mm

Y_1 (+ve) = mm

Mean displacement $d =$ mm.

Unknown *d.c.* voltage $V = v \times d =$ volts.

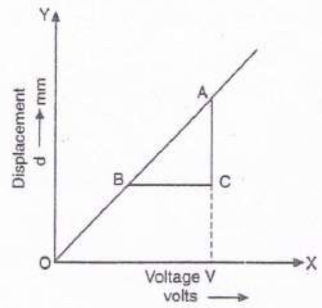


Fig. 42.13

Precautions. 1. The spot of light should not be allowed to stay at one point to avoid damage to the screen.

2. The variable resistance R should have a suitable value.

3. Always decrease the brightness of the spot of light to minimum before proceeding to the next observation.

4. The C.R.O should be handled very carefully.

Lissajous figures. *When a particle is acted upon simultaneously by two simple harmonic motions at right angle to each other the resultant path traced out by the particle is called a Lissajous figure.*

Since simple harmonic motions plotted against time give sinusoidal configurations two sinusoidal electrical inputs to a cathode ray oscilloscope will give Lissajous pattern on the screen. The exact pattern traced out *i.e.*, the nature of the resultant path depends upon the frequencies (or periods), amplitude and phase relationships of the two inputs.

(*a*) *Equal frequencies* (or *periods*). Let the two simple harmonic vibrations having the same period take place along the X and Y axes respectively. These can be represented as

$$x = a \sin \omega t$$

and $$y = b \sin (\omega t + \phi)$$

where a and b are the respective amplitudes and the Y-vibrations is *ahead* of the X-vibration by a phase angle ϕ.

$$\text{If } \phi = 0$$

$$x = a \sin \omega t$$

$$y = b \sin \omega t$$

or $$y = \frac{b}{a} x$$

This represents a straight line through the origin as shown in Fig. 42.18. (*i*). The slope is given by

$$\tan \theta = \frac{b}{a}$$

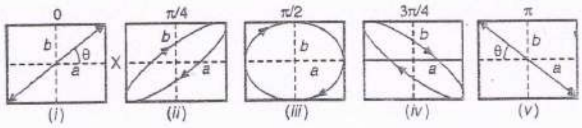


Fig. 42.18

If $\phi = \pi/2$ $$x = a \sin \omega t$$

$$y = b \sin (\omega t + \pi/2) = b \cos \omega t$$

$\therefore$ $$\frac{x^2}{a^2} + \frac{y_2}{b^2} = 1$$

This represents a *symmetrical* ellipse whose major and minor axes coincide with X and Y axes respectively as shown in Fig. 42.18 (*iii*).

If $a = b$ the resultant curve is a circle given by

$$x^2 + y^2 = a^2$$

If $\phi = \pi$ $$x = a \sin \omega t$$

$$y = b \sin (\omega t + \pi) = - b \sin \omega t$$

$\therefore$ $$y = -\frac{b}{a} x \cdot$$

This again represents a straight line through the origin as shown is Fig. 42.18. (*v*). The slope is given by

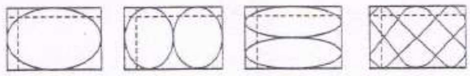
$$\tan \theta = -\frac{b}{a}$$

For $\phi = \pi/4$ and $\phi = 3\pi/4$ we get oblique ellipses as shown in Fig. 42.18. (*ii*) and (*iv*)

As ϕ exceeds π the whole cycle is repeated in the *reverse* order.

(*b*) *Frequencies in the rations of 1 : 2.* When the frequency of the Y-vibration is double that of the X-vibration but the two are in phase ($\phi = 0$), the curve traced out is shown in Fig. 42.19 (*ii*).

If, however, the frequency of the X-vibration is double that of Y-vibration, then the pattern obtained is as shown in Fig. 42.19. (*iii*).



(*i*) $\frac{Y\text{ freq.}}{X\text{ freq.}} = 1$ (*ii*) $\frac{Y\text{ freq.}}{X\text{ freq.}} = 2$ (*iii*) $\frac{Y\text{ freq.}}{X\text{ freq.}} = \frac{1}{2}$ (*iv*) $\frac{Y\text{ freq.}}{X\text{ freq.}} = \frac{3}{2}$

Fig. 42.19

In fact, the frequency ratio of the two inputs may be determined from an analyses of the Lissajous figures produced. A simple method is to enclose the Lissajous figures in a rectangle whose sides are parallel to the formation axes of the figure and note the *number* of *tangency points* along the *vertical* (Y-axis) and the *horizontal* (X-axis). The ratio of the number of tangency points is in the *inverse* ratio of the two frequencies *i.e.*

$$\frac{\text{Number of tangency points along } X\text{-axis}}{\text{Number of tangency points along } Y\text{-axis}} = \frac{\text{Frequency of } Y\text{-vibration}}{\text{Frequency of } X\text{-vibration}}$$

An alternate method is to count the number of points at which the vertical and horizontal lines cross the figure. In other words

$$\frac{\text{Frequency of } Y\text{-vibration}}{\text{Frequency of } X\text{-vibration}} = \frac{\text{Number of crossings along the } X\text{-axis}}{\text{Number of crossings along the } Y\text{-axis}}$$

The cases of $\frac{Y\text{ freq.}}{X\text{ freq.}} = \frac{1}{1}, \frac{2}{1}, \frac{1}{2}, \frac{3}{2}$ are shown in Fig. 42.19 (*i*), (*ii*) (*iii*) and (*iv*).

Experiment 9(f) To find unknown frequency of an oscillator using Lissajous figures.

Apparatus. Cathode ray oscilloscope (CRO), Oscillator of unknown frequency, variable frequency oscillator, connecting cables.

Procedure.

1. Connect one of the oscillator O_1 (say known) to the vertical input i.e. Y-plates and the second oscillator O_2 (unknown) to the horizontal input (X-plates).
2. Put on the C.R.O. Set audio oscillator O_1 to a frequency 1000 Hz (say). Adjust the frequency of O_2 such that you get an ellipse. The unknown frequency of O_2 at this stage shall also be 1000.
3. Decrease the frequency of oscillator O_2 keeping the frequency of O_1 same. Stop when you get a figure of " ∞" (horizontal eight). At this stage the frequency of one is double that of the second.
4. Increase the frequency of oscillator O_2 keeping the frequency of O_1 same. Stop when you get a figure of "8" (Vertical eight). At this stage the frequency on X plates is double that of the frequency of Y plates.
5. Similarly obtain Lissajous figures of ratio 1 : 3, 2 : 3, 3 : 1, 3 : 2.

Observations. Vertical input frequency = 1000 Hz

Shape of figure	*No. of points on*		*Unknown frequency Y freq./X freq.* $= \frac{x}{y}$
	X-axis	*Y-axis*	
Ellipse parabola	2	2	$\frac{Y\text{ freq.}}{X\text{ freq.}} = \frac{2}{2} = 1$
8			
∞			

Mean value =..Hz

Result: The mean value of frequency of given oscillator is ....Hz

Precautions.

1. *Take all the precautions of handling C.R.O.*
2. *The frequency of the oscillator O_2 should be changed gradually.*

Experiment 9(g) To find unknown frequency of an oscillator without using Lissajous figures (direct method).

Apparatus. Cathode ray oscilloscope (CRO), Oscillator of unknown frequency, connecting cables.

Procedure. 1. Switch on CRO and do the basic settings as explained in experiment 9(f).

2. Now switch on the oscillator of unknown frequency and connect its output to channel-1 of CRO.

3. Using voltage sensitivity knob, adjust the amplitude of the waveform obtained to suitable value.

4. Using Time Base (TB) or sweep knob, make a stable pattern of the waveform on the screen.

5. Using X and Y shift knobs, bring one crest of waveform at the origin and measure the separation between two consecutive crests in terms of the divisions marked on the screen. Multiply this value with the time base factor (TB), which gives the time period (T) of the waveform. Take reciprocal of time period, which gives the frequency of the waveform. Now trace the waveform of the screen using trace paper and pencil and keep a record of this trace. (If it is not possible to trace the waveform for some reason, then take its snapshot and then keep the printout of snapshot in your record).

6. Change the value of time base factor and repeat step 5 and again find the frequency. Then take mean of both these values.

Observations:

S. No.	Peak to peak Amplitude V (Volts)	Time base factor TB (s)	No. of div. Between two consecutive crests: n	Time Period $T = n \times TB$ (s)	Frequency $f = \frac{1}{T}$ (Hz)
1.					
2.					

Mean value =..Hz

Result: The mean value of frequency of given oscillator is ....Hz

Precautions and Sources of error: Same as experiment no. 9(f)

10. Experiment

Objective:

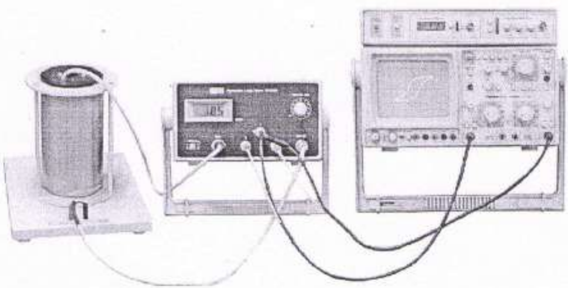
Study of the hysteresis loop for a given ferromagnetic material on a CRO using a solenoid

Equipments Needed:

1. CRO
2. Ferromagnetic Sample
3. Solenoid
4. Hysteresis Loop Tracer

Procedure:

1. Take sample holder and insert a ferromagnetic sample in the lower side.



2. Now insert this sample holder in the solenoid.
3. Connect the mains cord to instrument (Hysteresis Loop Tracer) on the back side.
4. Before switch 'On' the Hysteresis Loop Tracer, connect din connector cable of sample holder to the **Input** of the Hysteresis Loop Tracer.
5. Connect solenoid to **Solenoid** socket of Hysteresis Loop Tracer using three pin connector cable.
6. Connect 'Y' terminal of Hysteresis Loop Tracer to CRO 'Y' terminal with the help of BNC to 4 mm connector cable and other terminal of its cable to the 'E' terminal of Hysteresis Loop Tracer.
7. Similarly connect 'X' terminal of Hysteresis Loop Tracer to CRO 'X' terminal with the help of BNC to 4 mm connector cable and other terminal of its cable to the 'E' terminal of Hysteresis Loop Tracer.

Note: Here red terminal of both cables should be connected to 'Y' and 'X' terminals respectively of Hysteresis Loop Tracer and black terminal of both cable should be connected to 'E' terminal to Hysteresis Loop Tracer.

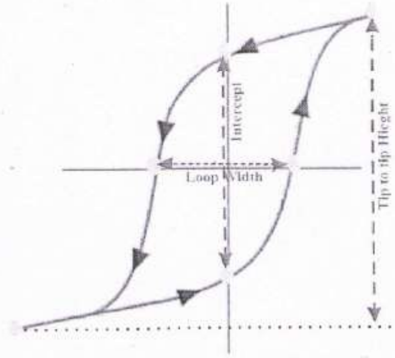
8. Keep CRO in 'XY' mode.
9. After installation of complete setup, Switch 'On' the Hysteresis Loop Tracer and CRO.

10. Adjust the magnetic field intensity with the help of **Magnetic Field** knob of the tracer.

11. Here magnetic field in Gauss will displays on DPM in accordance to the intensity of magnetic field.

12. Now the Hysteresis Loop of the taken sample will be displayed on CRO.

13. Adjust this Hysteresis Loop on the CRO screen using both Volts/Div knobs (X & Y) such that you can read all parameters of this loop easily.



Observations:

Equipment diameter of pickup coil = 3.21 mm

$g_x = 100$ (Total gain of both amplifier)

$g_y = 1$ (Gain of amplifier)

Sample = Commercial Nickel (standard)

Length of Sample (C) = 39 mm

Diameter of Sample (a) =1.17 mm

Cross Sectional Area of Sample (A_S) = $\Pi\ r_1^2 = 1.074$

Cross Sectional Area of pickup coil (A_C) = $\Pi\ r_2^2 = 8.088$

Therefore, Area ratio $\dfrac{A_S}{A_C} = \dfrac{1.074}{7.088} = 0.133$ mm

Demagnetizing Factor (N) = C/a = 39/1.17 = 33.33

= 0.0029 (As per Appendix)

Calibration:

By Adjusting N & $\frac{A_E}{A_c}$ as given above the J-H loop width is too small. Thus both are adjusted to three times i.e. 0.399 (0.4) & 0.0087 (near about zero) respectively. This instrument is also calibrated internally i.e. Demagnetization = near about zero & Area Ratio =0.4.

Set Magnetic Field: 200(rms)

e_x = 80 mm

e_x = 8.0 V (If read by applying on Y input of CRO)

For area ratio of unity:

$e_x = \frac{80}{0.4} = 200$ mm..(1)

$e_x = \frac{8}{0.4} = 20$ V..(2)

Now $G_0(rms) = \frac{H_a}{e_x}$

Where, Ha = rms value of magnetic field = 200 (from the display)

$G_0(rms) = 200/200$ (from eq. (1))

$G_0(rms) = 1$ G/mm

$G_{0\,(Peak\ to\ Peak)} = 1 \text{ X } 2\sqrt{2} = 2.828$ G/mm...............(3)

$G_0(rms) = 200/20$ (from eq. (2))

$G_0(rms) = 10$ G/V

$G_{0\,(Peak\ to\ Peak)} = 10 \text{ X } 2\sqrt{2} = 28.2$ G/V..................(4)

Calculation:

Loop Width = ... mm

= ......mm (after dividing by the multiplying factor 3)

Note: Here Loop Width is a distance between both intersection points on horizontal axis (x) in mm which is multiplied by position of X channel's Volt/Div knob.

Tip to Tip Height = ...V

Note: Here Tip to Tip Height is a distance between both peak points of loop on vertical axis (Y) in cm (Division) which is multiplied by position of Y channel's Volt/Div knob.

Intercept = ...V

Note: Here Intercept is a distance between both intersection points on vertical axis (Y) in cm (Division) which is multiplied by position of Y channel's Volt/Div knob.

1. **Coercivity:**

$$H_c = \frac{G_0 e_x}{\left[\frac{A_s}{A_c} - N\right]}$$

Where, e_x = ½ x Loop Width

2. **Saturation Magnetization:**

$$\mu_s = \frac{J_s}{4\Pi}$$

Where,

$$J_s = \frac{G_0 \mu_0 g_x (e_y)_s}{g_y\left[\frac{A_s}{A_c} - N\right]}$$

$(e_y)_s$ = ½ x Tip to Tip height

3. **Retentivity:**

$$\mu_r = \frac{J_r}{4\Pi}$$

Where,

$$J_r = \frac{G_0 \mu_0 g_x (e_x)_r}{g_y\left[\frac{A_s}{A_c} - N\right]}$$

$(e_y)_r$ = ½ x Intercept

Results:

Sample	Coercivity	Saturation Magnetization	Retentivity
Commercial Nickel	--------------Oe	---------------Gauss	------------Gauss
Hard Steel	--------------Oe	---------------Gauss	------------Gauss
Soft Iron	--------------Oe	---------------Gauss	------------Gauss

Typical Example

Loop Width = **30** mm

= **10** mm (after dividing by the multiplying factor 3)

Tip to Tip Height = **3.6** V

Intercept = **2.8** V

1. Coercivity:

$$H_c = \frac{G_0 e_x}{\left[\frac{A_s}{A_c} - N\right]}$$

Where,

$e_x = ½ \times$ Loop Width $= ½ \times 10 = 5$ mm

$G_0 = 2.828$ G/mm (from eq. **(3)**)

$\frac{A_s}{A_c} = 0.133$

$N = 0.0029$

Now

$$H_c = \frac{2.828 \times 5}{[0.133 - 0.0029]}$$

$$\mathbf{H_c = 108.68}$$

2. Saturation Magnetization:

$$\mu_s = \frac{\bar{J_s}}{4}$$

Where,

$$J_s = \frac{G_0 \mu_0 g_x (e_y)_s}{g_y\left[\frac{A_s}{A_c} - N\right]}$$

$g_y = 1$

$g_x = 100$

$\mu_0 = 1$ (Permeability of free space)

$\frac{A_s}{A_c} = 0.133$

$N = 0.0029$

$(e_y)_s = ½ \times$ Tip to Tip Height $= 3.6/2 = 1.8$ V

$$J_s = \frac{28.2 \text{ x } 1 \text{ x}100 \text{ x } 1.8}{1x[0.133 - 0.0029]}$$

$$J_s = 39016.14$$

Now

$$\mu_s = \frac{39016.14}{4 \text{ x } 3.14}$$

$$\mathbf{\mu_s = 3.1 \text{ K gauss}}$$

3. **Retentivity:**

$$\mu_r = \frac{J_r}{4}$$

Where,

$$J_r = \frac{G_0 \mu_0 g_x (e_x)_r}{g_y \left[\frac{A_s}{A_c} - N\right]}$$

$g_y = 1$

$g_x = 100$

$\mu_0 = 1$

$\frac{A_s}{A_c} = 0.133$

$N = 0.0029$ (Permeability of free space)

$(e_y)_r = ½ \text{ x Intercept} = 2.8/2 = 1.4 \text{ V}$

$$J_r = \frac{28.2 \text{ x } 1 \text{ x } 100 \text{ x } 1.4}{1x[0.133 - 0.0029]}$$

$$J_r = 303445.8$$

Now

$$\mu_r = \frac{30345.8}{4 \text{ x } 3.14}$$

$$\mathbf{\mu_r = 2.4 \text{ K gauss}}$$

Note: The above observation and calculation are given as a typical example.

Appendix

Demagnetization factors for ellipsoids of revolution for prolate spheroids, c is the polar axis.

C/a	$N_c/4$	C/a	$N_c/4$	C/a	$N_c/4$
1.0	0.333 333	4.0	0.075 4.7	20	0.006 749
1.1	0.308 285	4.1	0.072 990	21	0.006 230
1.2	0.286 128	4.2	0.070 693	22	0.005 771
1.3	0.266 420	4.3	0.068 509	23	0.005 363
1.4	0.248 803	4.4	0.066 431	24	0.004 998
1.5	0.232 981	4.5	0.064 450	25	0.004 671
1.6	0.218 713	4.6	0.062 562	30	0.003 444
1.7	0.205 794	4.7	0.060 760	35	0.002 655
1.8	0.194 056	4.8	0.059 039	40	0.002 116
1.9	0.183 353	4.9	0.057 394	45	0.001 730
2.0	0.173 564	5.0	0.050 821	50	0.001 443
2.1	0.164 585	5.5	0.048 890	60	0.001 053
2.1	0.156 326	6.0	0.043 230	70	0.000 805
2.3	0.148 710	6.5	0.038 541	80	0.000 637
2.4	0.141 669	7.0	0.034 609	90	0.000 518
2.5	0.135 146	7.5	0.031 275	100	0.000 430
2.6	0.129 090	8.0	0.028 421	110	0.000363
2.7	0.123 455	7.5	0.025 958	120	0.000311
2.8	0.118 203	9.0	0.023 816	130	0.000270
2.9	0.113 298	9.5	0.021 939	140	0.000236
3.0	0.108 709	10	0.020 286	150	0.000 209
3.1	0.104 410	11	0.017 515	200	0.000125
3.2	0.100 376	12	0.015 297	250	0.000083
3.3	0.096 584	13	0.013 490	300	0.000060
3.4	0.093 015	14	0.011 997	350	0.000045
3.5	0.089 651	15	0.010 749	400	0.000 036
3.6	0.086 477	16	0.009 692	500	0.000024
3.7	0.083 478	17	0.0008 790	600	0.000017
3.8	0.080 641	18	0.0018 013	700	0.000013
3.9	0.077 954	19	0.0007 339	800	0.000010

11. Aim. To find the velocity of ultrasound in a given liquid using ultrasonic interferometer.

Apparatus. Ultrasonic interferometer, sample liquid, high frequency generator.

Formula Used. If λ is wavelength of ultrasonic waves in a given liquid and d is distance between two consecutive current maxima, then velocity of ultrasonic waves in the liquid is given by

$$V = 2df$$

Theory. The schematic diagram of an ultrasonic inter ferometer is shown in figure (35). In this interferometer, ultrasonic waves are produced using piezoelectric method. The apparatus consists of an ultrasonic cell, which is a double walled brass cell with chromium plated surfaces and has a capacity to contain liquid upto 10ml volume. The least count of micrometer screw is 0.001 cm and pitch scale has length 25 mm. Ultrasonic waves of known frequency are produced by a quartz crystal which is fixed at the bottom of the cell. This crystal produces ultrasonic waves, which travel through the liquid filled in the cell. These waves are reflected from a movable metallic plate attached to micrometer screw. These reflected waves come toward quartz crystal. Thus waves generated by quartz crystal and reflected by metallic wave super impose an each other. If the separation between quartz plate and reflecting plate is exactly equal to whole number multiple of wavelength of ultrasonics, then standing waves are produced in the liquid medium. At this point, acoustic resonance occurs and this gives rise to an electrical resonance on the generator driving the quartz plate. Due to this the anode current of R.F. (Radio frequency) generator becomes maximum. If we increase or decrease

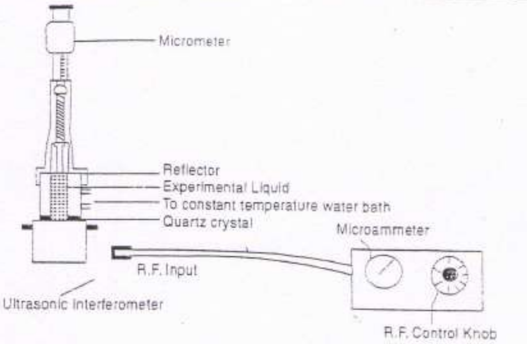


Fig. 35.

the distance between quartz place and reflecting plate exactly by an amount $\frac{\lambda}{2}$ or its multiple, then anode current again becomes maximum. If d is the separation between successive adjacent maximum anode current then

$$d = \frac{\lambda}{2}$$

or

$$\lambda = 2d \qquad \text{...(1)}$$

The frequency of the ultrasonic waves is equal to the frequency of oscillation of quartz crystal, which can be noted from R.F. generator. Let it be 'f'. Thus velocity of ultrasonic waves is given by

$$V = \lambda f = 2df \qquad \text{...(2)}$$

Further adiabatic compressibility of the liquid (β), which is equal to reciprocal of bulk modulus of elasticity (K) is also given as

$$\beta = \frac{1}{K} = \frac{1}{\rho V^2} \qquad \text{...(3)}$$

Procedure:-

1. Fill the ultrasonic cell with a given liquid and close the cell.

2. Connect the quartz crystal to R.F. generator and switch on the apparatus.

3. Adjust the frequency of R.F. generator so that ultrasonic waves are produced in liquid due to vibrations of quartz crystal and detectable current is noted on the microammeter attached to the generator.

4. Adjust the micrometer screw slowly so that current shows a maximum. Note this reading of screw. Again rotate the screw in same sense to note next consecutive maximum reducing of current. Now find the distance moved (d) by the screw by subtracting two readings.

5. Repeat the procedure two or three times by rotating screw in the same sense.

6. Note down frequency of ultrasonics from R.F. generator and then find velocity of ultrasonic waves from following table :

Least count of micrometer screw = ...

Table for finding wavelength of ultrasonics :

S. No.	Position of Screw at one maximum d_1	Positon of Screw at next consecutive maximum (d_2)	Distance moved $d = [d_1 - d_2]$
1.			
2.			
3.			

Mean separation between two Consecutive maxima = d = ...

Frequency of ultrasonics used = f = ...

Velocity of Ultrasonic waves in given liquid $V = 2df$ = ...

Result. The velocity of ultrasonics in a given liquid is ......

Precauions and Sources of Error

1. The least count of screw gauze must be carefully noted.

2. Screw must be rotated in one direction to avoid backlash

3. Ultrasonic cell should not be overfilled with the liquid.

4. There should not be any air gap between the quartz plate and reflecting plate.

12. To find the dielectric constant and polarizability of a solid sample.

Apparatus Required. A standard capacitor (≈ 50 pF), two gold plated circular metal discs, a dielectric sample, an A.F. oscillator, digital voltmeter, an inductor, cathode ray oscilloscope (C.R.O.), screw gauze, vernier callipers, connecting wires, resistance box etc.

Theory. The circuit diagram for the experiment is shown in figure (16). It contains an inductor, a standard capacitor C_s, a capacitor with dielectric slab (also called as dielectric cell) of capacity C_d and a suitable resistance R in series. The assembly is connected to a suitable a.c. source of variable frequency. Normal a.c. from household power supply cannot be used because its frequency (50 Hz) is very low and capacitors offer high reactance $\left(X_c = \frac{1}{c\omega}\right)$ to low frequency a.c. Thus frequency of a.c. source is chose suitably so that the passage of current through both capacitors is easy. This is achieved by checking wave shape of a.c. using a C.R.O. The frequency is so adjusted that a purely sinusoidal wave form of voltage/current exists in the circuit. Suppose ω is angular frequency of a.c. passed

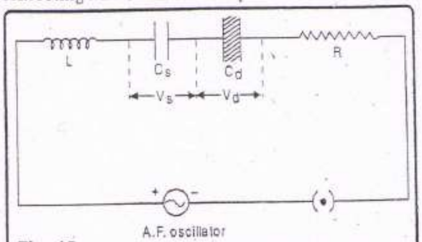


Fig. 16.

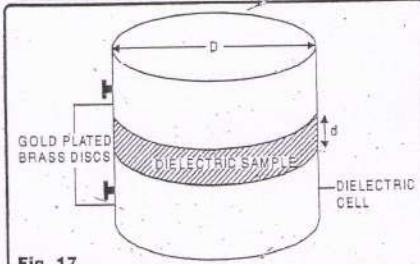


Fig. 17.

$X_{cs} = \frac{1}{c_s \omega}$ = capacitive reactance of standard capacitor

$X_{cd} = \frac{1}{c_d \omega}$ = capacitive reactance of dielectric cell

D = diameter of gold plated brass discs

d = distance between gold plated brass discs

= thickness of the dielectric sample

K = dielectric constant of dielectric sample

V_s = voltage across standard capacitor

V_d = voltage across dielectric cell

$A = \frac{\pi D^2}{4}$ = area of each gold plated brass disc

I_s = current passing through standard capacitor

I_d = current passing through dielectric cell

In series combination, current through all the components remains same. Hence

$$I_s = I_d$$

$$\Rightarrow \quad \frac{V_s}{X_{Cs}} = \frac{V_d}{X_{Cd}}$$

$$\Rightarrow \quad V_s \omega C_s = V_d \omega C_d$$

$$\Rightarrow \quad C_d = \frac{V_s C_s}{V_d} \qquad \ldots(i)$$

Suppose dielectric slab is removed from gold plated brass discs such that separation between plates is still 'd' *i.e.* plates are not allowed to touch each other. Then capacity of the capacitor becomes C_0, which is given by

$$C_0 = \frac{A \epsilon_0}{d} = \frac{\pi D^2 \epsilon_0}{4d} \quad \ldots(ii)$$

Let K is dielectric constant of the substance. Then by definition, it is equal to ratio of capacity of capacitor with dielectric slab to the capacity without dielectric slab.

i.e.
$$K = \frac{C_d}{C_0} = \frac{V_s C_s}{V_d} \times \frac{4d}{\pi D^2 \epsilon_0}$$

$\therefore$
$$K = \frac{4d V_s C_s}{\pi D^2 \epsilon_0 V_d} \quad \ldots(iii)$$

Using equation (*iii*), Dielectric constant of sample can be found.

The volume polarizability of solid dielectric is given as:

$\alpha = \varepsilon_0 (K-1)V$; where V is the volume of specimen

Procedure. (*i*) Connect the A.F. a.c. generator to the terminals of C.R.O. and adjust the calibration of generator so that a purely sinusoidal wave is appeared just before clipping. Note that the voltage output from A.F. generator should be in millivolt range only.

(*ii*) Disconnect the A.F. generator from C.R.O. and make connections as shown in the circuit diagram shown in fig. (17). Do not change the settings of oscillator throughout the experiment after calibration is done.

(*iii*) Switch on the unit. Using digital voltmeter, find the voltage across standard capacitor and then across dielectric cell.

(*iv*) Disconnect the circuit and using screw gauze find thickness (d) of the dielectric ~~Saple~~ Sample inserted between gold plated discs.

(*v*) Disconnect the circuit and using vernier callipers find diameter D of the brass discs.

(*vi*) Insert various values in standard formula to find the dielectric constant of the material.

(*vii*) Repeat the experiment with different samples.

Formula used. Let
d = thickness of dielectric slab
D = diameter of brass plate
C_s = capacity of standard capacitor
V_s = voltage across standard capacitor
V_d = voltage across dielectric cell
K = Dielectric constant
α = Volume Polarizability
V = Volume of the specimen

(*i*) $K = \frac{4d V_s C_s}{\pi D^2 \epsilon_0 V_d}$

(ii) $\alpha = \varepsilon_0 (K-1)V$