PYP100

First Year B. Tech. Laboratory

Department of Physics
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Contents

Guide to minimize errors

General:

1. Always write (and read!) the procedure for the experiment you are supposed to do before you come to the laboratory. Draw a diagram/circuit diagram of the apparatus as it will help you to set up the experiment. If there is any data to be noted down only once, e.g., the least counts of apparatus, room temperature, (note these down first). You are likely to forget to do so at the end. Always record all observation with a pen, not a pencil and do not overwrite. If you have taken down a wrong reading, cross it out so that the original can still be seen and write the correct reading next to it.

2. In every experiment if possible, first carry it out once without recording anything. This gives you an idea of what are the difficulties you may have when you actually record observations.

3. Always try to complete all the calculations before you leave the lab, that way you will immediately know if you have forgotten to note down some essential observations.

Tables:

1. On instruments like spectrometers which have two scales, always record readings from both scales separately. Similarly when you measure temperature difference with tow thermometers or any other difference with two "identical" instruments interchange them and record a second set

in the same table.

2. When calculating differences from a table use the method given below.Take an even number of readings and divide the table into two halves. Take the difference of the first reading of the first half and the first reading of the second half of the table. Then take the difference of the second reading of the first half and the second reading of the second half of the table. Proceed in this fashion down the table taking the difference of the corresponding readings from the two halves of the table.

Table 1: *
Example: To find the deflection/150 g.

S.No.	Weight in g.	Deflection in cm.	Deflection/150g (cm/g)
1	w	65.2	——-
2	$w + 50$	65.4	——-
3	$w + 100$	65.6	——-
4	w + 150	65.7	65.7 - 65.2 = 0.5
5	w+ 200	66.0	66.0 = 65.4 = 0.6
6	w + 250	66.2	66.2 - 65.6 = 0.6
7	w + 300	66.4	Ignored for even no. of readings

Never use any of the readings more than once, even if one of the values remains unused as above. This way any errors you may have made in recording a particular reading only affects one of the differences in the table.

Graphs:

1. As far is possible, choose the scale on the axis of any graph such that the least count of the graph paper is equal to the least count of the variable being plotted on that axis. Always write the proper units on the labels for each axis, and the proper units for the slope if you find it.

2. To calculate slopes there are two possibilities.

(a) If the data falls on a straight line, make a table of differences as shown above and calculate the slope from the table.

(b) If the data does not fall on a straight line, proceed as follows.

To calculate the slope at (x, y), take the data from three points on either side of (x, y), and form a table as given below. The slope at x, y is then

$x - 2.5h$	$y1$ —		
		$- y2 - y1 = dy1$ ——	
$x - 1.5h$	$y2$ —		$- dy - dy1 = d(dy1)$
$x - 0.5h$	$y3$ —		
		$- y4 - y3 = dy$ ——	
x	y		
$x + 0.5h$	$y4$ —		
$x + 1.5h$	$y5$ —		
		$- dy2 - dy = d(dy2)$	$- y6 - y5 = dy2$ ——
$x + 2.5h$	$y6$ —		

equal to,
$Slope(x, y) = [dy + \{dy1 + d(dy1)/2h\} + \{dy2 - d(dy2)/2h\}]/3h$

The above formula follows from the usual definition of the derivative and Taylor series expansions about (x, y).

If the data are not equally spaced about (x, y) then the two second derivative terms will not cancel but if h is comparable to the least count then no appreciable error is made in using this simple formula even in such a case.

Though it might appear from the above that every calculation can be done from a table. plotting a graph always shows you the general behavior of the data and should be done. When doing so, the curve need not pass through all the data points but (must be smooth and as close as possible a fit) to all of them.

To draw such a curve, take a piece of transparent plastic tube, of the type used in room coolers, or a strip of transparent plastic 1” $*$ 12” of the type used for covering books or making overhead transparencies. Bend this strip on your graph paper (it must be stiff) so that it passes close to the data points. Hold it in position and use it as a guide to draw the curve.

Results:

Calculate and report the error in your results, as will be described in detail below, the three most commonly used measures are,

1. Probable error

2. Maximum possible error or instrumental error.

3. Percentage error or deviation from the standard value.

The last need not be reported, as the conditions of your experiment are not the same as those under which standard values are measured. You can however mention the standard value if you know it.

If you have more than five independent observations always calculate the probable error otherwise use the maximum possible error.
An example of how to report your results. If you measured the coefficient of linear expansion of copper to be 0.00001856/K with a maximum possible error of 0.000002365/K then write the answer as,
Coefficient of Linear expansion of Copper= $(1.86 + 0.24) * 10^{-}5/K$
the standard value at room temperature is= $1.66 * 10^{-}5/K$.
While calculating results, retain all the significant figure in the result is comparable to the most significant figure in the error.

Errors:

As mentioned above, errors can be of many kinds and a brief description follows. First of all there are the so called systematic errors, e.g. personal ones like parallax in observing meter readings, or instrumental ones like backlash or wrong marking of the scale. Please avoid these errors while taking down your readings.

Apart from these however the fact that every instrument has finite accuracy(a finite least count) means that if you take several observations very carefully they will still not give you identical results,. If your observations are good then the results of each set will be distributed randomly about a mean value which is the true result.

To characterize this spread in the results due to the finite least count of the apparatus we use two kinds of error measurements:

1. Maximum Possible Error

2. Probable error.

Maximum Possible Error:

Consider the measurement of the density of a solid cube of Mass M and side L. Then the density is,

$$D = (\frac{M}{L^3}) \tag{1}$$

However any measurement of mass M or weight can only be performed to an accuracy dM, the least count of the balance used. Similarly, lengths L can be measured to within the accuracy dL of the measuring rod used. To calculate the inherent (instrumental error) due to the least counts of the measuring instruments we start by taking logs on both sides followed by differentiation:

$$\frac{\Delta D}{D} = \frac{\Delta M}{M} + 3\frac{\Delta L}{L}. \tag{2}$$

As the errors is general can be positive or negative, to find the maximum error, we must take the absolute magnitudes of all the derivatives involved and add them. The corresponding fractional error is referred to as the (maximum possible error or instrumental error). This formula is also sometimes referred to as the log error. This error must always be calculated and the result written down as,

$$Density = D \pm \Delta D \tag{3}$$

Note that in this method, if the difference or sum of two experimental quantities appears in a formula, then the error doubles. For example, the heat transferred per unit time Q across a sample by conduction is proportional to the temperature difference $(T_1 - T_2)$ across it. $Q = S(T_1 - T_2)$. The maximum possible error in this case is:

$$\frac{dQ}{Q} = \frac{dS}{S} + \frac{2dT}{(T_1 - T_2)} \tag{4}$$

Apart from such inherent instrumental errors, there are the random individual errors that you make in taking down each reading. To deal with these, we use the concept of probable error.

Probable error:

You are probably aware from courses on probability theory that under very general assumptions, any long sequence of independent observations of a variable x will be found to follow a Gaussian or normal distribution,

$$p(x)dx = (1/2S)exp[-(x-\bar{x})^2/2S]dx. \tag{5}$$

Here $p(x)$ is the probability that the observation lies in an interval dx about the value x. Then as can be easily seen,

$$Themean = \bar{x} = \int xp(x)dx \tag{6}$$

$$andstandarddeviation = S = \{\int (x-\bar{x})^2 xp(x)dx\}^{1/2} \tag{7}$$

The quantity S is a measure of how spread out your observations are about x and thus a measure of "goodness" or otherwise of the readings. It is referred to as the (probable error).
The formula as given above is impractical as it requires an infinite number of observations to evaluate the integrations. When only a finite number, n of observations is made, we replace the integrals by summations to obtain,

$$\bar{x} = (1/n)\sum_j x_j, \tag{8}$$

$$S = (1/n)\sum_j (x_j - \bar{x})^2. \tag{9}$$

This quantity must always be calculated and reported when the number of observations is large(> 4). The result then is reported as,

$$Result = x \qquad \pm\, dx \qquad \pm\,(S) \tag{10}$$

instrumental error   probable error

Note that the two errors are not to be summed.

Problems:

1. Student in a class get the following marks out of 50,
36.5, 30, 20, 32, 29, 36.5, 26.5, 22, 32.5, 22, 29.5, 18.
Find the mean mark and the standard deviation after normalizing the total to 100. Plot a gaussian with the same mean and deviation along with the data given above on a graph.

Parallax Removing:

For optics experiments (in this lab for the Fresnel's Biprism experiment) another important error introducing factor is parallax- so for such experiments, we have to learn how to remove parallax.

In all cases of optical measurements where an accurate determination of the position of an image is sought for, we take recourse to the method of parallax.

Let P_1 represent a line drawn on transparent screen and P_2, the image of a linear object. Both P_1 and P_2 stand perpendicular to the plane of paper. An eye placed in the position E behind the screen sees both the line coincident. As the observer moves his eyes to the position E_1 and E_2, a relative motion occurs between P_1 and P_2. The same relative motion takes place when the image is formed between P_1 and the eye. this relative motion ceases only when P_1 and P_2 coincide. This method of finding the position of an image by making it coincide with a reference line and point is known as the method of parallax.

In order to ascertain, during adjustment, whether the image is formed in front of or behind the screen, move your eyes across the line joining P_1 and P_2. If the image moves in the same direction as the eye (with respect of P_1 the reference line), then the image is further away from the eye than the screen. If the image moves in the opposite direction, then it is nearer to the eye than the screen.

To avoid parallax, either the screen or the lens or the mirror forming the image or the object itself is slowly displaced until there is no parallax between the image and the reference line.

Using the balance:

1. Look at the plumb-line and make sure, that the balance is level. If necessary, level it by turning the leveling screw at the base or ask for help.

2. Determine the 'zero point', i.e. the equilibrium position of the pointer when passed are empty.

3. Place body to be weighed on left-hand pan and weights systematically , only when the beam is in the arrested position and then release the beam and check.

4. By trial put enough weight on right pan so that the new position of the pointer appears to lie within 5 pointer to the right of zero point. Allow the beam to oscillate and take readings of 3 to 5 successive turning points. Call it Q.

5. Add 10 mgm weight to right-hand pan and find corresponding rest-position call it R. Record the data as follows:

Load on left-pan	Load on right pan	Turning points Left	Turning points Right	Mean Left	Mean Right	Zero point	Rest positions
Nil	Nil	a) 4.9 b) 5.3 c) 5.6	a) 15.1 b) 14.8	5.2	15.0	10.2 (P)	
Body	15.23 g	a) 10.1 b) 10.5 c) 10.8	a) 20.4 b) 20.1	10.5	20.3		15.4(Q)
Body		a) 3.8 b) 3.4 c) 3.1	a) 9.6 b) 9.5	3.4	9.7		6.6(R)

Mass of body:

$W = 15.23$ is smaller than that of body by an amount which causes displacement of pointer $= 15.4 - 10.2 = 5.2$ div. Now, causes displacement of 5.2 div would be caused by$5.2/8.8 * 10mgm = 5.9mgm = 0.0059gm$. Therefore mass of body$= 15.23 + 0.0059 = 15.2359$.

1.

Study of a power supply

1.1 Introduction

A car battery can supply 12 volts. So can 8 dry cells in series. But no one would consider using the dry cells to start a car. Why not? Obviously, the dry cells cannot supply the large current required to start the car. The point is that the resistance of the source for the car battery($\sim$ 0.1 ohm) is considerably smaller than that for the 8 dry cells($\sim$ 5 to $\sim$ 70 ohms) in *series**.A power supply which happens to be another commonly used source in the laboratory has a widely varying resistance; for a regulated power supply it may be as small as 0.1 ohm. A source of emf figure 1.1(a) ,therefore, must be represented not just by its voltage V_s but by its *source resistance* R_s as well figure 1.1(b). It is convenient to think of the source V_s and its resistance R_s as enclosed in an imaginary box(indicated by the dotted line in figure 1.1(b) with terminals A and B, which we can put to any use we like. Electrical networks may be complicated but it is often very useful to think of parts of it as a 'box' with certain parameters associated with it-in the above case the parameters being V_s and R_s.

* There are, of course, many other factors that dictate practical use of a power source. Consideration of cost, convenience of use, rechargeability, available power and energy etc. are some of these. For example, a dry cell may give only a few watt-hours of energy and cannot be recharged whereas a car battery can give 500 watt-hours and, with care, can be recharged any number of times. A power supply, on the other hand, derives its power continuously from the a.c. mains and hence needs no charging and can deliver any amount of energy. We shall however, not discuss these factors here, important as they are.

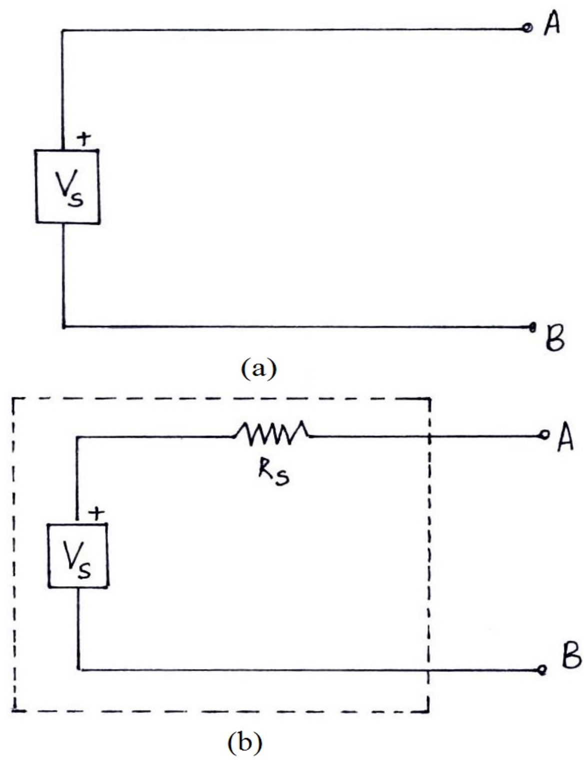


Figure 1.1:

Suppose we are given such a box with terminals A and B and we have to determine R_s and V_s. First let us see how to do this in principle, We connect a voltmeter of very high resistance(ideally infinite) so that it draws no current. It will measure V_s directly. We can now connect an ammeter(ideally zero resistance) and measure the current which will be

$$i = V_s/R_s \tag{1.1}$$

Thus, we may *define* the source resistance as the *open circuit* voltage between A and B divided by the current when A and B are *short-circuited.* In practice, we may have to exercise caution since the short circuit current may be very large and damage the instrument or the source itself.

We may now adopt the following attitude. The terminals A and B provide a certain source of voltage V_s with a source resistance R_s. Actually, R_s may include other circuit elements as well. For example, think of the arrangements

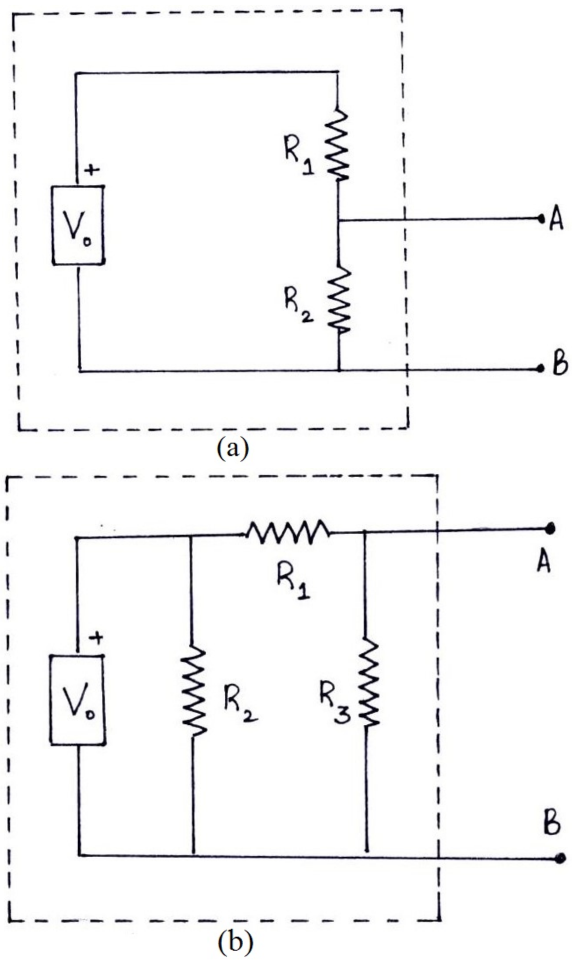


Figure 1.2:

in figure 1.1(a) and figure 1.1(b). For these too we can represent the 'source' by a certain output voltage V_s and source resistance R_s as shown in figure 1.1(b). For the case of figure1.1(a) Ohm's law gives us

$$V_s = V_o \frac{R_s}{R_1 + R_2}, R_s = \frac{R_1 R_2}{R_1 + R_2} \tag{1.2}$$

We can now say that we have a source of output voltage V_s across the terminals AB, with an effective resistance R_s. This effective source resistance R_s is often called the *output resistance* of the device as seen from AB. We shall develop the above ideas with a few simple experiments.

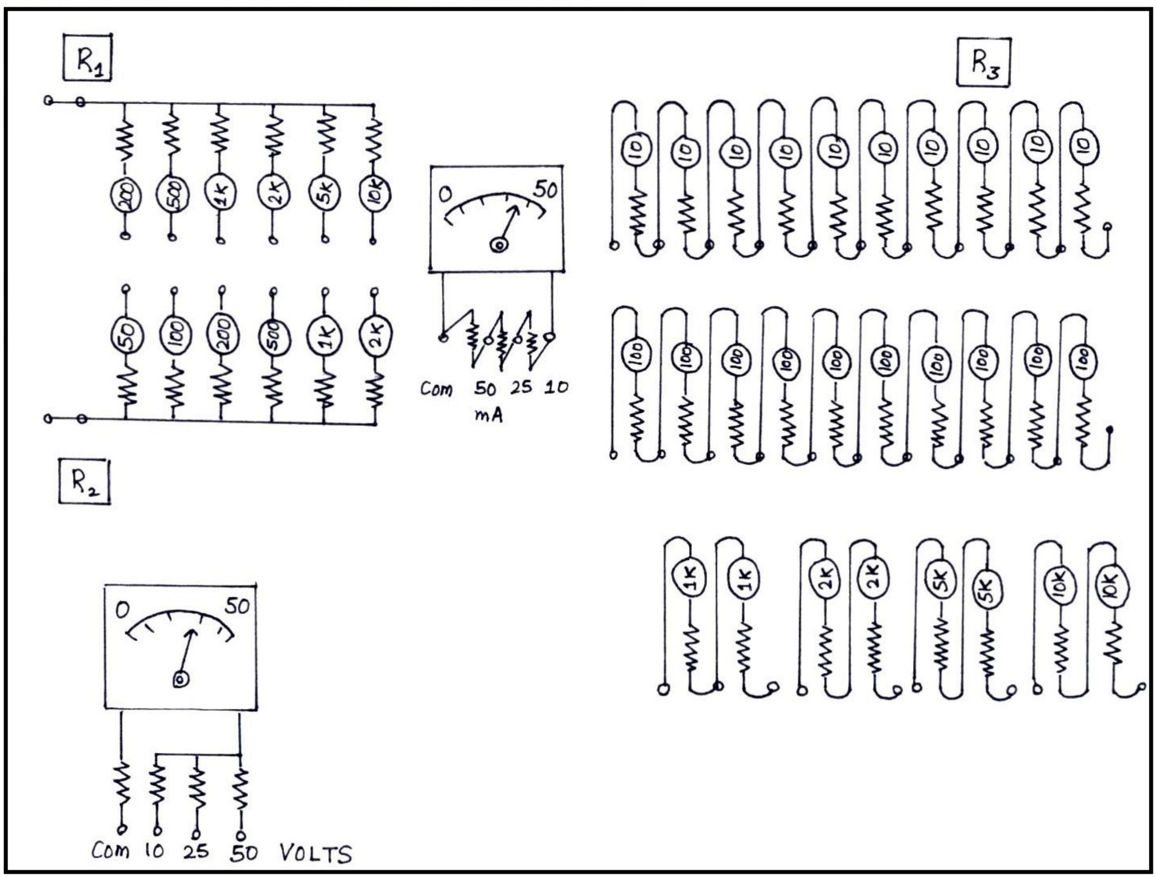


Figure 1.3: The network board

1.2 The Network Board-1

The network board for our experiment is shown in Plate 1. It contains three groups of resisters R_1,R_2,R_3, each group having several different resistors to choose from. It has a d-c milliammeter and a d-c voltmeter. Figure 1.3 shows the details of connections provided underneath the board. It will be seen that one could choose any one resistor from group R_1 and any one from group R_2 to make up a 'source' like that in figure 1.1(a). The third set of resistors R_3 are all connected in series and can be used as load. One could plug-in at any pair of points and get the desired value of the *load*.

1.3 Experiment A

To obtain the output voltage and output resistance of a given source.

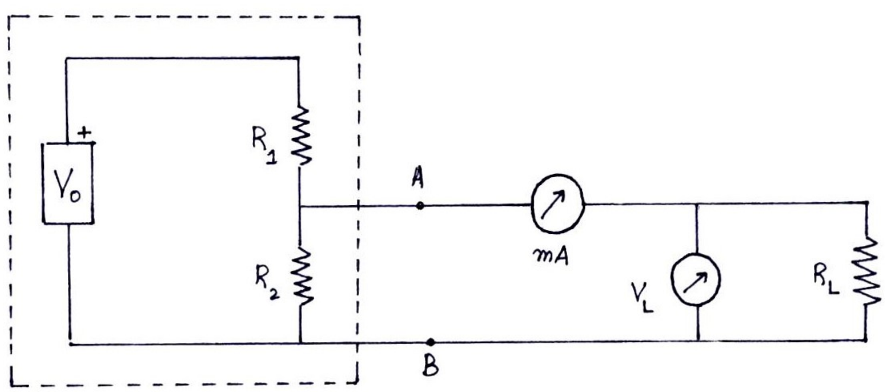


Figure 1.4:

Let the dotted 'box' in the figure 1.4 with AB for its output terminals be our 'source'. As can be seen from the figure, in fact it consists of a power supply of voltage V_o and a potential divider arrangement made of resistors R_1 and R_2. We have to measure its output voltage across AB and then calculate its output resistance R_s.

V_s is measured by connecting the voltmeter directly across AB. Of course, it is implied here that the resistance of the voltmeter is so large that the current flowing through it can be neglected.

Now connect a resistor R_L called *load resistor* along with a milliammeter. The current i drawn from the source is measures by the millimammeter and the new voltmeter reading V_L would be lower than V_s. If R_s be the output resistance of the source then

$$V_s - iR_s = V_L \tag{1.3}$$

Thus the output resistance R_s is given by

$$R_s = \frac{\text{Drop in output voltage}}{\text{Load current}} = \frac{V_s - V_L}{i} \tag{1.4}$$

If we take several different values of R_L, we shall be drawing different currents i. The voltage drop $V_s - V_L$ will also correspondingly change. You may tabulate these values, compute R_s each time from eq(1.4), and obtain the mean R_s. Alternatively, you may draw a graph between V_L and i as shown in figure 1.5, see if it is a straight line, and obtain R_s from its slope and V_s from its intercept on the V_L axis (since i=0 for this intercept V_s would be the same as V_L) Can you appreciate why it is much better to calculate R_s from the graph rather than directly from your observations ?

Represent your results $V - s$,$R - s$ with a diagram like that in figure 1.1(b). This would be the 'equivalent circuit' for the actual source in fig 1.4.

1.4 Experiment B

To study the variation of the output resistance R_s with changes in values of R_1 and R_2, the ratio R_1/R_2 remaining constant.

In the arrangement of figure 1.4, if the power supply is of voltage V_o and resistance zero, then by ohm's law the output voltage across AB should be

$$V_s = V_o \frac{R_2}{R_1 + R_2} \tag{1.5}$$

You may check the measured V_s against the value calculated from eq(1.5). The dependence of the value of the output resistance R_s on R_1 and R_2 is

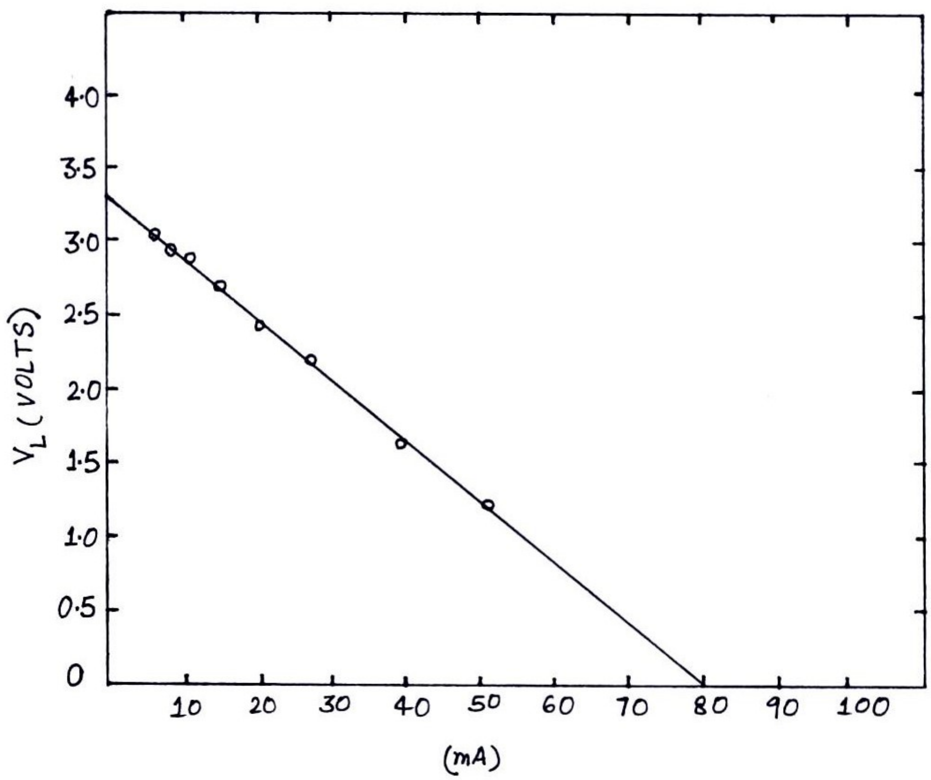


Figure 1.5:

obvious. Eq(1.5) shows that if both R_1 and R_2 are changed by the same factor, V_s does not change. The value of R_s should, however, change. Let us examine this by experiment.

With one set of R_1 and R_2 measure R_s as in Expt A. Now change the resistors xR_1 and xR_2 where x is some common factor. Measure R_2 again. Repeat this with different values of x and examine how R_s varies with x.

The behavior of R_s with x can be discussed as below. Figure 1.6(a) and figure 1.6(b) are equivalent. One can now see from the latter that if the power supply itself has a negligible resistance, then inside the 'source' R_1 and R_2 are in parallel, so that the output resistance of the source as seen at AB should be

$$R_s' = \frac{R_1 R_2}{R_1 + R_2} \tag{1.6}$$

By changing both R_1 and R_2 by a factor x, the new output resistance R_s' will be given by

$$R'_s = \frac{xR_1.xR_2}{xR_1 + xR_2} = \frac{xR_1R_2}{R_1 + R_2} = xR_s \tag{1.7}$$

Thus for a given ratio of R_1/R_2 i.e. for a given ratio of V_s/V_0, the output resistance comes out to be proportional to x.

Using Ohm's law, deduce an expression for the current i drawn by a load R_L connected across AB in figure 1.6(a). Use this result to obtain expressions for V_s and R_s.

1.5 Experiment C

To study the power delivered by a source at different loads

A load resistor, connected across the terminals of a 'source', draw some current from it and thus consumes the power delivered to it by the 'source'. It is interesting to study how the latter varies with the load. If, for a certain load R_L, the current is i, the voltage across the load is V_L, then the power P delivered by the 'source' is given by

$$P = V_L i \tag{1.8}$$

Connect different resistors R_L and measure current i and voltage V_L each time figure 1.7. Tabulate these data and compute the power P using eq(1.8). Also plot against R_L and draw a smooth curve through the observation points figure 1.8.

The curve has a broad maximum for some value of R_L. What is so special about this particular load? If you measure the output resistance R_s of the source(Expt. A) you will find that the power delivered is maximum when the load R_L has the same value as R_s.

1.6 Experiment D

To learn more about 'load matching' and power dissipation in a circuit

We have already seen in Expt B how for a given ratio of R_1/R_2, the output voltage V_s does not depend on the individual values of R_1 and R_2

whereas the output resistance R_s does. Using this knowledge try different arrangements of R_1 and R_2. Measure the output resistance R_s in each case (Expt A). Also measure the variation of the power P delivered to the load R_L for each value of R_s.

Plot the following quantities as a function of the load; (a) the load current i (b) the voltage V_L across the load (c) the power dissipated in the load (d) the fraction of power dissipated in the load upon power expended by the source. You will see that maximum power is delivered when the load R_L is equal to the output resistance R_s. This disarmingly simple result is of great importance and you will come across it again and again in various forms. The idea is that the load resistance should match the output resistance for maximum power $transfer^*$. You will also notice that the current i is maximum when R_L is zero, the voltage V_L across the load is maximum when R_L is infinite but the power iV_L dissipated in the load is maximum when $R_L = R_s$ and is equal to $V_s^2/4R_s$. Remember, this is not the power expended by the source which is $V_s^2/2R_s$.

A source of output voltage V_s and output resistance R_s when connected across a load R_L gives a current $i = \frac{V_s}{R_s+R_L}$ and delivers power to the load directly given by $P = i^2R_L$ Show, using differential calculus, that P is maximum when $R_L = R_s$.

1.7 Experiment E

To study the reflected load resistance in a network**

Consider figure 1.9(a). When R_L is not connected, let the current through the circuit be i. On connecting R_L, this current increases to some value i_o which means that the load R_L connected across AB increases the current from i to i_o.

We can achieve the same result if we connect a suitable load R_L' across

*This statement is true for alternating current circuits also. There we talk of output impedance instead of output resistance and the principle assumes its general name-the principle of impedance matching.

**For doing this experiment, you will need a resistance box in addition to the Network Board as shown in figure 1.3. Also note that in experiment on reflected load resistance measurement a power supply with an output voltage V_o and negligible output resistance is used as the source.

CD(which means directly across the power supply). This load R'_L seen by the source is called as the *reflected load resistance*.

For the simple circuit shown in figure 1.9 you can also calculate the reflected load resistance R_L by applying Ohm's law but in more complex networks such calculations may not be all that simple. Nevertheless, the fact remains that for a load R_L across any two points(AB) in a network, simple or complex, you can always determine the reflected load R'_L as seen by the power supply(across CD). In this sense therefore, the network acts as a 'transformer'. It is usually called an *impedance transformer* when the network has components other than pure resistance also.

More generally, we can replace the actual load R_L by a load R'_L in another part of the circuit such that the current drawn from the source is the same. One then calls R'_L as the *transfer load*(transfer resistance or transfer impedance as the case may be). An example of this is shown in figure1.10.

Deduce an expression for the current in figure 1.9(a) when R_L is connected. Deduce a similar expression for the case of figure 1.9(b) when R'_L is connected. Hence, obtain an expression for the reflected load resistance. Draw conclusions for the limiting cases of $R_L \to \infty$ and $R'_L \to \infty$

In the study of complicated circuits impedance transformations lead to considerable simplicity of analysis and are widely resorted to. We should, therefore, try to see this atleast in a simple circuit like the one shown in figure 1.11.

Use a resistance box for R_L along with the network board for this experiment. First keep $R'_L = \infty$(plug off) and read the current in the milliammeter when $R_L = \infty$ and when R_L has a given value. Let these readings be i and i_o. Now set $R_L = \infty$, plug-in R'_L and adjust its value such that the current has a value of i_o. Read the value of R'_L at this stage.

Keeping R_1,R_2 and R unchanged, take different values of load R_L and for each case experimentally obtain the transfer load. It may be worthwhile to plot R'_L against R_L and see how it varies with R_L.

In the circuit of figure 1.9(a), the load R_L, on being connected across the output terminals AB, increases current from i to i_o. Show that the transfer load(reflected resistance) R'_L as seen at CD is given by $R'_L = \frac{V_s}{i_o - i}$ where V_s is the output voltage at AB. (Thus R'_L can be deduced from measurements i,i_o unlike the method of direct substitution suggested in Expt E)

1.8 Experiment F

To make a simple equivalent circuit for a power 'source' ***

In Experiment A, you took a simple source figure 1.4 of output voltage V_s and output resistance R_s. Now you may take a far more complicated arrangement, like the one shown in figure 1.12(a) and measure its $V - s$ and the series resistance is adjusted to be R_S. This is an 'equivalent circuit' corresponding to the circuit of figure 1.12(a). We may check this equivalence directly by experiment.

Make any network and choose any two points AB in that network as the 'output terminals'. Apply different loads R_L at these terminals and each time measure the current i drawn and the voltage V_L across AB. From these calculate V_s and R_s as in Expt A. Now take a power-supply and adjust its voltage to the value V_s. Connect a resistor of value R_s in series with it Figure 1.12(b). Then apply the same loads R_L across its output terminals AB and each time measure i and V_L. Compare these results with those obtained with the complicated network and see if the equivalence is complete.

Even when there is more than one source of emf in the network, the equivalence holds. In a-c circuits, with inductors and capacitors also present, the equivalence involves some more details, but is still a very useful concept.

*** This could be done immediately after Expt A as an exercise to see how any 'source'(with whatever complicated details) can be replaced by an equivalent circuit of an emf V_s and a series resistance R_s. You would need some extra resistors in addition to your Network Board for doing this experiment

APPENDIX
Carbon Resistors

Carbon, either alone or in combination with other materials, is used in making a class of resistors which are commonly used in radio and other communication circuits. After the advent of transistors and integrated circuits where one seldom handles large power, their use has gone up phenomenally. The commonest form of mass-produced resistors is the *composition resistor*, in which the conducting material, graphite or some other form of carbon, is mixed with fillers that serve as diluents and combined with an organic binder. Two general types of composition resistors are the *solid body*, which is moulded or extruded, and the *filament type*, in which carbon is baked on a glass or a ceraminc rod and sealed in a ceramic or bakelite tube.

Composition resistors of the usual type are, however, notoriously unstable in resistance values. If they are used only at a low power level, the change in resistance results principally from the effect of humidity on the unit. If operated near the rated load, the changes in resistance result primarily from decomposition of the organic binder.

Much better stability is found in a special film type of resistor known as a pyrolitic or "cracked carbon" resistor. Such resistors are made by depositing crystalline carbon at a high temperature on a ceramic rod by "cracking" an appropriate hydrocarbon. In one process for making these film resistors, carbon is deposited from methane gas in a nitrogen atmosphere from which water vapour and oxygen are carefully excluded. No binder is used, and the carbon deposits consist of a hard gray crystalline form from which graphite and carbon black are completely absent. After the deposit is formed, the resistor is adjusted to its required value by cutting a helical groove around the cylinder with a diamond impregnated copper wheel. This removes part of the deposit and leaves a helical conductor of a suitable length and width for the desired resistance. After terminals are applied by a suitable process, the surface of a resistor is lacquered with some silicon type of varnish to provide insulation, moisture resistance and mechanical protection. These are then sorted out by measurement with a bridge in series having a tolerance of 10% or 5% or less.

For 1 watt 10k resistors of this type, a typical temperature coefficient is -0.02% per °C (minus sign indicates a decrease of resistance with increase in temperature unlike the wire-wound resistors) and for a 5megaohm resistor this figure is -0.04% per °C.

There are some other advantages in using these film resistors. Their compactness of shape and size renders them easier to handle and suitable to fit in a small space. They are avilable over a wide range of resistance(from 1 ohm to 1000megaohms or more). The 10% series are available in values starting from 1 ohm in a geometric progression of about 1.5 namely, 1, 1.5, 2.2, 3.3, 4.9... ... . Similarly the values in the 5% series are in a geometric progression of 1.2 namely, 1, 1.2, 1.5, 1.8, 2.2... ... ... The resistance values are sometimes marked with colour bands. The colour code is-

Black 0, Brown 1, Red 2, Orange 3, Yellow 4, Green 5, Blue 6, Violet 7, Gray 8.

A simple way to remember this is the mnemonic - *B.B. Roy Goes to Bombay Via Gateway* [Perhaps you could make a better one].

You will notice four coloured bands, three narrow and one broad, on such resistors. The first two narrow ones, represent the first two numbers, and the third represents the number of zeroes after two numbers. The three narrow bands thus give the value of the resistance. the (fourth) broad one representing the tolerance is either a silver or a gold band, the former for 10% and the latter for 5%. Suppose on a resistor the colour bands are like this. Brown, Gray, Red and Gold. This would mean a value of 1800 i.e. 1.8k with 5% tolerance.

REFERENCE

1.Blackburn, Components Handbook, Vol. 17
2.M.I.T Radiation Laboratory, Mc Graw Hill, 1949.

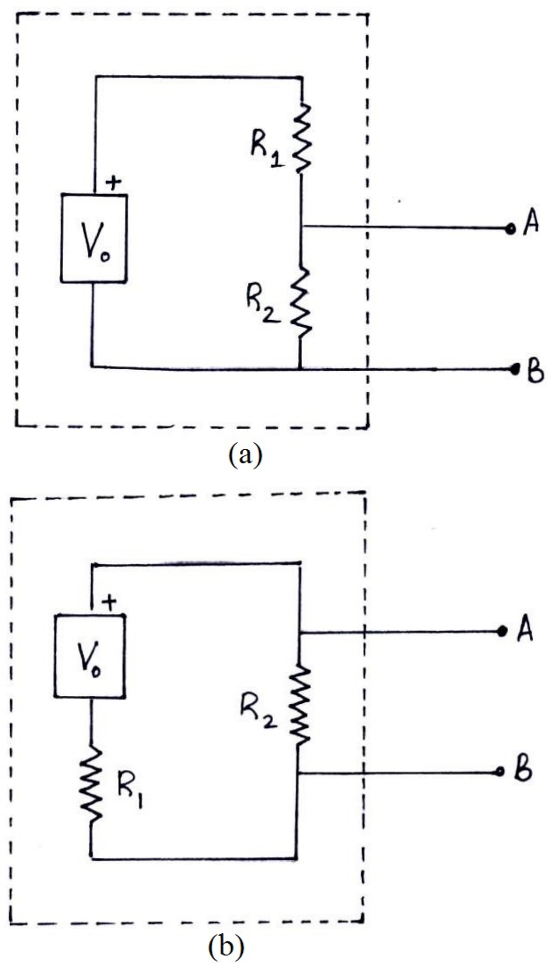
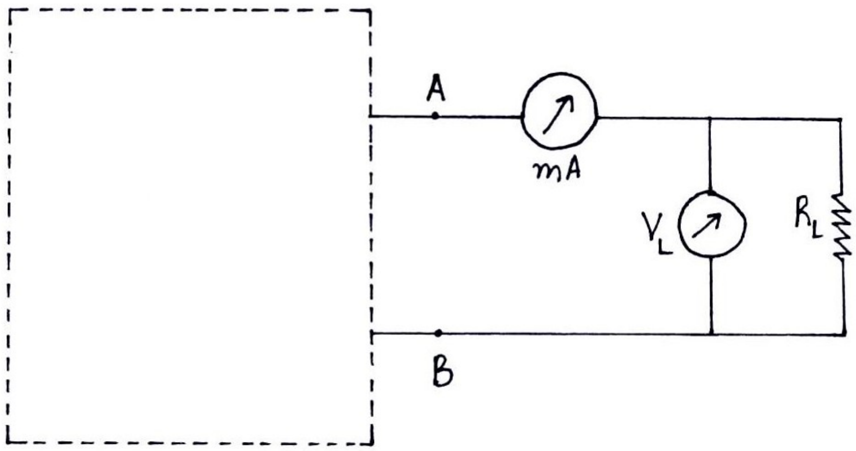


Figure 1.6:



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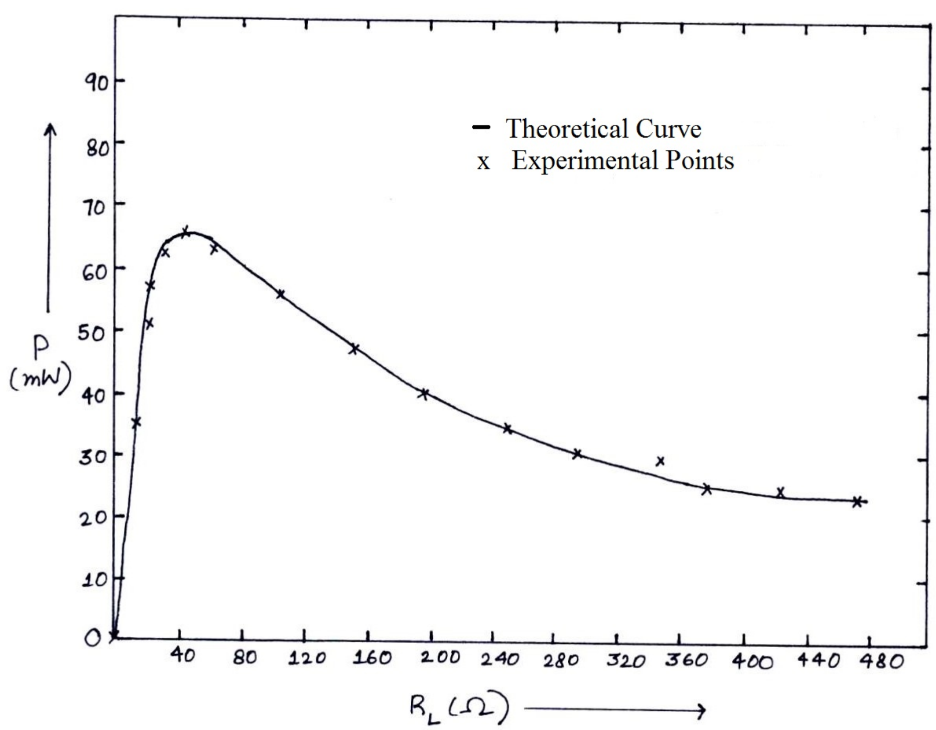
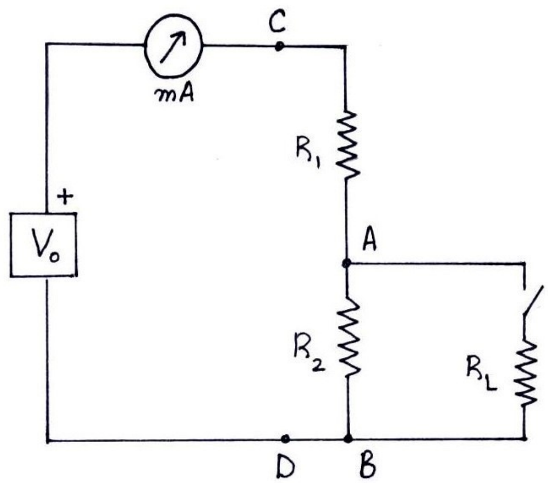
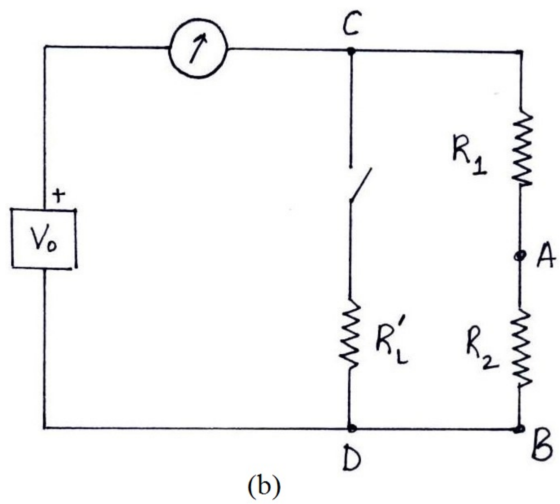


Figure 1.8:



(a)



(b)

Figure 1.9:

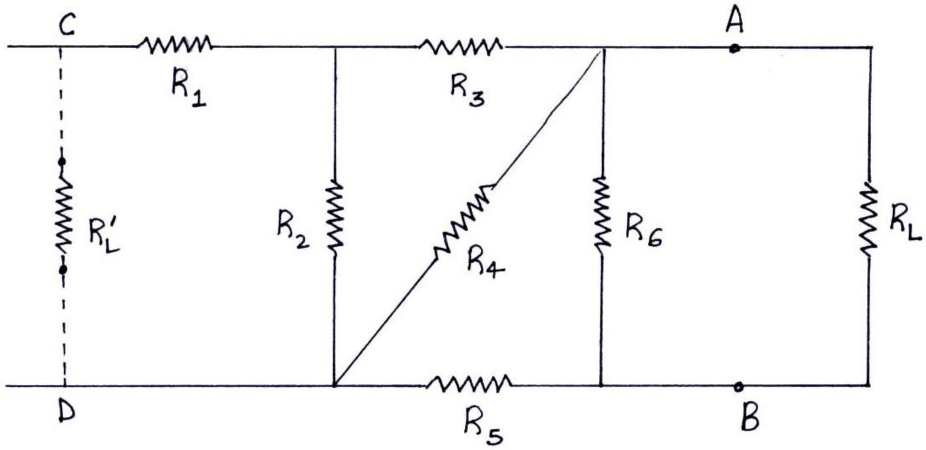


Figure 1.10:

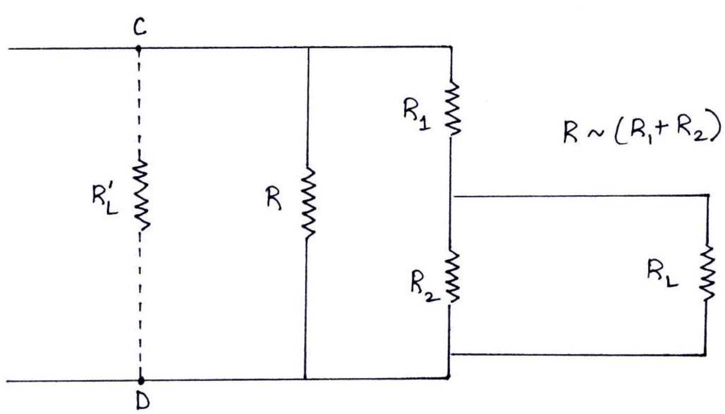


Figure 1.11:

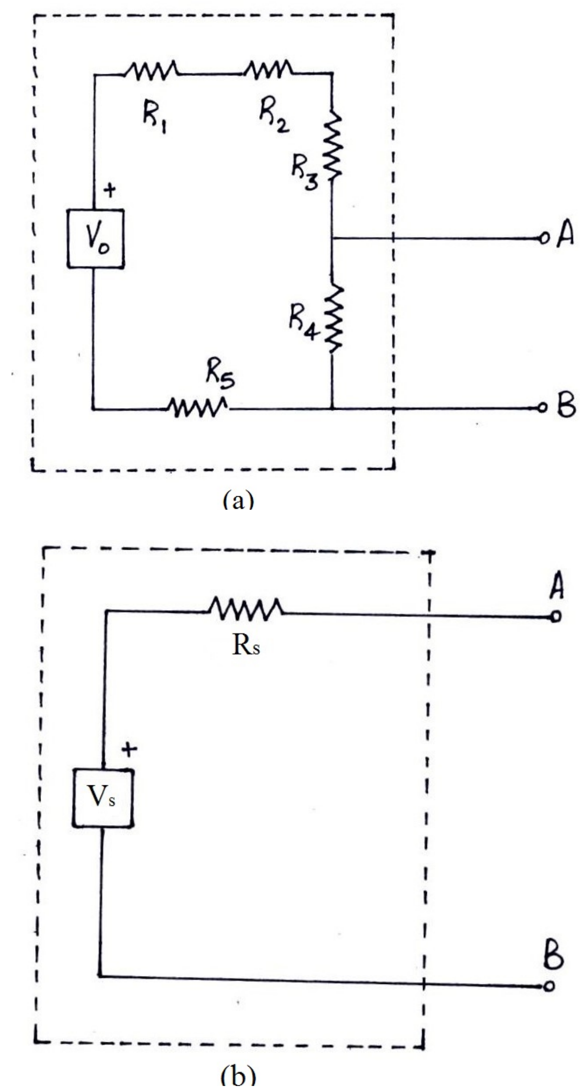


Figure 1.12:

2.

Phase Measurement By Superposition

2.1 Introduction

The method of vector diagrams for determining the magnitudes and relative phases of voltages and currents in a-c networks is not easy in many cases. Consider, for example, the following circuit.

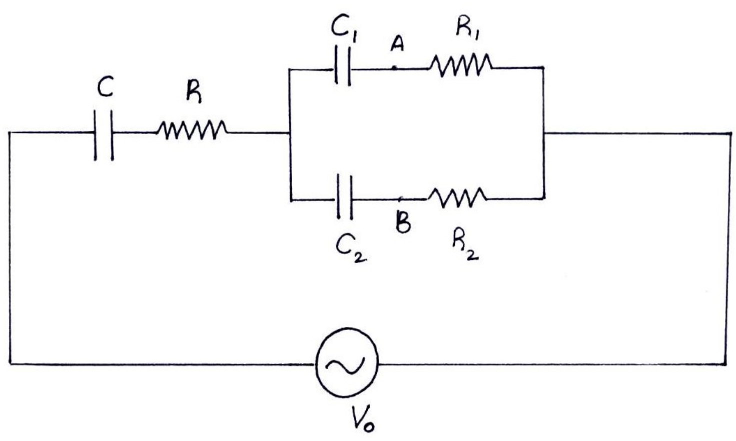


Figure 2.1:

If you want to know the phase difference between the voltages V_A and V_B

it would not at all be a simple matter to infer this from a vector diagram.(Try it). For this reason, we introduce a method by which you can determine phase differences *directly* and study phase relationships in various networks.

2.2 Principle of measurement

The principal we shall employ is *superposition* of the voltage to be measured and a *fixed standard voltage* so that the phase is determined relative to that of the standard voltage. We shall refer to this superposition as 'mixing'.

The fixed(standard) voltage may be derived from any coherent source*; in this board it is the output of a transformer. Suppose we wish to measure the phase of a signal V_i different, say higher, from the voltage V_s of the standard signal; this is connected to a potential divider** P(with a variable pot) and the output adjusted to give exactly the same magnitude as the standard voltage.

We can now mix the two voltages so that we get either $V + V_S$ or $V - V_S$. This can be easily done by first mixing the voltages in one way as in figure 2.2(b) and then reversing the polarity of one of the two voltages for mixing figure 2.2(c). On vector diagrams the two cases are illustrated below:

We can measure the magnitude of the resultant in the two cases. From figure 2.3 it can be seen(derive these results yourself) that

$$V^- = 2V \sin\frac{\delta}{2} \tag{2.1}$$

and

$$V^+ = 2V \cos\frac{\delta}{2} \tag{2.2}$$

so that

$$\frac{V^-}{V^+} = \tan\frac{\delta}{2} \tag{2.3}$$

This immediately gives the phase difference δ. In this way, all phases are determined relative to the coherent standard.

*i.e, the standard source and the voltage to be measured have a phase difference that does not change with time. See Appendix I for this.

**The resistance of the potential divider should be sufficiently high(it is about 100k in the network designed by us) so that it does not disturb the phase or magnitude of the voltage measured

There may be cases when the voltage to be measured is smaller than the standard voltage. In this case, *we drop the standard voltage* across the potential divider until it has the same magnitude as the voltage to be measured and then the mixing is carried out.

2.3 Network Board

A schematic diagram of the lay out of the board is given below:

The board provides the coherent standard voltage from a transformer output(about 20volts). There is a switch for reversing its polarity, i.e. for changing its phase by π.

There is a set of four resistors of equal value(20k) in series connected to a variable pot(20k) so that a continuous adjustment of voltage is possible from the voltage divider.

You are also provided a whole range of L, C and R values and a voltmeter. There is another transformer which provides different voltages for applying to any network you may construct and study.

2.4 Experiment A

To study the relative phases of voltages across resistors and capacitors in series

A supply of about 100volts is connected to as series of resistors. Choose a voltage across one of the resistors (conveniently about 30volts) and measure its phase in the manner suggested; i.e. by dropping to the 'standard voltage' and mixing it. Repeat this for the other resistors. What information do you get about the phase relationships amongst the voltages across the various resistors?

Now do the same for a number of capacitors in series. Interpret your results.

2.5 Experiment B

To measure the phase difference between V_R and V_C in a simple RC circuit. Connect a resistor and a capacitor in series to a source V_o.

Measure the phase difference between V_R and V_S (i.e between V_R and V_o. If the outputs of the two transformers are in phase, the phase of V_R relative to V_S and V_o would be identical). Similarly, determine the phase difference between V_C and V_S. See if the phase difference between V_R and V_C inferred from this is as should be. Here some confusion may arise in the calculation of δ_R,δ_C and δ_{RC} (shown in figure 2.5). What you actually measure are the V^+ and V^- values in each case. Now you may find yourself in a dilemma, whether to divide V^+ by V^- or V^- by V^+ to calculate δ_R (or δ_C) and whether δ_R and δ_C are to be added or subtracted(from each other) to obtain $\delta_R C$. The following vector diagram will help you to sort out this.

From the figure it can be easily seen that

$$\tan\frac{\delta_R}{2} = \frac{V_1^-}{V_1^+}; \tan\frac{\delta_C}{2} = \frac{V_2^-}{V_2^+} \tag{2.4}$$

and

$$\delta_{RC} = \delta_R + \delta_C \tag{2.5}$$

Thus, in both cases divide V^- (the resultant of smaller magnitude) by V^+(the resultant of larger magnitude) to obtain δ_R and δ_C. Now add the two to get δ_{RC}. Similar vector diagrams can help resolving this tangle in any other case as well. Try this for a variety of values for R and C.

The phase difference between V_o and V_R is given by $\tan^{-1}\omega CR$.
Verify this.

2.6 Experiment C

To study more about phase relationships in an RC network

With a capacitor and a set of resistors in series measure the phases(relative to the standard) of V_C, V_{CR_1},V_{CR_2} etc.

Represent them by vectors starting from the same point. See also if you can construct a polygon with the vectors. You can take a number of capacitors in series with a resistor and repeat this experiment. Now you can make measurements on capacitors and resistors connected in different ways. For instance, measure the phase difference V_{in} and V_{out} in the circuit given below.

Interpret your results.

The RC combination is sometimes used for shifting the phase of a signal. In the RC network [Figure 2.7] it can be shown that a phase shift of 180° occurs for frequency $f = \frac{1}{2\pi RC\sqrt{6}}$. *For 50hz,the value of RC turns out to be about 1.3msec. Choose 1μf capacitors and a value of R around 1.3k and make up such a circuit. Now measure directly the phase difference between* V_{in} *and* V_{out}. *In addition to the phase shift there is also attenuation of the signal so that if* V_{in} *is 220volts,* V_{out} *will turn out to be only 7volts.*

You may also measure the phase differences between V_{in} *and the voltages after the first pair CR(i.e. across the first resistor) and after the second pair CR. See if the phase changes by 60° each time. (It should not!)*

If you measure the phase difference between V_C *and* V_R, *say the first pair following the input, you will find that it is not 90° as you may imagine at first glance. Can you explain this?*

2.7 Experiment D

To study the phase relationships in an LR circuit

Connect an inductor and a resistor in series to a source V_o. Measure the phase difference between V_o and V_L, V_o and V_R. You can determine, from this, the phase difference δ between V_L and V_R. This will not be $\pi/2$ since there is power loss in the inductor. You can easily show(try this) that δ is given by

$$\tan\left(\frac{\pi}{2} - \delta\right) = \frac{r}{\omega L} \tag{2.6}$$

where r is the effective power loss resistance of L. Compare the value r you obtain this way to the value obtained by triangulation. An agreement within a factor of two is to be considered satisfactory.

The phase difference between V_o and V_R is given by $\tan^{-1}(\frac{\omega L}{R+r})$
Verify this for a large number of combinations.

2.8 Experiment E

To study the phase of V_R in an LCR circuit

Connect an LCR circuit in series. Measure the phase difference between

V_R and V_o. This phase difference is given by $\tan^{-1}(\frac{\omega^2 LC-1}{\omega C(R+r)}$ and will be zero at resonance. Verify this by varying C and then study how δ_{OR} changes as you pass through resonance, i.e. as you go from
LC $< \frac{1}{\omega^2}$ to LC $> \frac{1}{\omega^2}$

2.9 Experiment F

To study the phase relationships amongst various voltages in an LCR circuit

In an LCR circuit, measure the phase differences $\delta(V_o, V_{Lr})$ and $\delta(V_o, V_C)$ and hence determine $\delta(V_C, V_{Lr})$. Measure these phase differences directly for various values of C and calculate $\delta(V_C, V_{Lr})$ in each case. It ought to be independent of C. You may also infer the phase difference between V_L and V_o. This will be given by $\tan^{-1}(\frac{R+r}{\omega L})$.

The phase of V_{Lr} relative to that V_o is given by

$$\tan^{-1}\left(\frac{R/\omega L}{1+\frac{r(R+r)}{\omega^2 L^2}}\right) \tag{2.7}$$

(Establish the relation). Check this from your results.

2.10 Experiment G

To design equivalent circuits for 'hybrid' RC networks.

Construct a network as follows:

Measure the phases of the currents in different branches of the circuit. This is done by measuring the phases of V_{R_1}, V_{R_2} and V_r where r is a small resistance that you may add in the C branch to measure the phase of the current in that branch.

From the data you have, reconstruct an equivalent RC series circuit. Wire up an actual circuit with these components, measure the magnitude of Z(the impedance), the current and its phase. Verify the equivalence.

You may try other circuit combinations yourself and establish equivalent circuits.

2.11 Experiment H

To measure the phase of the voltage across any two points in a complex network

Measure the phase difference between V_A and V_B in the network shown in figure 2.1. You may try other networks where it is very difficult to measure the phase of the voltage across any two points in the network by the method of vector diagrams. In all such cases you will be able to measure it by this method directly.

2.12 Experiment I

To study the phase relationships amongst various voltages in an LCR circuit

In an LCR circuit measure the phase differences $\delta(V_o, V_{Lr})$ and $\delta(V_o, V_C)$. Hence determine $\delta(V_C, V_{Lr})$. Do this for various values of C. Check if $\delta(V_C, V_{Lr})$ is independent of C. You may infer also the phase difference $\delta(V_o, V_L)$ though its not directly measurable(because of r).

Figure 2.9 gives the full line triangle for voltages V_o, V_R and V_{LCr}, while the phase angles measured are $\delta(V_o, V_{Lr}) = \chi$ and $\delta(V_o, V_C) = \theta$. The deduced angle is $\delta(V_C, V_{Lr}) = \phi = \theta - \chi$. From figure 2.9 we note that

$$\tan \delta(V_o, V_C) = \tan \theta = \frac{I_o(R+r)}{I_o(\omega L - \frac{1}{\omega C})} = \frac{R+r}{\omega L - \frac{1}{\omega C}} \tag{2.8}$$

and

$$\tan \phi = \frac{I_o r}{I_o \omega L} = \frac{r}{\omega L} \tag{2.9}$$

From these expressions one can deduce the expression for $\delta(V_C, V_{Lr}) = \chi$, since $\chi = \theta - \phi$.

APPENDIX-I

Need For Coherent Sources

In this board we have used a *coherent* standard voltage for mixing with the voltage whose phase is to be determined. Now the phase difference between these two voltages ought to stay constant over the time you take to make these measurements. In general, phases of line voltages hardly maintain constancy over such long periods of time and it is of no use to compare phases of two a-c voltages which are entirely independent of each other. It is for this reason that in the board, the standard voltage, namely the output of a transformer, is deprived from the line which also feeds the network of the board so that in spite of line fluctuations, *phase differences* in your experiment remains constant.

This idea, namely that coherent sources have to be derived from the same origin, is akin to the one you come across in interference experiments in physical optics such as, for example, Fresnel's biprism. In the case of light, phase changes of a source occur in about 10^{-8} sec. Since the frequency of visible light is about 6x10^{11}hz, this means phase fluctuations occur in some 10^{6} cycles. Despite this, the stability is poor since our eye is unable to follow variations in such a short time which is the reason why you do not observe interference patterns with independent sources.

The a-c line supply normally achieves a stability of about 1% in frequency. Thus if you spend 10minutes in taking your readings, your observations last some 30000 cycles and the uncertainty in phase is many times a full cycle. needless to say, two such sources can hardly be coherent over period of measurement.

If you can manage it, try to get two separate audio oscillators tuned to the same frequency and convince yourself that they are not coherent.

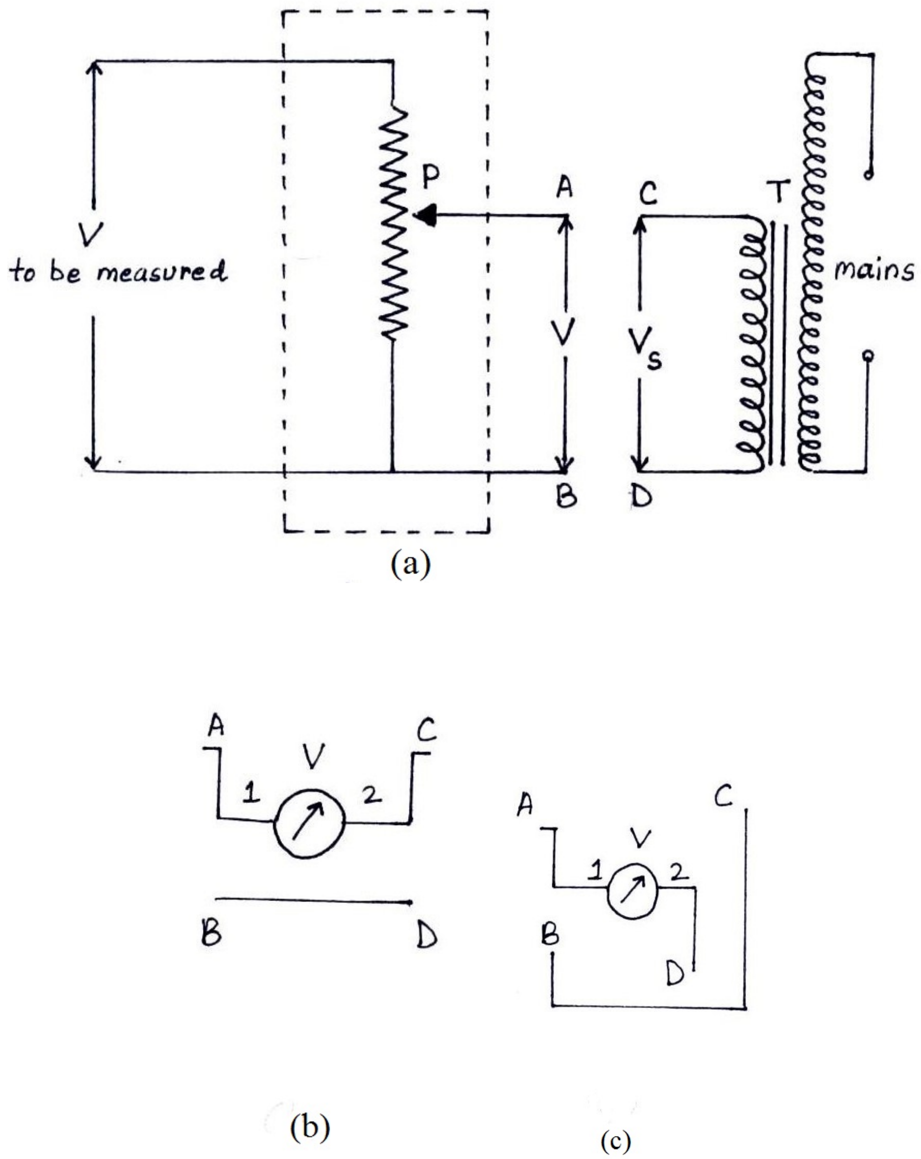


Figure 2.2: (a) An arrangement to achieve $|V| \equiv |V_S|$ and mix the two voltages. (b) and (c) Voltage measurements after superposition and reversal of polarity of one of the voltages

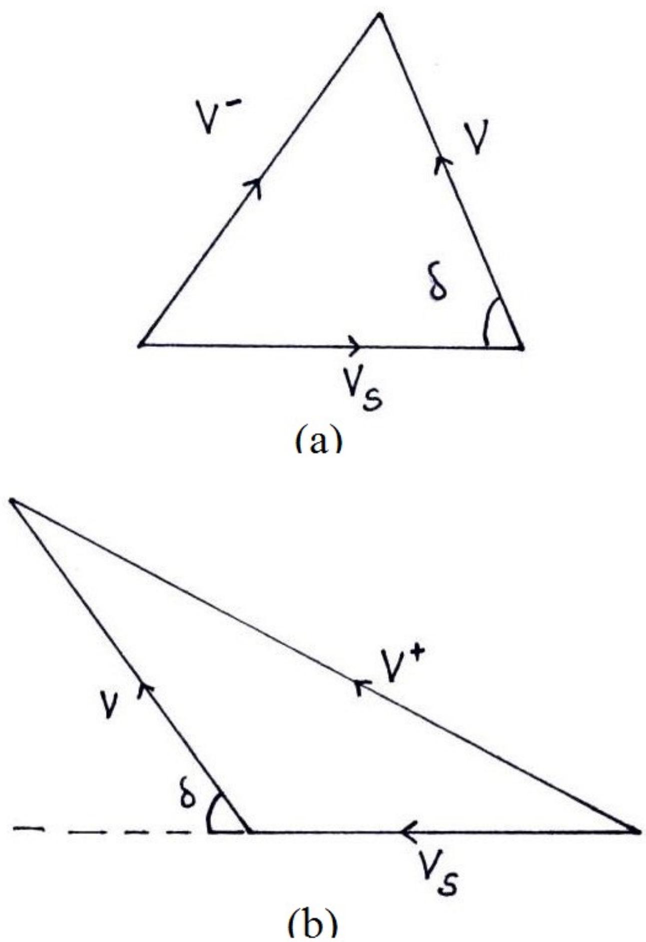


Figure 2.3:

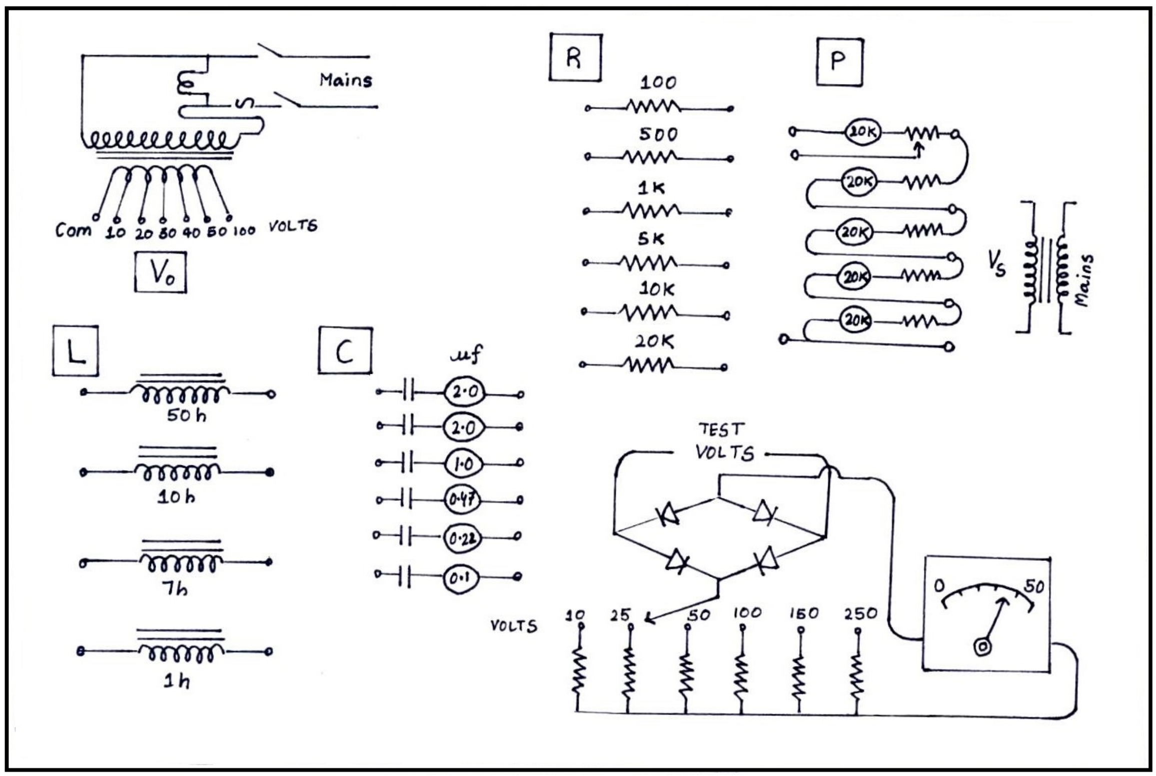


Figure 2.4:

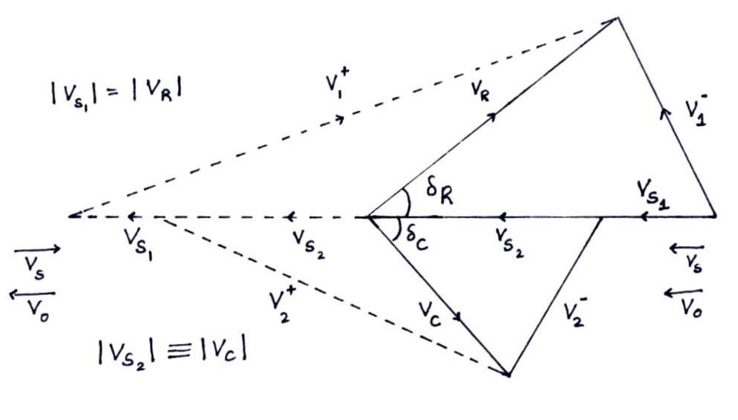


Figure 2.5: You can see that (a)Phase of V_R (or V_C) is same relative to V_s and V_C (b) δ_{RC}=$\delta_R + \delta_C$

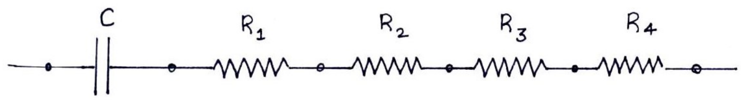


Figure 2.6:

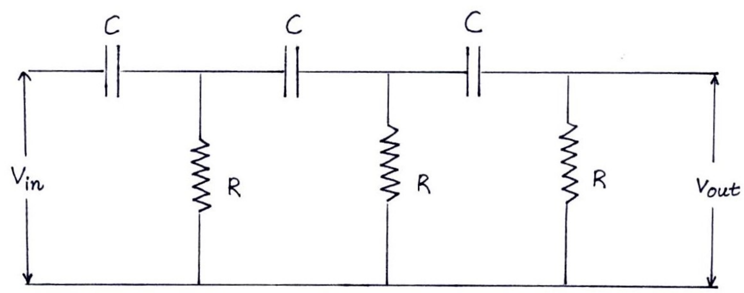


Figure 2.7:

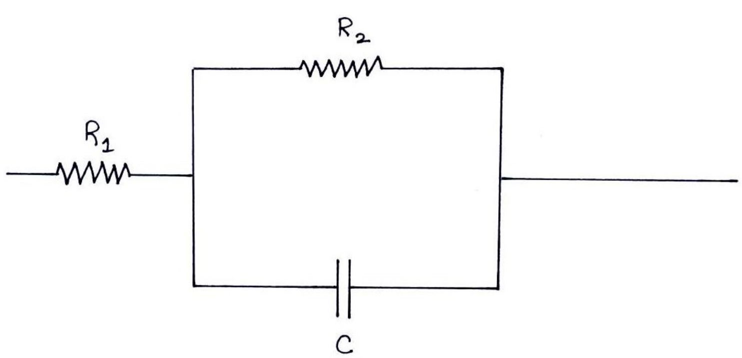


Figure 2.8:

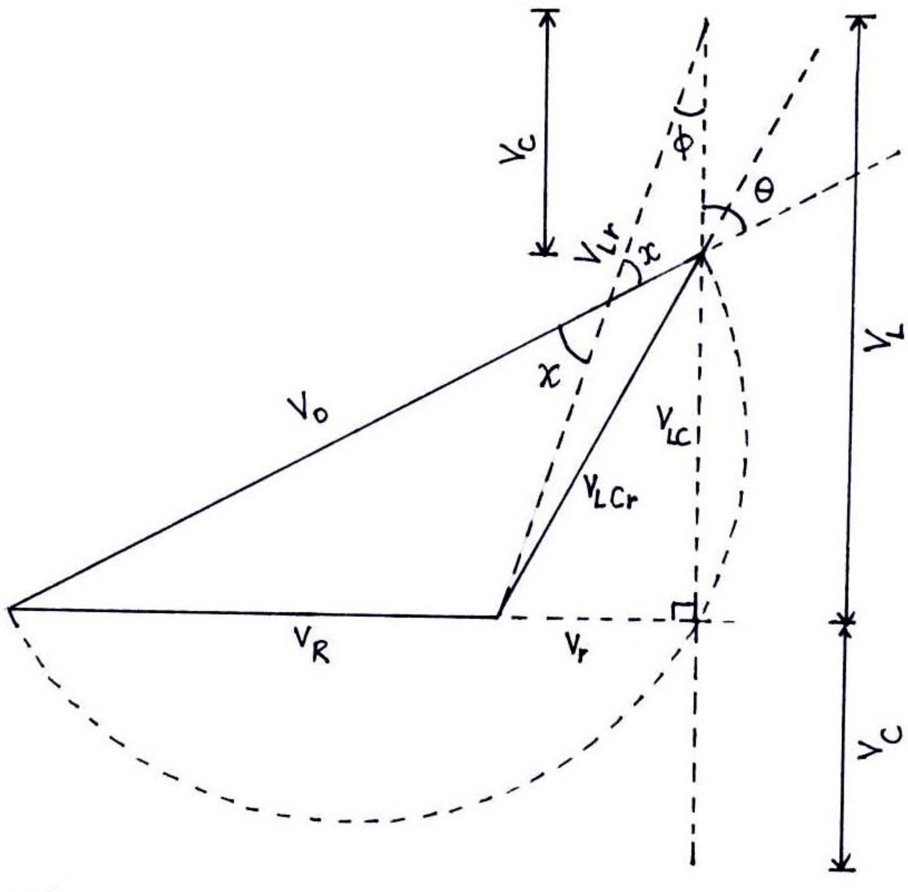


Figure 2.9:

3.

Magnetic field inside Helmholtz coil arrangement

Related Topics

Maxwell's equations, wire loop, flat coils, Biot-Savart's law, Hall effect.

Principle

The spatial distribution of the field strength between a pair of coils in the Helmholtz arrangement is measured. The spacing at which a uniform magnetic field is produced is investigated and the superposition of the two individual fields to form the combined field of the pair of coils is demonstrated.

Equipment

1	Pair of Helmholtz coils	06960.00
1	Power supply, universal	13500.93
1	Digital multimeter	07134.00
1	Teslameter, digital	13610.93
1	Hall probe, axial	13610.01
2	Meter scale, demo, l = 1000 mm	03001.00
1	Barrel base -PASS-	02006.55
1	Support rod -PASS-, square, l = 250 mm	02025.55
1	Right angle clamp -PASS-	02040.55
3	G-clamp	02014.00
1	Connecting cord, l = 750 mm, blue	07362.04
3	Connecting cord, l = 750 mm, red	07362.01

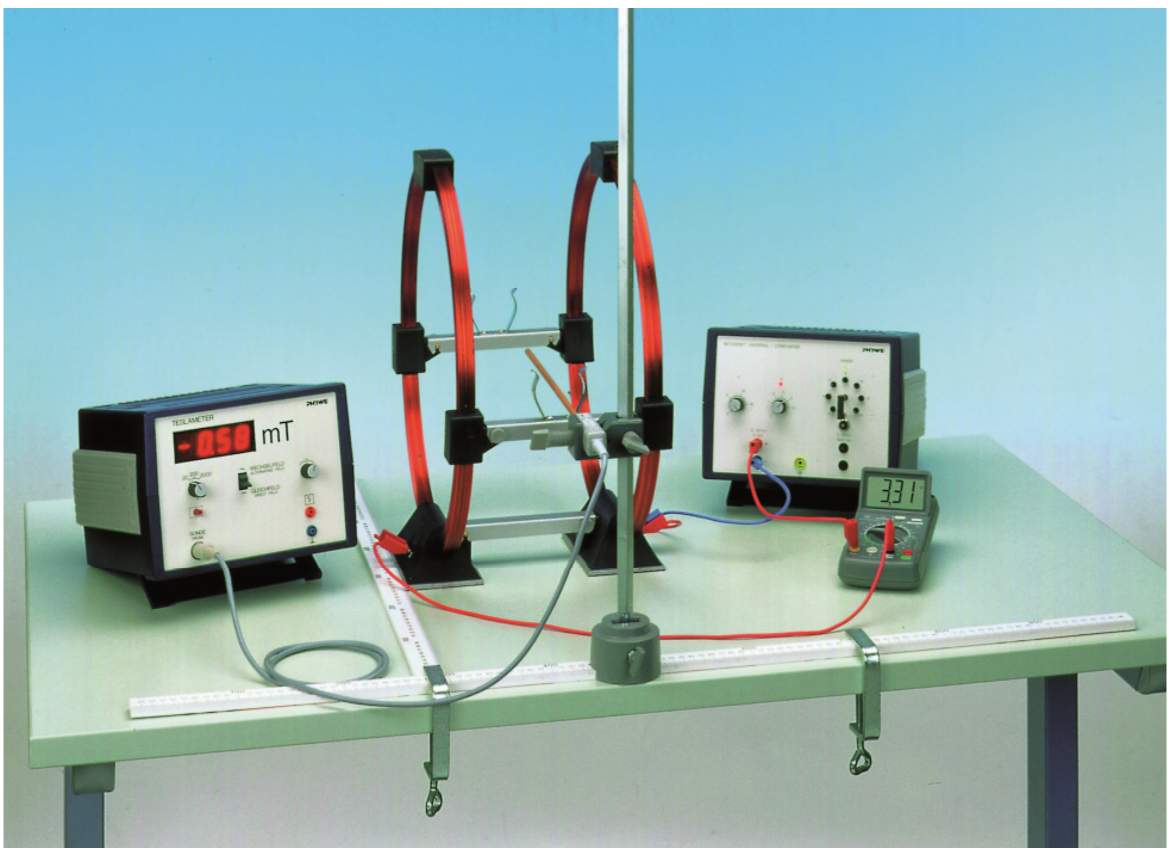


Fig. 1: Set-up of experiment P2430301

Tasks

1. Measure the magnetic flux density along the *z*-axis of the flat coils when the distance between them $a = R$ (R = radius of the coils) and when it is greater and less than this.
2. Measure the spatial distribution of the magnetic flux density when the distance between coils $a = R$, using the rotational symmetry of the set-up:
   a. measurement of the axial component B_z
   b. measurement of radial component B_r
3. Measure the radial components B_r' and B_r'' of the two individual coils in the plane midway between them and to demonstrate the overlapping of the two fields at $B_r = 0$.

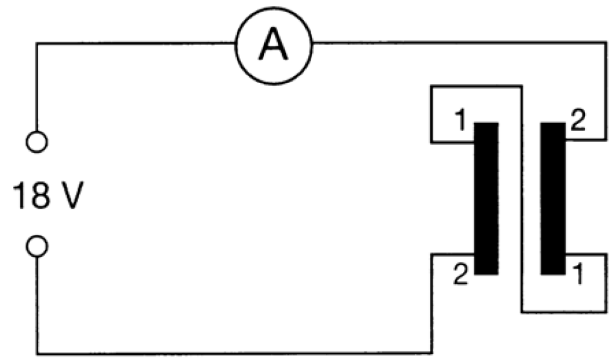


Fig. 2: Wiring diagram for Helmholtz coils.

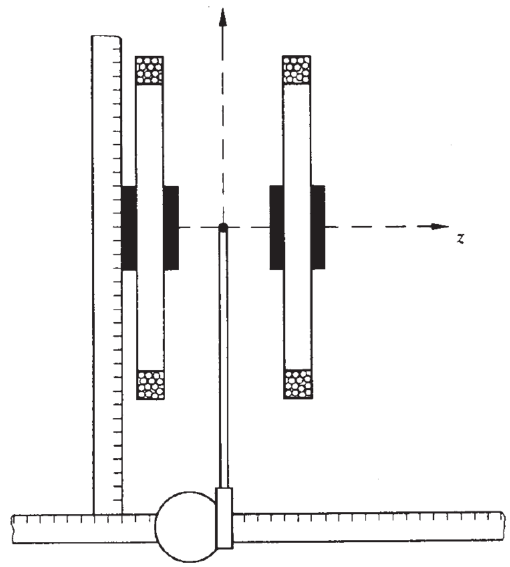


Fig. 5: Measuring B_r (z, r).

Set-up and Procedure

Connect the coils in series and in the same direction, see Fig. 2; the current must not exceed 3.5 A (operate the power supply as a constant current source). Measure the flux density with the axial Hall probe (measures the component in the direction of the probe stem).

The magnetic field of the coil arrangement is rotationally symmetrical about the axis of the coils, which is chosen as the *z*-axis of a system of cylindrical coordinates (z, r, Φ). The origin is at the centre of the system. The magnetic flux density does not depend on the angle Φ, so only the components B_z (z, r) and B_r (z, r) are measured.

Clamp the Hall probe on to a support rod with barrel base, level with the axis of the coils. Secure two rules to the bench (parallel or perpendicular to one another, see Figs. 3–5). The spatial distribution of the magnetic field can be measured by pushing the barrel base along one of the rules or the coils along the other one.

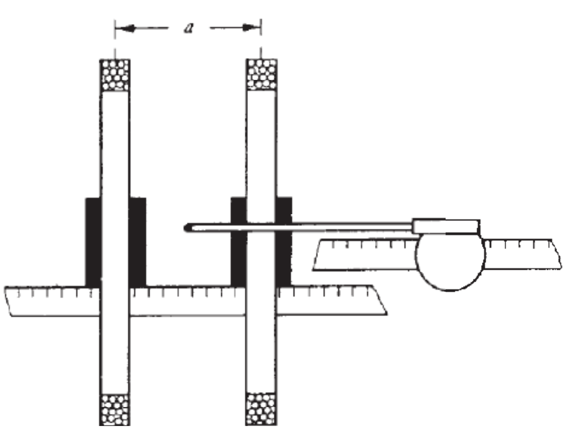


Fig. 3: Measuring B (z, r = 0) at different distances a between the coils.

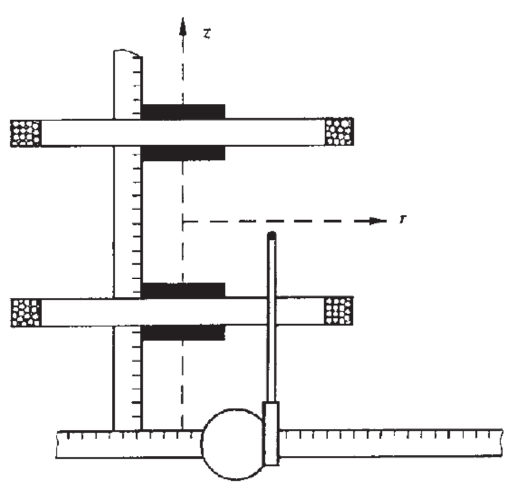


Fig. 4: Measuring B_z (z, r).

Notes

Always push the barrel base bearing the Hall probe along the rule in the same direction.

1. Along the z-axis, for reasons of symmetry, the magnetic flux density has only the axial component B_z. Fig. 3 shows how to set up the coils, probe and rules. (The edge of the bench can be used instead of the lower rule if required.) Measure the relationship $B(z, r = 0)$ when the distance between the coils $a = R$ and, for example, for $a = R/2$ and $a = 2R$.
2. When distance $a = R$ the coils can be joined together with the spacers. a) Measure $B_z(z, r)$ as shown in Fig. 4. Set the r-coordinate by moving the probe and the z-coordinate by moving the coils. Check: the flux density must have its maximum value at point ($z = 0$, $r = 0$). b) Turn the pair of coils through 90° (Fig. 5). Check the probe: in the plane $z = 0$, B_z must = 0.
3. Short-circuit first one coil, then the other. Measure the radial components of the individual fields at $z = 0$.

Theory and evaluation

From Maxwell's equation

$$\oint_K \vec{H}\mathrm{d}\vec{s} = I + \int_F \int \dot{\vec{D}}\mathrm{d}\vec{f}\mathrm{d}t \qquad (1)$$

where K is a closed curve around area F, we obtain for direct currents ($\dot{D} = 0$), the magnetic flux law

$$\oint_K \vec{H}\mathrm{d}\vec{s} = I \qquad (2)$$

which is often written for practical purposes in the form of Biot-Savart's law:

$$d\vec{H} = \frac{I}{4\pi}\frac{d\vec{\iota} \times \vec{\rho}}{\rho^3} \qquad (3)$$

where $\vec{\rho}$ is the vector from the conductor element $\mathrm{d}\vec{l}$ to the measurement point and $\mathrm{d}\vec{H}$ is perpendicular to both these vectors.

The field strength along the axis of a circular conductor can be calculated using equation (3). (Fig. 6).

The vector $\mathrm{d}\vec{l}$ is perpendicular to, and $\vec{\rho}$ and $\mathrm{d}\vec{H}$ lie in, theplane of the sketch, so that

$$dH = \frac{I}{4\pi\rho^3}d\iota = \frac{I}{4\pi}\cdot\frac{d\iota}{R^2 + z^2} \qquad (4)$$

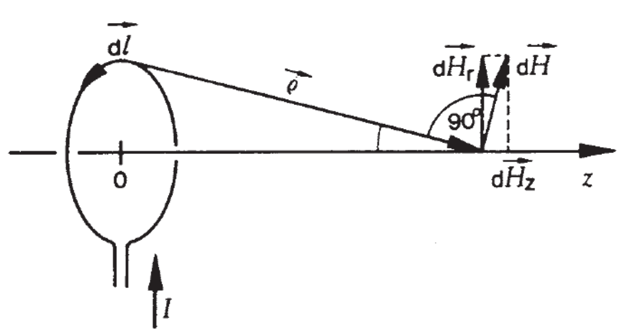


Fig. 6: Sketch to aid calculation of the field strength along the axis of a wire loop.

$\mathrm{d}\vec{H}$ can be resolved into a radial $\mathrm{d}H_r$ and an axial $\mathrm{d}H_z$ component. The $\mathrm{d}H_z$ components have the same direction for all conductor elements and the quantities are added; the $\mathrm{d}H_r$ components cancel one another out, in pairs. Therefore,

$$H_r = 0 \tag{5}$$

and

$$H = H_z = \frac{I}{2} \cdot \frac{R^2}{(R^2 + z^2)^{3/2}} \tag{6}$$

along the axis of the wire loop, while the magnetic flux density

$$B(z) = \frac{\mu_0 \cdot I}{2R} \cdot \frac{1}{\left(1 + \left(\frac{z}{R}\right)^2\right)^{3/2}} \tag{7}$$

The magnetic field of a flat coil is obtained by multiplying (6) by the number of turns N. Therefore, the magnetic flux density along the axis of two identical coils at a distance α apart is

$$B(z, r = 0) = \frac{\mu_0 \cdot I \cdot N}{2R} \cdot \left(\frac{1}{\left(1 + {A_1}^2\right)^{3/2}} + \frac{1}{\left(1 + {A_2}^2\right)^{3/2}} \right) \tag{8}$$

where

$$A_1 = \frac{z + \alpha/2}{R}, \quad A_2 = \frac{z - \alpha/2}{R}$$

When $z = 0$, flux density has a maximum value when $\alpha < R$ and a minimum value when $\alpha > R$. The curves plotted from our measurements also show this (Fig. 7); when $\alpha = R$, the field is virtually uniform in the range

$$-\frac{R}{2} < z < +\frac{R}{2}$$

Magnetic flux density at the mid-point when $\alpha = R$:

$$B(0.0) = \frac{\mu_0 \cdot I}{2R} \cdot N \cdot \frac{2}{\left(\frac{5}{4}\right)^{\frac{3}{2}}} = 0.716\, \mu_0 \cdot N \cdot \frac{I}{R}$$

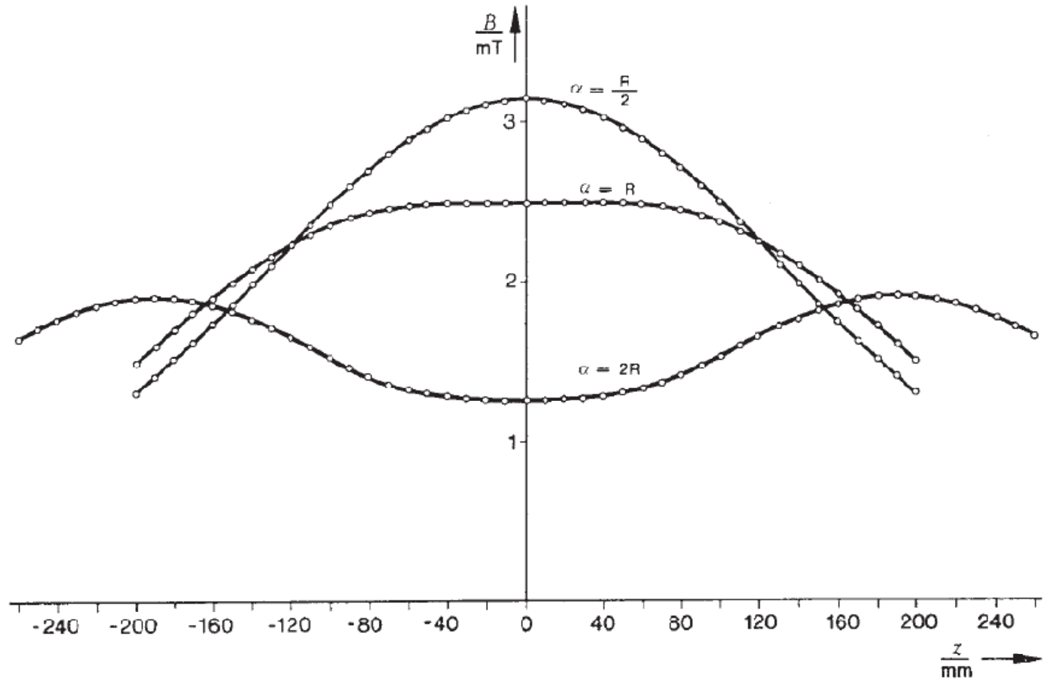


Fig. 7: $B\,(r = 0)$ as a function of z with the parameter α.

when $N = 154$, $R = 0.20$ m and $I = 3.5$ A this gives:

$B\,(0.0) = 2.42$ mT.

Our measurements gave $B\,(0.0) = 2.49$ mT.

Figs. 8 and 9 shows the curves $B_z\,(z)$ and $B_r\,(z)$ measured using r as the parameter; Fig. 10 shows the super-position of the fields of the two coils at $B_r = 0$ in the centre plane $z = 0$.

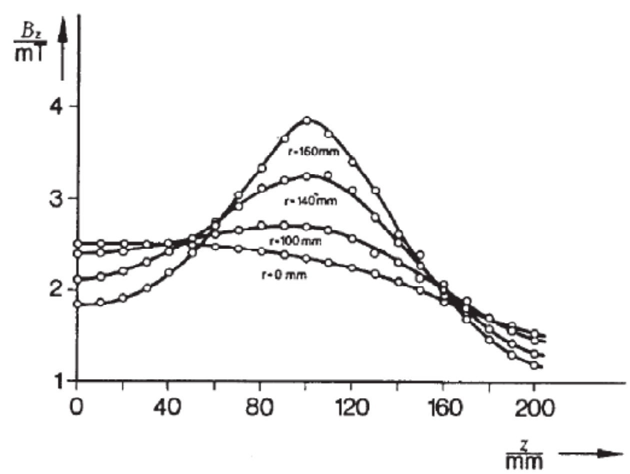


Fig. 8: $B_z\,(z)$, parameter r (positive quadrant only).

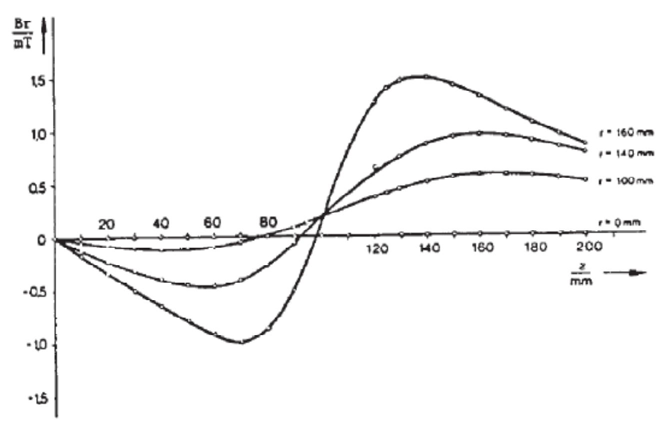


Fig. 9: $B_r\,(z)$, parameter r (positive quadrant only).

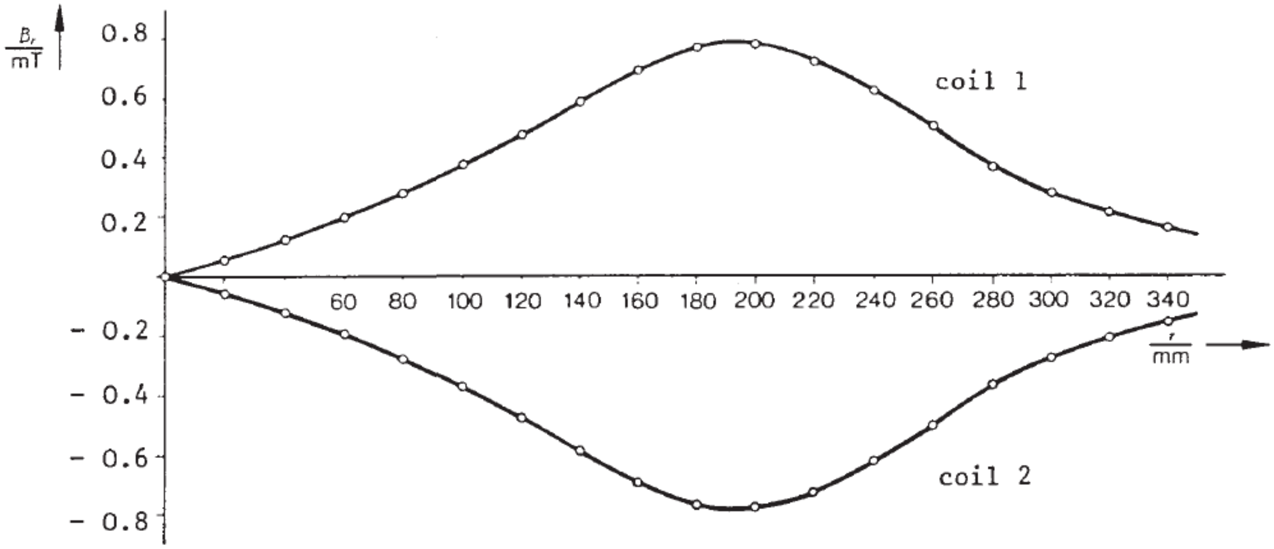


Fig. 10: Radial components $B_r'(r)$ and $B_r''(r)$ of the two coils when $z = 0$.

PHYWE excellence in science

Teslameter, digital Hall probe, axial Hall probe, tangential	13610-90…99 13610-01 13610-02

PHYWE Systeme GmbH & Co. KG
Robert-Bosch-Breite 10
D-37079 Göttingen

Telefon +49 (0) 551 604-0
Fax +49 (0) 551 604-107
E-mail info@phywe.de

Operating instructions

The unit complies with the corresponding EC guidelines.

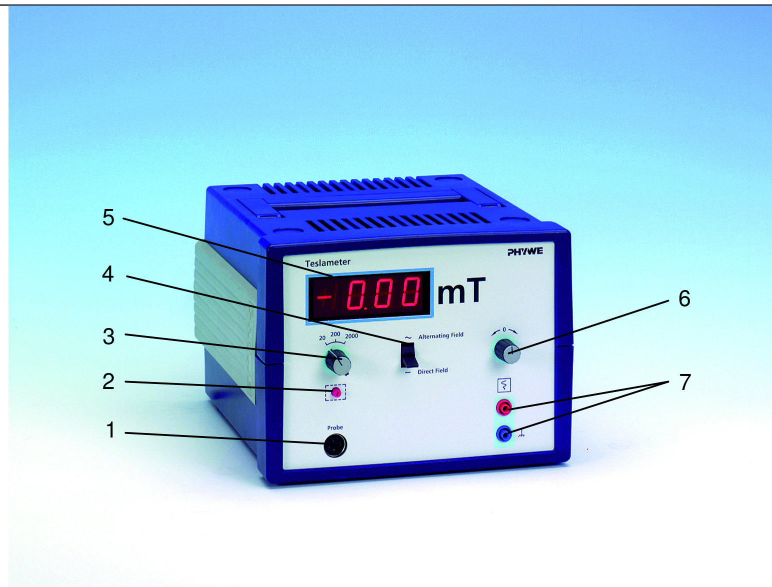


Fig. 1: 13610-90…99 Front view of the Teslameter, digital

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1 SAFETY PRECAUTIONS

Caution!

- Carefully read these operating instructions before operating this instrument. This is necessary to avoid damage to it, as well as for user-safety.
- Check that your mains supply voltage corresponds to that given on the type plate fixed to the instrument.
- Install the instrument so that the on/off switch and the mains connecting plug are easily accessible.
- Do not cover the ventilation slits.
- Only use the instrument in dry rooms in which there is no risk of explosion.
- Only use the instrument for the purpose for which it was designed.

2 PURPOSE AND CHARACTERISTICS

The teslameter is suitable for measuring magnetic flux density (induction) *B* accurately. Two hall probes are supplied for use as sensors. One of them is specially designed for measuring fields oriented axially in relation to its rod-shaped stem (axial probe, order no. 13610-01). It is suitable for measuring fields inside coils for instance. The stem is 30 cm long to allow measurements to be taken easily even in the middle of long coils. The second probe measures fields perpendicular to its stem (tangential probe, order no. 13610-02), which is extremely thin and flat for measurements in narrow air gaps down to about 1 mm.
The meter has 3 switchable measuring ranges:

0 to…20 mT (accuracy 0.01 mT)
0 to…200 mT (accuracy 0.1 mT)
0 to…1000 mT (accuracy 1 mT)

3 FUNCTIONAL AND OPERATING ELEMENTS

The plugs for connecting the mains lead supplied with the meter and the power switch are to be found on the back of the meter.
Fig. 1 shows the teslameter with the controls and functional elements on the front panel:

1 *Input*
socket for connecting the hall probes 13610-01 and 13610-02.
2 *Adjusting screw*
for rough zeroing.
3 *Stepping switch*
for selecting the measuring range.
4 *Changeover switch*
for selecting the „ALTERNATING FIELD“ and „DIRECT FIELD“ measurement modes.
5 *Digital display*
for displaying the values measured. 3 digit display with sign for the direction of the field and decimal point.
6 *Adjusting knob* for fine zeroing
7 *Output*
for connecting an external measuring instrument, e.g. a recorder. Output voltage: 1 mV per digit.

4 HANDLING

The teslameter is connected to the AC mains with the lead supplied and switched on with the power switch on the back of the case. Changing the primary safety fuse: The fuse holder is in the upper part of the mains socket of the instrument, and so is only accessible when the connecting cord is not plugged in. Unplug the connecting cord, open the fuse holder using a screwdriver, take out the defect fuse and replace it with a new one (first check the specification of this against the data on the type plate), then fit the fuse holder back in the mains socket.
Should this fuse blow when the instrument is switched on, never replace it with a more resistant fuse! A defect is indicated and the instrument must be returned to the Phywe service department for repair.

4.1 Using the probes

The component of the magnetic induction in the direction of the axis of the probe is measured with the axial probe. The measuring point is right at the end of the stem. The direction of direct fields can also be detected: if the field is directed towards the handle of the probe (e.g. in front of the north pole of a bar magnet) the value displayed is positive, whereas it is negative when the field is in the opposite direction.
The tangential probe is provided with a protective tube that has to be removed before any measurements are taken. The Hall sensor is embedded in a flat plastic stem about 1 mm thick. Its position (measuring point) in the stem is clearly visible. In this case the component of the magnetic induction perpendicular to the face of the probe is measured. The direction of the field can also be detected when direct fields are being measured: a positive reading indicates that the field enters the probe from the direction of the surface of the handle that carries the nameplate, whereas a negative value indicates that the field has the opposite direction.
The probes generally have to be positioned accurately for precise measurement. They are easily held using a stand. The bosshead order no. 02040-55 is ideal. To avoid damaging them the probes should always be held by the metal tube provided for the purpose at the end of the handle rather than clamping the stem.

4.2 Zeroing

This procedure as described below is only necessary when direct fields are to be measured. In the case of alternating fields the meter is zeroed automatically within a few seconds, although a display of 1 digit (10^{-5} T) is unavoidable in the 20 mT range.
The mode switch (***4***) is to be brought into the „DIRECT FIELD“ (Gleichfeld) position. Once the hall probe selected for the measurement has been connected to input (***1***), but before any field is applied to it, the display is set on zero with the adjusting knob (***6***). Should this prove impossible the knob is turned to the middle position and the value displayed minimised by turning the adjusting screw (***2***) with a screwdriver; fine adjustment is then repeated with the adjusting knob (***6***).
We recommend zeroing in the most sensitive range (20 mT) to avoid the need for re-adjustment when higher ranges are subsequently selected.
It should be noted that the earth’s magnetic field alone can produce a reading of ± 4 digits (40 μT) in this range. If no compensation for this field is to be made during zeroing the zero adjustment knob is to be set so that turning the probe through 180° only results in the sign, and not the absolute value of the field strength displayed, changing.
When the fields of conductors carring a current are to be measured, before zeroing we recommend positioning the probe at the measuring point to be used with the magnetic field current switched off; this eliminates any interference from static stray fields at the same time.
When measuring in the 20 mT range zeroing is to be checked in the first few minutes after the meter is switched on and corrected if necessary. We recommend switching it on about ten minutes before starting to take measurements, by which stage zero drift is insignificant.

4.3 Measuring direct fields

Once the meter has been zeroed it is ready to take measurements. The mode switch (***4***) must be in the „DIRECT FIELD“ position. The value „1“ displayed without leading zeros indicates overranging and hence the need to switch to a higher range. The direction of the field is also indicated in this case.

4.4 Measuring alternating fields

The mode switch (***4***) is moved to the „ALTERNATING FIELD“ (Wechselfeld) position. The display returns to zero within a few seconds when there is no field acting on the probe. The meter is then ready for use immediately. It should be noted that in this mode the meter responds to changes in the field strength within about 3 s. The rms value of the value of the magnetic induction, which is assumed to be sinusoidal, is displayed. The meter is calibrated for an alternating field frequency of 50 Hz. However extremely accurate measurements are possible at frequencies of up to 500 Hz (limit frequency 5 kHz). The value „1“ displayed without leading zeros indicates overranging and hence the need to switch to a higher range. Positive values are always displayed in this mode. Turning the probe through 180° at a fixed measuring point does not affect the value displayed.

4.5 Using the analog output

External measuring instruments can be connected to the pair of 4 mm sockets (***7***). In addition to yt and xyt recorders possibilities include computer-aided measuring systems (e.g. COBRA3 Basic-Unit 12150-50).
The output voltage corresponds to the digital display. It is 1 mV per digit; the limits of the indicating range correspond to

the output voltage of ± 1.999 V (positive polarity only with alternating field measurements). The measuring instrument connected should have an internal resistance of at least 20 kΩ.

5 NOTES ON OPERATION

This high-quality instrument fulfills all of the technical requirements that are compiled in current EC guidelines. The characteristics of this product qualify it for the CE mark.

This instrument is only to be put into operation under specialist supervision in a controlled electromagnetic environment in research, educational and training facilities (schools, universities, institutes and laboratories).

This means that in such an environment, no mobile phones etc. are to be used in the immediate vicinity. The individual connecting leads are each not to be longer than 2 m.

The instrument can be so influenced by electrostatic charges and other electromagnetic phenomena that it no longer functions within the given technical specifications. The following measures reduce or do away with disturbances:

Avoid fitted carpets; ensure potential equalization; carry out experiments on a conductive, earthed surface, use screened cables, do not operate high-frequency emitters (radios, mobile phones) in the immediate vicinity. Following a blackout failure, operate the on/off switch for a reset.

6 TECHNICAL DATA (TYPICAL FOR 25°C)

Operating temperature range 5...40°C	
Relative humidity < 80%	
Measuring range	10-5 to1 T
Indicating range	10-5 to 2 T
Accuracy	
Direct field	± 2%
Alternating field 50 to 500 Hz	± 2%
Alternating field 500 to 1000 Hz	± 3%
Material of the Hallsensors	GaAs, monocrystalline
Temperature coefficient	
(10 to 40°C)	≤ 0.04%/K
Limit frequency	
(measurement of alternating field)	5 kHz
Analog output	
Voltage range	0 to ± 2 V
Calibration factor	1 mV/digit
Protection class	I
Connecting voltage	see type plate
(+6%/-10%)	
Mains frequency	50/60 Hz
Power consumption	10 VA
Mains fuse	see type plate
(5 mm x 20 mm)	
Case dimensions	225 x 235 x 170 mm
Weight	approx. 3.75 kg
Hall probe, axial	
Probe length (without handle)	300 mm
Diameter of the stem	6 mm
Weight	approx. 0.38 kg
Hall probe, tangential	
Dimensions of the stem	
(without handle)	75 x 5 x 1 mm
Weight	approx. 0.20 kg

7 EXPERIMENTAL LITERATURE

Handbook Laboratory Experiments Physics 16502-32

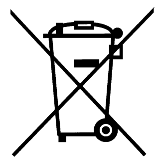
8 NOTES ON THE GUARANTEE

We guarantee the instrument supplied by us for a period of 24 months within the EU, or for 12 months outside of the EU. Excepted from the guarantee are damages that result from disregarding the Operating Instructions, from improper handling of the instrument or from natural wear.

The manufacturer can only be held responsible for the function and technical safety characteristics of the instrument, when maintenance, repairs and alterations to the instrument are only carried out by the manufacturer or by personnel who have been explicitly authorized by him to do so.

9 WASTE DISPOSAL

The packaging consists predominately of environmentally compatible materials that can be passed on for disposal by the local recycling service.



Should you no longer require this product, do not dispose of it with the household refuse.

Please return it to the address below for proper waste disposal.

PHYWE Systeme GmbH & Co. KG
Abteilung Kundendienst (Customer Service)
Robert-Bosch-Breite 10
D-37079 Göttingen

Phone +49 (0) 551 604-274
Fax +49 (0) 551 604-246

4.

Study of Resistors, Capacitors and Inductors with an AC Source

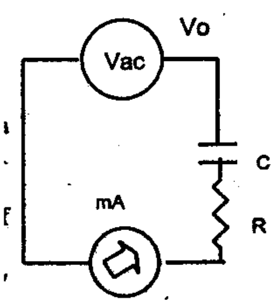
Experiment 4 : STUDY OF RESISTANCE, CAPACITOR AND INDUCTOR BY AC SOURCE

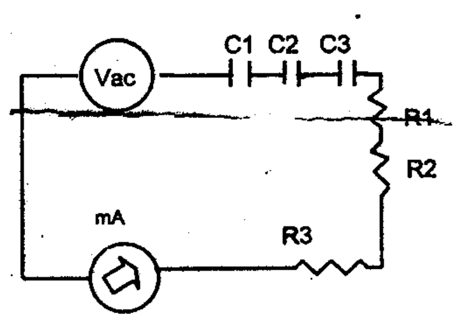
1.0 AIM :

A. To study simple RC circuit and to show that currents are in quadrature. Determine the effective ac resistance.
B. To represent the deviation in the behaviour of an actual capacitor by adding a shunt resistance.
C. To determine the effective series resistance for a capacitor corresponding to a shunt across it and verify it experimentally.
D. To determine equivalent power loss resistance of an inductor as a function of resistance and input voltage.

2.0 : DETAILED PROCEDURE AND CALCULATION :

A. To study simple RC circuit





Experimental procedure:

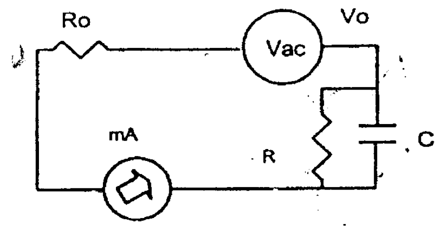
Make the electrical circuit as shown below (Fig.) Measure the voltages across capacitor V_c and Resistor V_R and current I flowing in the curcuit. Select another capacitor of different value and adjust R such that the current I remains the same. Repeat the procedure for atleat five different values of capacitors.
Make another circuit Fig. In which three resistors are connected in series with three series connented capacitors and apply voltages. Measure voltage across each componens.

Calculations:

1.Compare the measured value of current I with the calculated one from the formula $V_R = IR$ and $V_c = I / \omega c$ in each case.

1. Plot V_c verses $1 / c$ and determine the value of frequency f.
2. Determine the impedance of the circuit by formula $Z = V_o / I$ and verify theoretically.
3. From the vector diagram between V_R, V_c and V_o, show that $V_o^2 = V_R^2 + V_c^2$ in all the cases.
4. Show that the sum of resistive voltage and the sum of capacitive voltage are in quadrature in circuit b.

B1. To represent the deviation in the behaviour of an actual capacitor by adding a shunt resistance.



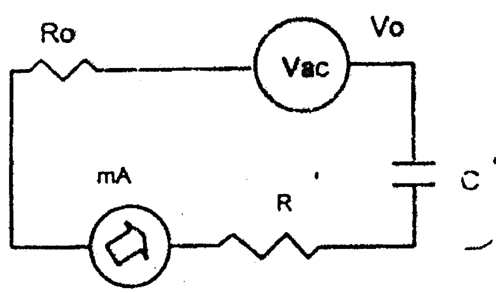
Expcuimental procedure:

Connect the circuit as shown below. Measure voltages V_o, $V_{cR}$and V_{R0}. Increase the value of R in five steps from a low value to a very high value. Measure the current flowing through the circuit, I_o, current through R, I_R and current through C, I_c for each value of R.

Calculations:

1. Draw five voltage vector diagrams to evaluate the effect of increasing R on the performance of capacitor.
2. Draw five current vector diagrams and show that I_R and $I_c$are in quadrature.

B2 : To detemine the effective series resiostance for a capacitor corresponding to a shunt across it.



Experimental Procedure :

Connent a resistor R in parallel to a capacitor C as shown in the figure below. Meaqsure the voltages V_{CR}, V_{RO}, and V_O and current to flowing through them. Take minimum tree sets.

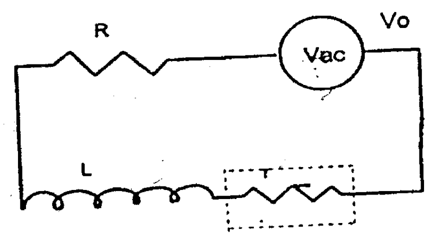
Calculations:

1 Draw vector diagrams and measure $V_{R'}$ and $V_{C'}$. Determine R' and C' from the triangle and using the relation given below.

$$R' = V_C^2 / (R\, I_O^2)$$

3. Show that the same current flows in the circuit byt connenting R' and C' in series.

C. To study the equivalent power loss resistance of an inductor.



Experimental procedure:
Connect the LR circuit as shown in figure below (where r is the power loss resistance of inductor). Measure voltage across inductor V_L, voltage across resistance V_R' and source voltage V_O. Keeping R and L constant , take five sets with different V_O and L, by selecting five different values of R.

Calculations :

1. Calculate r for all the observations from vector diagrams.
2. Draw graphs between r vs V_O and r vs R.

2.0 : DETAILED DISCUSION :

A capacitor C and a resistance R are connected in series to the source along with the current meter. Measure I, V_c, V_R and V_{RC}, the last one being the voltage across R and C together.
Verify the relations

$V_R = IR$ and $V_C = I / \omega C$

where ω is the angular frequency (i.e. $\omega=2\pi$ times the frequency f of the a-c supply). From Equation (5.1) can you say what would happen to the relative values of V_R and V_C at very low and very high frequencies?

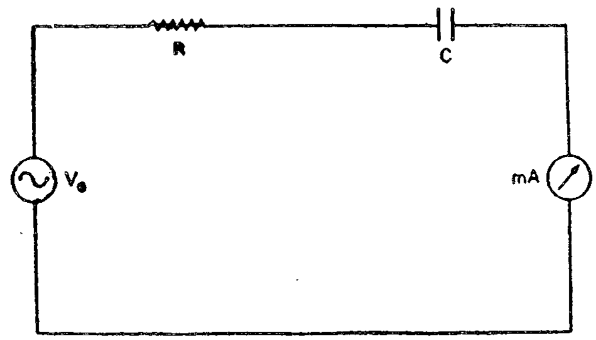


FIGURE 5.2

Use different values of C and adjust R in each case to obtain the same current. Draw a graph between V_C and $1/C$.

EXPERIMENT 5-C *To study the vectorial addition of voltages across the capacitor and the resistor in an RC circuit.*

Connect some capacitors and some resistors in series to the source (Fig. 4.11). Establish the relation

$$V_{C_1}\,\omega C_1 = V_{C_2}\,\omega C_2 = \ldots\ldots = \frac{V_{R1}}{R_1} = \frac{V_{R2}}{R_2} = \ldots\ldots = I \quad \ldots (5.4)$$

As far as rms values of currents and voltages are concerned, the impedance $1/\omega C$ plays the same role as the resistance R.

Notice that the voltages V_R and V_C do not add algebraically. For example, for just one capacitor and one resistor in series,

$$V_R + V_C > V_0$$

(V_0 being the source voltage). Do you see that

$$V_R^2 + V_C^2 = V_0^2$$

Explain this on a vector diagram. Also check for a series of resistors and capacitors that

$$V_{R1} + V_{R2} + V_{R3} = V_{R123}$$

and $$V_{C1} + V_{C2} + V_{C3} = V_{C123}$$

where V_{R123} is the voltage across all the three resistors in series and V_{C123}, the voltage across all the three capacitors.

EXPERIMENT 5-D

To study the deviation in the behaviour of an actual capacitor from an ideal one.

With a constant source voltage V_0, connect a resistor and a capacitor in series and measure V_R and V_C. For different values of R and C (keeping source voltage fixed), construct the vector triangles of sides V_R, V_C and V_0; the best way is to draw all the triangles with the same base V_0. Then, for different values of V_R and V_C, we ought to obtain right-angled triangles with V_0 as hypotenuse: Thus, the vertices of the triangles ought to be on a semi-circle. In reality it may not be so. Can you guess the reason?

EXPERIMENT 5-E

To represent the deviation in the behaviour of an actual capacitor by a series resistance.

From the foregoing experiment you have probably learnt the difference between an ideal and an actual capacitor. The latter always has some leakage across it which can be represented by a leakage resistance, in series or in parallel with it. This would imply that its reactance is not purely capacitive. This and the next experiment will help you to understand these remarks better.

Connect a capacitor and a number of equal resistors in series with the source [Fig. 5.3(a)]. Measure the potential differences in pairs V_{C0} and V_{04},

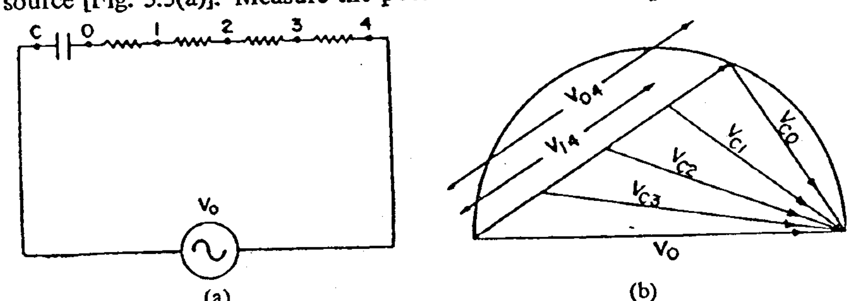


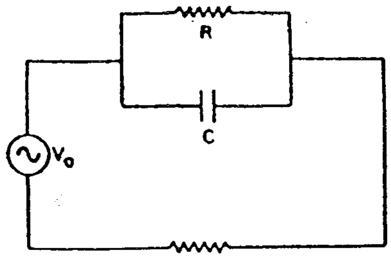
FIGURE 5.3

V_{C1} and V_{14}, V_{C2} and V_{24}, V_{C3} and V_{34}. With the source voltage V_0 as base, construct triangles for each of these pairs [Fig. 5.3(b)].

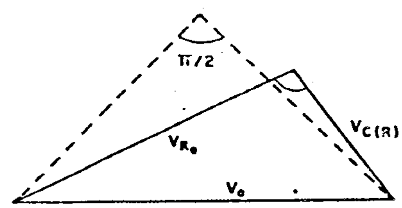
Determine (from the diagram) the phase difference between constituents of each of the above pairs, for example, between V_{C0} and V_{04} and so on. You will find that whereas the phase difference between V_{C0} and V_{04} is almost $\pi/2$ with the vertex of the triangle nearly touching the semi-circle, the same is not true of the pairs V_{C1} and V_{14}; V_{C2} and V_{24} etc. The phase difference in these cases is quite different from $\pi/2$ and the vertices lie well inside the semi-circle. Thus, when you measure V_{C1}, V_{C2} etc. what you are effectively doing is to associate some resistance with the capacitor and then measure the voltage across the combination which makes the vertex move inwards. This is an *exaggerated* picture of an actual capacitor. In this sense, you can represent the behaviour of a non ideal capacitor by treating it as a combination of a small series resistance and an ideal capacitor of a slightly higher capacitance. (see Experiment 5H).

EXPERIMENT 5-F *To represent the leakage resistance of a capacitor by a shunt.*

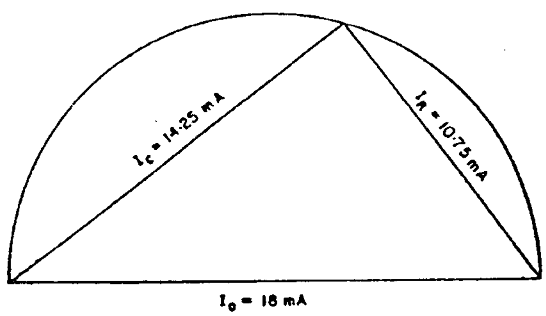
Connect a resistor R in parallel with a capacitor C (Fig. 5.4a) and then this combination in series with another resistor R_0 and the source of power.



(a)



(b)



(c)

FIGURE 5.4

Measure $V_{C(R)}$, V_{R_0} and V_0 (the source voltage). Draw a vector diagram for these voltages (Fig. 5.4b). You will notice that the phase difference between $V_{C(R)}$ and V_{R_0} is not $\pi/2$. By varying R you will also notice that the phase difference approaches $\frac{\pi}{2}$ as R is increased. In fact, if you remove the shunt R and draw the vector diagram afresh (dotted) you will find the phase difference to be nearly $\pi/2$.

This means that a real capacitor (as opposed to an ideal one) can also be treated as having a large resistance as a shunt with it. However, the capacitors you have been using are not very far from ideal at least under the conditions used.

EXPERIMENT 6-D

To determine the equivalent power loss resistance of an inductor.

Connect the circuit of Fig. 6.15, where r is the resistive part of the inductor and is to be determined. Measure V_L, V_R, V_0 (the applied voltage) and draw the voltage triangle. You will find that the triangle is not a right angled one. Draw a semi-circle with V_0 as diameter and extrapolate the V_R line until it intercepts the semi-circle. You can now estimate the equivalent power loss resistance (from V_r) of the inductor since $r/R = V_r/V_R$. Compare

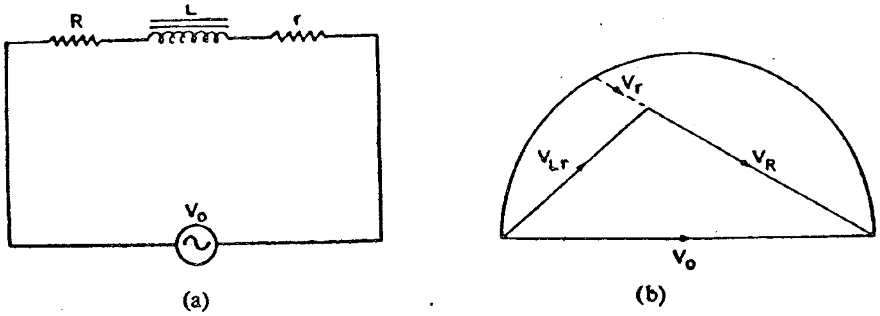


FIGURE 6.15

it with the d-c resistance of the coil (measure it directly with a meter). You will find that there is a difference—the equivalent power loss resistance r is not just the d-c resistance. This is because the power loss in an inductor is due to its d-c resistance plus the hysteresis and eddy losses in the core. Measure this equivalent resistance for different values of the a-c voltage. Why may it vary?

5.

Charging and discharging of a capacitor

5.1 Capacitors

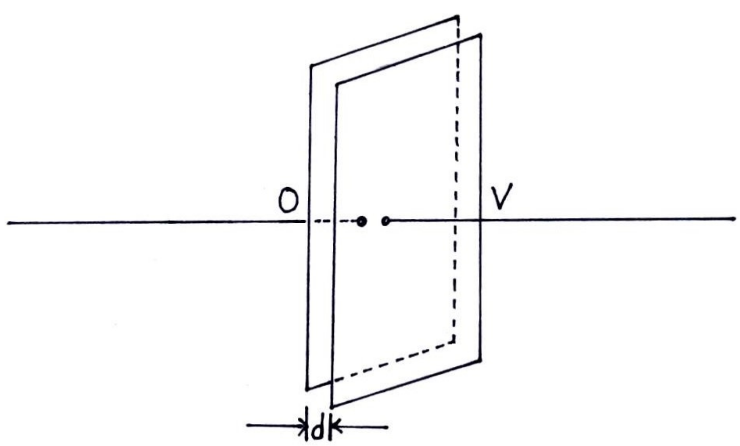


Figure 5.1:

A system of charges, physically separated, has potential energy. The simplest example is that of two metal plates of large area carrying opposite charges so that the potential difference is V. The energy stores is $\frac{1}{2}CV^2$ where C is the capacitance of the system. It is defined as the charge(on either plate) per unit potential difference and depends essentially on the geometry of the system. In the above case the capacitance is given by

$$C = \epsilon_o \frac{A}{d} \tag{5.1}$$

in mks units, where A is the area(in meter^2), d is the separation(in meters), ϵ_0 is a constant (8.85 X 10^{-12} in MKS units) and the unit of capacitance is a farad.(Refer to any standard text for the derivation of this formula).

A system, such as the above one, is called a condenser or, in modern parlance, simply a capacitor. We shall adopt the modern usage. It must not be assumed that a capacitor is always a set of plane parallel plates. Many other geometrical arrangements may be used and often are more practical(See Appendix I).

5.2 RC Circuit

The energy may be delivered by a source to a capacitor or the stored energy in a capacitor may be released in an electrical network and delivered to a load. For example, look at the circuit in Figure 5.2. If you turn the switch

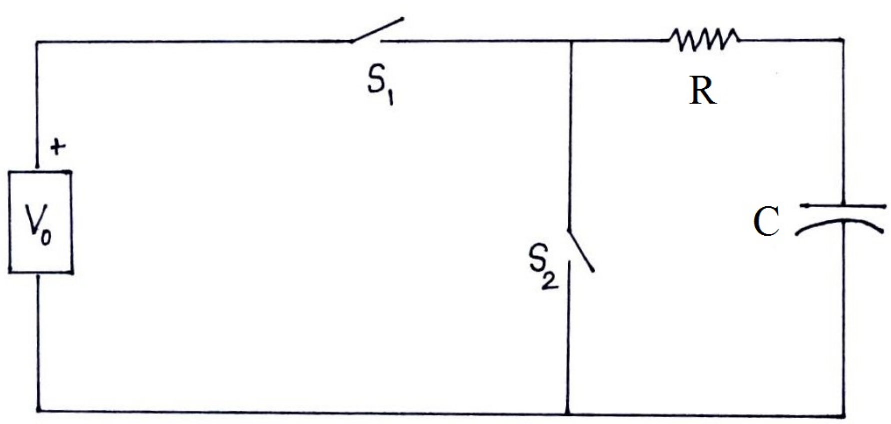


Figure 5.2:

S_1 on, the capacitor gets charged and when you turn on the switch S_2(S_1

off) the capacitor gets discharged through the load. The rate at which the charge moves, i.e. the current; this, of course, will depend on the resistance offered. It will be seen, therefore, that the rate of energy transfer will depend on RC where C is the capacitance and R some effective resistance in the circuit. It can be shown (Appendix II)that the charging of a capacitor can be represented by the relation

$$q = q_o(1 - e^{-t/RC}) \tag{5.2}$$

where q is the charge on the plates at time t; similarly, the discharge occurs according to the relation

$$q = q_o e^{-t/RC} \tag{5.3}$$

Thus, the rate at which the charge or discharge occurs depends on the 'RC' of the circuit. The exponential nature of the charging and discharging processes of a capacitor is obvious from equation5.2 and 5.3. You would have ample opportunity to learn more about it through the experiments that follow. From equation 5.3 it can be seen that RC is the time during which the charge on the capacitor drops to 1/e of the initial value. Further, since RC has dimensions of time, it is called the *time constant* of the circuit.

In the following series of experiments, you will study the time variation of charge, voltage and energy in an RC circuit.

5.3 The Network Board

The network board for these experiments consists of a number of resistors and capacitors and two d-c meters. The centrally pivoted meters facilitate measurements during both charging and discharging of a capacitor. Figure 5.3 shows the scheme of arrangement of these on the board and their connections underneath it. The capacitors are of electrolytic type(since you need high values of capacitance). These are meant for use with d-c power and great care must be taken to connect them with the right polarity.

In order to make the time constant RC of the circuit large the resistors also need to have high values and are, therefore, of carbon film type. Remember, the values marked on both R and C are not absolutely dependable, The resistance values are given within ±2% but the capacitance values have a tolerance of ±10% or more.

A regulated d-c power-supply and a stopwatch are also provided along with the board. Use of 20 to 25 volts from this supply would enable you

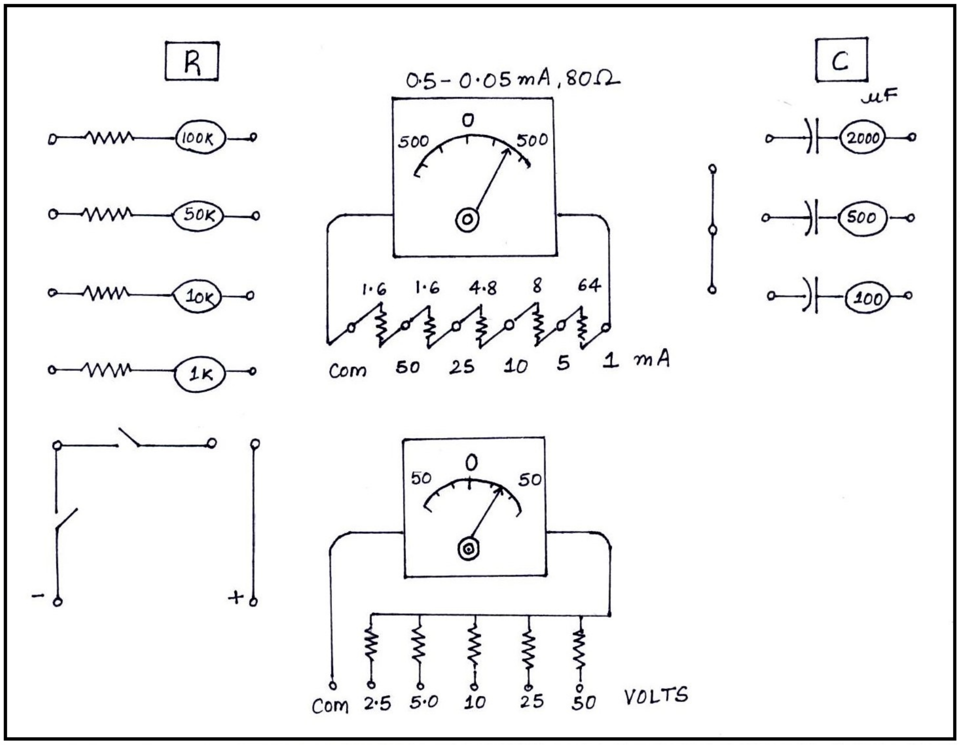


Figure 5.3:

to reduce the unwanted discharge through the voltmeter and considerably improve the performance of the experiments. This would be obvious from the following discussion. If you look at Figure 5.4 relating to the discharging of a capacitor, you would realize that on turning the switches S_1 and S_2 on, the capacitor would discharge through both the load R and the voltmeter V. If R_v be the resistance of the meter, the effective leakage resistance R' would be given by

$$R' = R\frac{R_v}{R + R_v} \tag{5.4}$$

The unwanted discharge through the meter can, therefore, be reduced only by making R_v much higher than R. This is accomplished in a simple way by using a higher voltage source and employing a higher range of the meter for detection. However, even this would not be adequate in case of smaller C values where you should employ a sort of 'sampling method' for voltage measurements. This consists in turning on the switch S_2 only at the instant

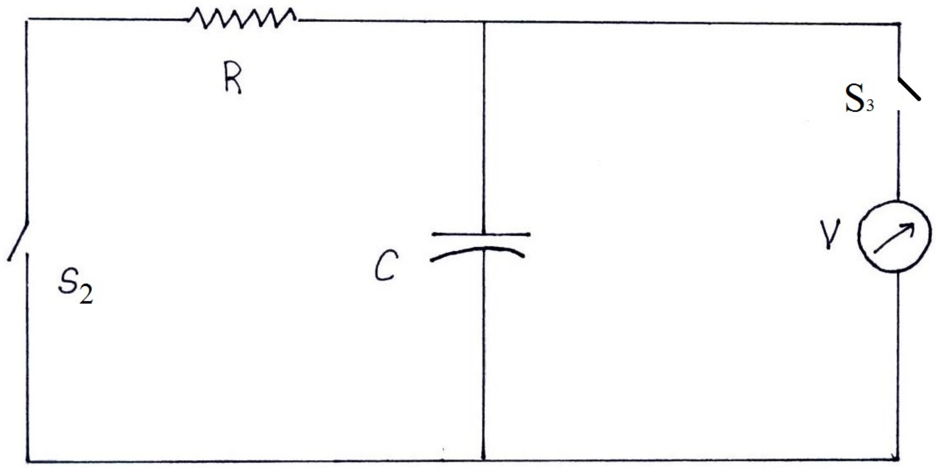


Figure 5.4:

when a measurement is to be made. You may find it difficult to read the meter, say every 2 seconds or so. In that case, take one set of readings at 0.6.12.18...sec., then the next set of readings at 2,8,14,20,...sec. and so on until you have a complete set of readings every 2 seconds.

5.4 Experiment A

To study the charging of a capacitor in an RC circuit

Take a resistor and a capacitor and complete the circuit as shown. Switch on the stop watch and the circuit simultaneously. Read the voltmeter every 2 second until the voltmeter indicates a maximum value V_o*. You may find it difficult to read the meter, say every 2 seconds or so. In that case, take one set of readings at 0.6.12.18...sec., then the next set of readings at 2,8,14,20,...sec. and so on until you have a complete set of readings every 2 seconds. Plot the voltage V_c across the capacitor as a function of time.Figure 5.6. To analyse the results, proceed as follows. The volage across a charging

*Theoretically speaking, in the case of a pure capacitor, the voltage across it should become equal to the source voltage V_o when the capacitor is fully charged. In practise, it is very seldom so. This is because there is always a leakage charge across the capacitor

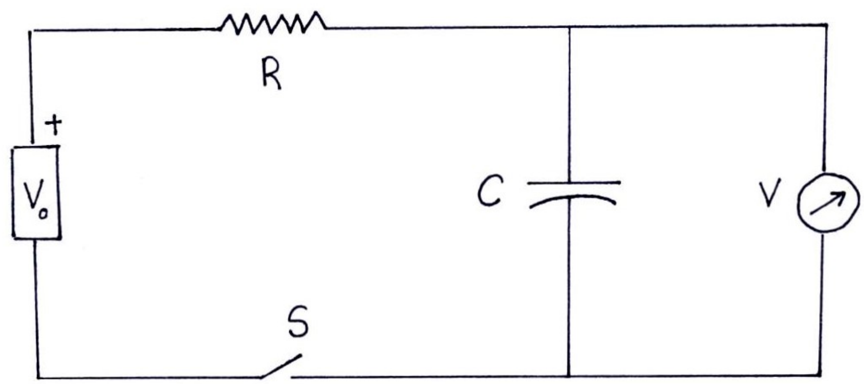


Figure 5.5:

capacitor is given by (see Appendix II).

$$V = V_o(1 - e^{-t/RC}) \tag{5.5}$$

where V_o is the maximum voltage. Eq 5.5 means that the capacitor charges exponentially. Let us verify these facts. Rewriting Eq 5.5, we get

$$\frac{V_o - V}{V_o} = e^{-t/RC} \tag{5.6}$$

If we now define a time $T_{\frac{1}{2}}$ at which the voltage is half the maximum i.e. $V = V_o/2$, the above expression would reduce to

$$T_{\frac{1}{2}} = RC \log_e 2 = 2.30RC \tag{5.7}$$

This clearly shows that for a given RC the time $T_{\frac{1}{2}}$ should be constant. Choosing values for $(V_o - V)/V_o$ in geometric progression in steps of $\frac{1}{2}$, the time intervals $\Delta T_{\frac{1}{2}}$ can be easily shown to be equal. See Figure 5.6

Eq 5.7 could be examined in yet another way. Make some measurements of $T_{\frac{1}{2}}$ for different RC combinations and plot these versus RC. In theory this should be a straight line; but the rated values of the components(particularly C may be as much as 10% off). Thus, the values as determined by you are probably more reliable than the specified ones.

Alternatively, you may plot $\log(V_o - V)$ against t to verify the Eq. 5.5 and the exponential nature of charging of the capacitor. You ought to get a straight line whose slope would give you the value of -1/RC.

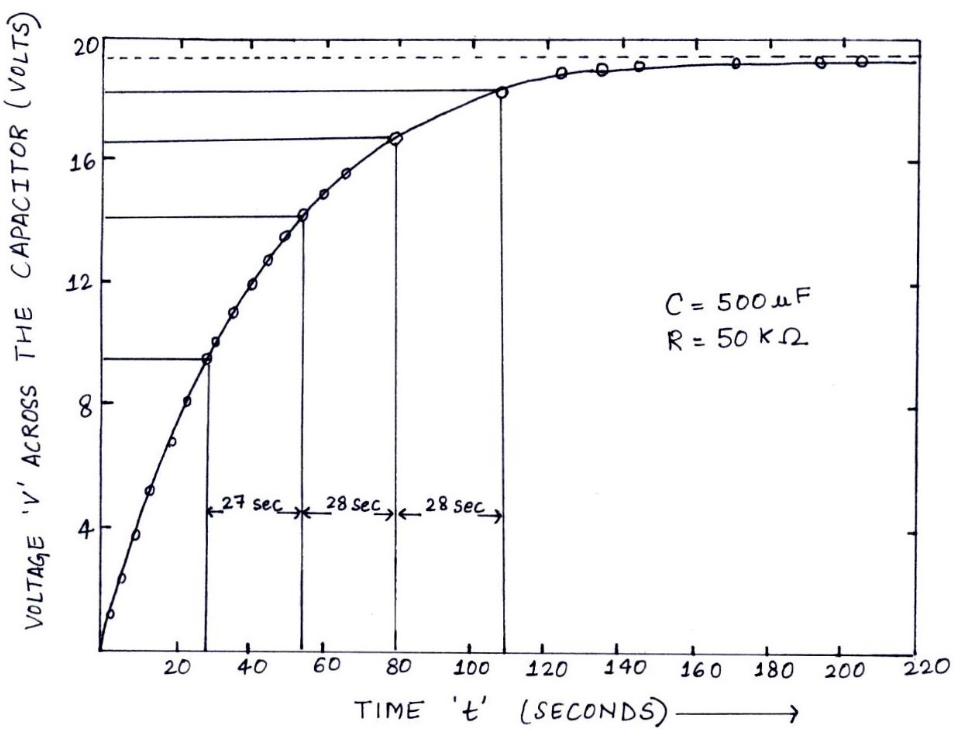


Figure 5.6: Exponential charging of a capacitor

5.5 Experiment B

To study the discharging of a capacitor

As shown in Appendix II, the voltage across the capacitor during discharge can be represented by

$$V = V_o e^{-t/RC} \tag{5.8}$$

You may study this case exactly in the same way as the charging in Expt A. However, remember that for the case of discharge $(V_o - V)/V_o$ has to be replaced by V/V_o and $\log(V_o - V)$ by log V.(why?) You would find that for the same set of R and C the time $T_{\frac{1}{2}}$ and hence the interval $\Delta T_{\frac{1}{2}}$ have the same value as in Expt A.

In the circuit shown figure 5.7, if the switch is turned on at time t=0 and turned off at $t = t_1$, the voltage across the input terminals AB ideally behaves as in figure 5.8. Plot the output across PQ in the same manner. Once *again, you should train yourself to think of the RC combination as a 'box' with input terminals AB and output terminals PQ. Suppose the circuit in the above question had been on for some time before the switch was suddenly disconnected. Display both the input and the output(voltages) as a function of time. Assume that the 'box' is now wired as follows figure 5.9 Discuss the*

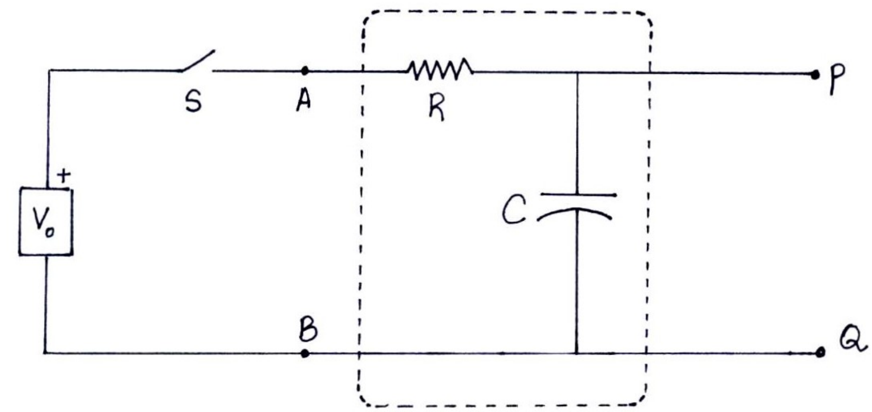


Figure 5.7:

input and output when the switch is turned on and later, turned off.

Exercises pertaining to Expts A and B

1. Change the voltage V_o of the power supply and see if, for a given RC, the time $T_{\frac{1}{2}}$ or the time interval $\Delta T_{\frac{1}{2}}$ remains the same. Do you expect it to change?

2. For a known resistance, the time $T_{\frac{1}{2}}$ determines the capacitance. Use this to determine first C_1 , then C_2 and finally the effective capacitance C with both C_1 and C_2 in parallel figure 5.10.

Verify the law $C = C_1 + C_2$ where C is the effective capacitance of the combination in parallel. Try this with various resistors R.

3. Use exactly the same method(by measuring $T_{\frac{1}{2}}$) to verify the law

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \text{.........} \tag{5.9}$$

for a set of capacitors in series with a resistor R [Figure 5.11]. Try with

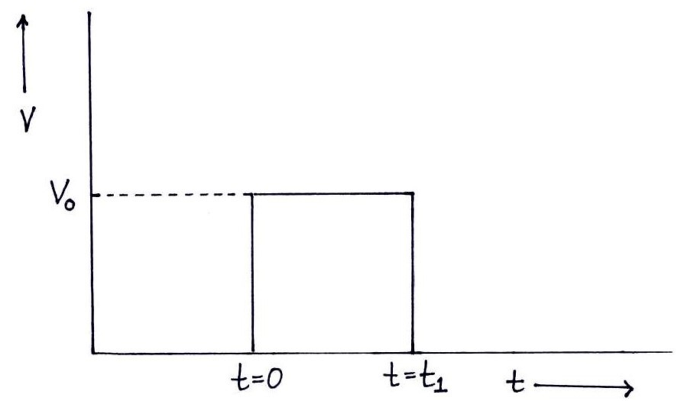


Figure 5.8:

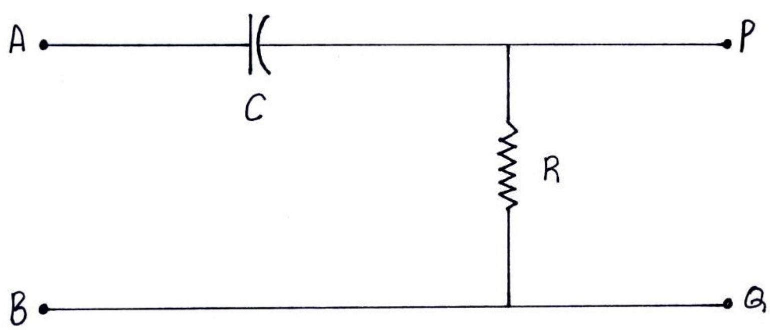


Figure 5.9:

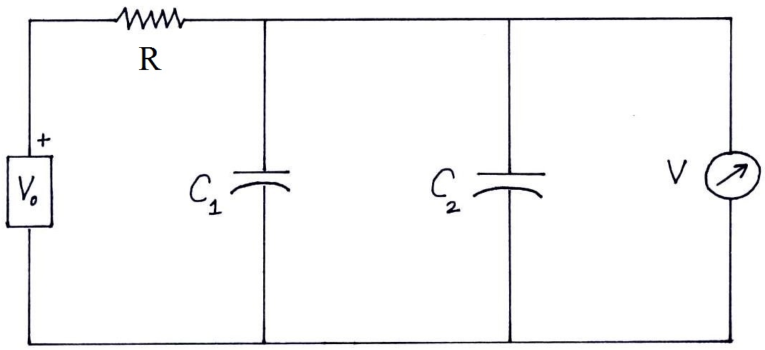


Figure 5.10:

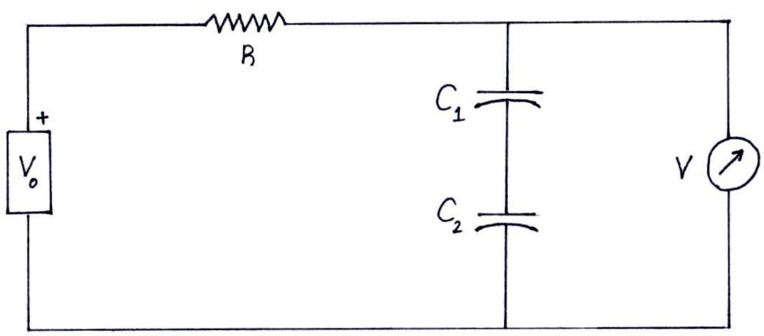


Figure 5.11:

different values of R as well.

4. Charge a set of capacitors connected in series.(Roughly, about 5 times $T_{\frac{1}{2}}$ will charge the capacitors to the maximum voltage). Measure the voltage across each and establish the law.

$$C_1V_1 = C_2V_2 = C_3V_3......... \tag{5.10}$$

5. Connect a set of capacitors in parallel. Measure the current through each of them** after a fixed interval of time either during the charging or

** You will have to use the terminals provided to the left of the capacitors for connecting the current meter in series with the capacitor individually during the discharging operation and establish the relation:

$$\frac{C_1}{i_1} = \frac{C_2}{i_2} = ... \qquad (5.11)$$

(in verifying such relations as 2-9,2-10 and 2-11, make sure to measure the capacitance yourself and not just trust the rated values).

6. With an RC time of around 30sec.,measure the voltage across R as a function of time while charging and discharging the capacitor. Pay particular attention to the polarity of the voltage across R in each case. It is for this reason that the voltmeter provided is centrally pivoted one. You would also notice that with the passage of time the voltage across the resistor goes on falling until it becomes zero when the capacitor is fully charged or discharged. If you use two voltmeters and measure the voltages across R and C simultaneously you can also verify that at all instants of time

$$V_R + V_C = V_o \qquad (5.12)$$

This is the verification of kirchoff's law.

5.6 Experiment C

To study the current flow during charging and discharging of a capacitor

The current flowing through an RC circuit is given by (Appendix II)

$$I = I_o e^{-t/RC} \qquad (5.13)$$

for the charging circuit and

$$I = -I_o e^{-t/RC} \qquad (5.14)$$

for the discharging circuit. Thus the current follows the same behaviour as the voltage with time except that its direction is opposite in the two cases.

Connecting the milliammeter in series with the resistor and the capacitor[Figure 5.12, study the behaviour of the current in the two cases [Figure 5.13]

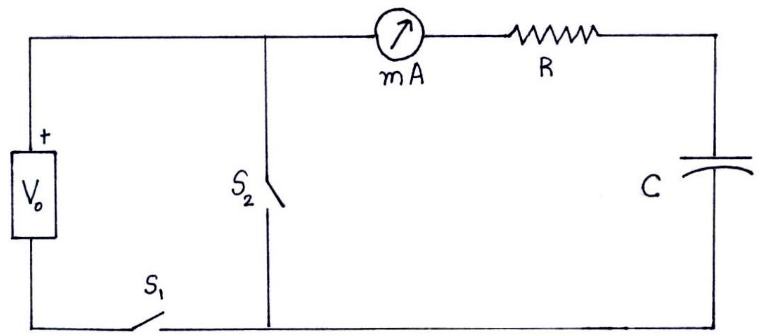


Figure 5.12:

Pay particular attention to the reversing of the current in the circuit. This is why a centrally pivoted current meter is provided.

Also, if you connect the voltmeter across R, in addition to the reversing of polarity in the voltage across R, you would discover that the whole of the voltage appears across it when you commence the charging or the discharging. Also verify if the maximum current I_o at the commencement of the charging and the discharging is given by

$$I_o = \frac{V_o}{R} \tag{5.15}$$

Further, you can see that at all instants of time

$$I = \frac{V_R}{R} \tag{5.16}$$

5.7 Experiment D

To estimate the leakage resistance of a given capacitor

Capacitors, once charged, do not maintain their charges indefinitely even when their terminals are left disconnected. (But, they often maintain it for long times. Do not poke your fingers at these terminals. You are always advised to deliberately discharge the capacitor before leaving your experiment). A capacitor loses its charge by leakage either through the dielectric between or the insulators which holds the capacitor electrodes in place. Thus, strictly speaking, any capacitor may be effectively represented as in figure 5.14 where

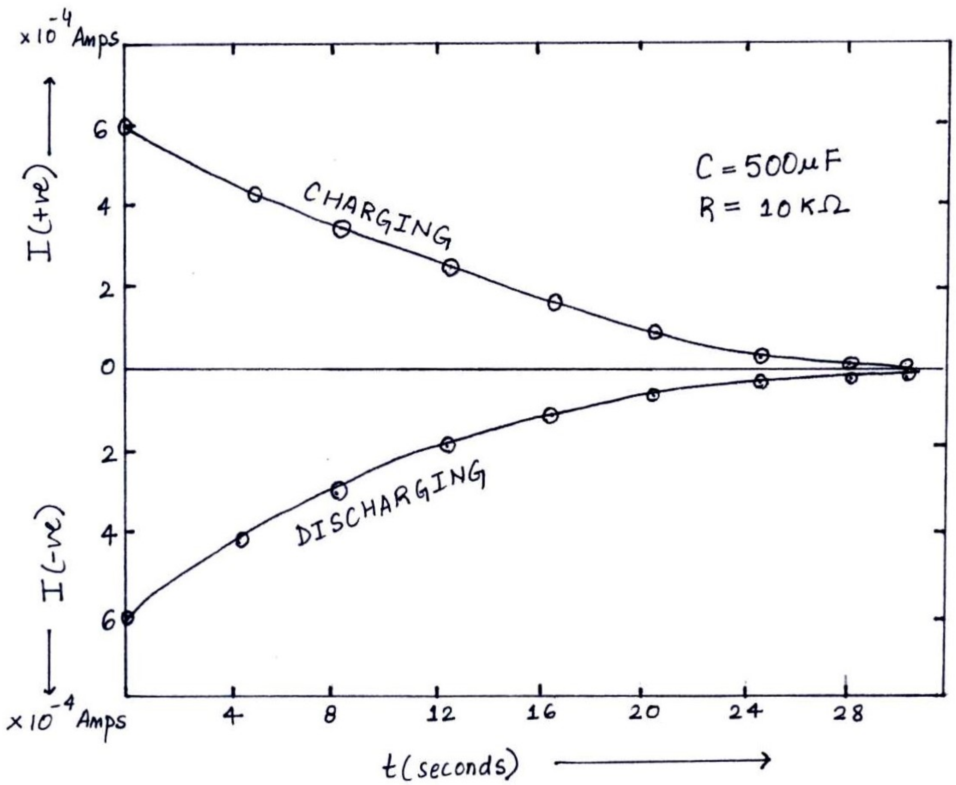


Figure 5.13: Behaviour of current in an RC circuit

R_C representing the leakage resistance of the capacitor C, is of the order of a few megaohms.

In the case of an ideal capacitor ($R_C = \infty$) when fully charges, the voltage V_C across it should be equal to V_o figure 5.5 and the final value of the charging current I in the circuit (figure 5.12) should be zero. In practice, as you would discover during the course of these experiments, this is not the case. V_C is always less than V_o and the charging current never drops down to zero. It is easy to understand these facts if you remember the true representation of a capacitor (figure 5.14) Take a resistor R and a capacitor C so that the time constant RC is of the order of 10sec. or more. Connect the in series with a milliammeter [figure 5.15(a)] (note how the capacitor has been represented). Turn on the switch and confine your attention to the current meter to observe how the charging current drops with time. After a time (5RC or more) the capacitor is expected to be fully charged and the current to be zero. On

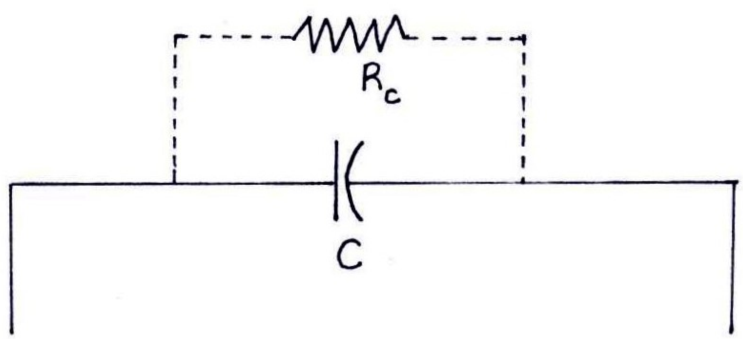


Figure 5.14: Representation of an actual capacitor

your meter it may indeeed appear as if the current has become zero but if you replace the milliammeter by a microammeter of movement 50μA or less[Figure 5.15(b)] you would find a small steady current flowing persistently no matter how long you wait. Measure this leakage current I_C. Assuming the voltage across the capacitor to be the same as V_o, the supply voltage(this is not quite correct), calculate the order of the leakage resistance R_C by

$$R_C = \frac{V_o}{I_C} \tag{5.17}$$

You must learn to make approximations like these($V_C \simeq V_o$) and understand why such approximations do not matter when it is only the order of magnitude of a quantity you are interested in.You should further, be able to appreciate the difficulty in measurement of V_C with a meter of finite resistance and hence the importance of the approximation $V_C = V_o$. However, if you are interested in knowing the leakage resistance more precisely you may calculate it as follows:

$$R_C = \frac{V_o}{I_C} - R \tag{5.18}$$

Do you see how the approximation involved in Eq.5.17 is taken care of in Eq.5.18 ?

If a capacitor of $50\mu f$ *and a leakage resistance of 2megaohms, in how much time will the charged capacitor, left to itself, lose half its charge?*

You may now connect the voltmeter across C[figure 5.15 and see how the leakage resistance R_C changes. Try to verify your result by calculation.

A capacitor of 100μf has a leakage resistance of 5megaohms. A voltmeter of resistance 500kilohms is connected across it to read the voltage. How much time would it take for the voltage to fall to a value 1/e times the initial value? Calculate first neglecting the leakage resistance and then taking it into account.

5.8 Experiment E

To measure the energy dissipated in charging a capacitor

Some energy is spent by the source in charging a capacitor. A part of it is dissipated in the circuit and the remaining energy is stored up in the capacitor. In this experiment we shall try to measure these energies.

With fixed values of C and R measure the current I as a function of time. The energy dissipated in time dt is given by I^2Rdt. The total energy dissipated is given by

$$E = \int I^2 R dt = R \int I^2 dt \tag{5.19}$$

This integral can be evaluated very easily by graphical method as follows:

From the observed values of I plot I^2 versus t[figure 5.16]. The area under the curve gives the value of the integral and R times this area is therefore a measure of the energy dissipated in the circuit.

Does the energy dissipated depend on the value of the resistance? A cursory glance at Eq5.19 would indicate that it should. You can test this as follows:

Plot the I^2, t curves for different values of the resistance R in the circuit and measure the area in each case. You will discover an amazing result-he energy dissipated thus would turn out to be independent of the charging resistance.

In charging or discharging a capacitor through a resistor an energy equal to $\frac{1}{2}CV^2$ *is dissipated in the circuit and is independent of the resistance in the circuit. Can you devise an experiment to measure it calorimetrically? Try to work out the values of R and C that you would have to employ in this experiment. Remember, capacitors having a high value of capacitance cannot* *withstand voltages higher than 50 to 60 volts and those which can withstand higher voltages have lower values for capacitance*

Suppose the total resistance in the circuit including that of the connecting wires is made zero, in what part of the circuit would the energy $\frac{1}{2}CV^2$ *be dissipated now? How will you modify your above calorimetric measurement for this case?*

Repeating this for the case of discharging, you will find that again an equal amount of energy is dissipated in the circuit. Since this energy in the case of discharging comes from the capacitor you can draw a simple conclusion from these experiments. Of the total energy drawn from the source in charging a capacitor, half is dissipated in the circuit and half is stored up in the capacitor irrespective of the value of the resistance. In other words, of the total energy spent in charging a capacitor you can recover only half of it.

5.9 Experiment F

To study the dependence of the energy dissipated on C and V

For a fixed voltage V_o, the energy dissipated is proportional to the value of C i.e. if E_1, E_2 etc. are the energies dissipated for capacitors C_1,C_2 etc., we shall have

$$\frac{E_1}{C_1} = \frac{E_2}{C_2} = ... \tag{5.20}$$

Measure the energies E_1,E_2 etc. graphically(Expt E) and check this.

For a fixed capacitance C, estimate similarly the energy dissipated for different values of the supply voltage V_1,V_2, etc. You may vary V from 5 to 20 volts or so. Establish the relation

$$\frac{E_1}{V_1^2} = \frac{E_2}{V_2^2} = ... \tag{5.21}$$

In fact, the energy dissipated is $\frac{1}{2}CV^2$(Appendix II); see, if you can verify this in all the experiments discussed.

The result that the energy dissipated($\frac{1}{2}CV^2$) in an RC circuit is independent of R seems strange. Try and see if you can present an argument to justify this. Discuss this in the limiting cases R$\to$0 and R$\to \infty$ also.

5.10 Experiment E

To study the adiabatic charging of a capacitor

Is there no way of eliminating or reducing the dissipation of energy $\frac{1}{2}CV^2$ in charging of a capacitor? The answer is yes, there is a way. Instead of charging a capacitor to the maximum voltage V_0 in a single step if you charge it to this voltage in small steps the dissipation of energy can be reduced. Theoretically speaking, if the successive steps are infinitesimally small the dissipation can be entirely eliminated. This is called adiabatic charging of a capacitor. You can verify this with the following experiment.

Suppose you want to charge a capacitor C to a voltage V_0. If you do that in a single step you know(ExptE) that an energy $\frac{1}{2}CV^2$ would have to be dissipated in the circuit. On the other hand, if you charge the capacitor to a voltage $V_0/2$ tp V_0 the total energy dissipated would be $\frac{1}{4}CV^2$. (Why?) You can check this experimentally. The trick is to first keep the charging voltage to $V_0/2$, let the capacitor charge for a time much greater than RC of the circuit, disconnect the power supply, increase its voltage to V_0, reconnect it and let the capacitor charge to V_0. Plot I^2, t curves for the two parts and find out the total energy dissipated in the process. Compare this with the area of the curve obtained when the capacitor is charged to V_0 in a single step and you would find the former to be roughly one-half the area in the latter case. The charging voltage in the two cases can be represented as shown in figure 5.17]. Now think how you can reduce this loss further. Check your answer experimentally.

A capacitor of 1000μf is connected in series with a resistor of 2kilohms. Calculate the energy dissipated in charging it to 20volts in a single step. How many equal steps will you have to employ to cut down this loss to one-tenth its value? Show these steps graphically(as in figure **??***) taking care to mark the appropriate value of Δt.*

Can you now think of the ideal charging method to reduce this loss to zero? Would it be possible to accomplish this in practise?

APPENDIX-I

Capacitors 1.**Paper and Other Capacitors**

Commercially available capacitors come in various forms for use in simple networks. A common one is the paper capacitor in which a pair of metal foils sandwich a thin paper. The whole assembly is then rolled into a bundle, dipped in wax and sealed against moisture. There may still be some leakage of charge through the paper particularly if the applied voltage is large. A practical consideration for a capacitor is always the voltage it can withstand without breakdown.

The capacitance of the system is somewhat increased when there is a dielectric(such as paper) between the electrodes. Other dielectrics commonly used are mica, ceramics and sometimes plastic films.

It can be seen that by reducing the distance between the electrodes one can increase the capacitance; but one cannot do this indefinitely. For a given voltage, electrical breakdown(i.e. current through the dielectric) occurs if the distance is too small. For example, if air is the dielectric and the capacitor is to withstand 100volts, a separation of at least 1/10 mm is required. The capacitance of a parallel plate capacitor is given by

$$C = \epsilon_o \frac{A}{d} \tag{5.22}$$

One can see from this relation(the reader is advised to do this arithmetic) that no more than about 10pico-farad per sq.cm (1 pico-farad $=10^{-12}$farad) can be achieved.

2.**Electrolytic Capacitors**

Some metals like aluminium, when placed in a suitable electrolyte and made the positive electrode(i.e. aluminium is the positive electrode) from a thin film (about 10^{-6}cm) of oxide. This film has a very high resistance to a flow of current in one direction(from aluminium towards electrode) and a very low one in the reverse direction. Thus, provided we use the aluminium side as the positive one, we can obtain fairly large capacitance, a micro-farad per $10cm^2$ area with this kind of system when the aluminium and the electrolyte form the two electrodes.

Even smaller film thicknesses can be made so that electrolytic capacitors can achieve as high as 10^{-4}farad for $10cm^2$. It is obvious that we cannot use an electrolytic capacitor with a-c unless we ensure that its polarity would not change.

Other limitations are that they have a larger leakage current than the ordinary capacitors, their life is shorter, their capacitance may change somewhat after a few months(even the values marked on the new ones may vary by as much as 20%) and the working voltages for these are lower.

In all the circuits wherein these capacitors have been used they are represented as in [figure 5.19], the curved line representing the negative can.

In using these electrolytic capacitors, remember to connect them with the right polarity and always below the rated voltage of the capacitor.

APPENDIX-II
Analysis of an RC circuit with a source of constant EMF

When a resistor and a capacitor are connected in series to a source of voltage V_o, we have

$$V_c + V_R = V_o \tag{5.23}$$

where V_c and V_R are the voltages across C and R. Writing

$$V_c = \frac{Q}{C} \tag{5.24}$$

and

$$V_R = RI = R\frac{dq}{dt} \tag{5.25}$$

where q is the charge on the capacitor and I the current, we have

$$\frac{dq}{dt} + \frac{q}{RC} = \frac{V_o}{R} \tag{5.26}$$

This equation is readily integrated after multiplying by the integrating factor $e^{t/RC}$,

$$qet/RC = \frac{V_o}{R}\int e^{t/RC}dt \tag{5.27}$$

$$qe^{t/RC} = CV_o e^{t/RC} + A \tag{5.28}$$

where A is a constant.

For charging, we assume the initial condition q=0 at t=0 which establishes the equation

$$q = q_o(1 - e^{-t/RC}) \tag{5.29}$$

where we have put $q_o = CV_o$

Similarly, for discharging, we set $q = q_o = CV_o$ at t=0 to give

$$q = q_o e^{-t/RC}) \tag{5.30}$$

The potential across the capacitor(q/C) follows exactly the same dependence on time as the charge.

The current is

$$I = \frac{dq}{dt} = \frac{q_o}{RC}e^{-t/RC} \tag{5.31}$$

or

$$I = I_o e^{-t/RC} \tag{5.32}$$

for the charging circuit and

$$I = -I_o e^{-t/RC} \tag{5.33}$$

for the discharging circuit. Thus the current follows the same behaviour with time except that the sign is reversed in the two cases.

When the source charges the capacitor, it does work. This work is simply

$$W = \int V_o I dt \tag{5.34}$$

since the rate of doing is $V_o I$. Using equation(2.32), we have

$$W = V_o I \int_0^\infty = V_o I_o e^{-t/RC} \tag{5.35}$$

since $V_o = \frac{q_o}{C}$ and $I_o = \frac{q_o}{RC}$
This can be written in either of the following forms:

$$W = CV_o^2 = \frac{q_o^2}{C} \tag{5.36}$$

An interesting point to note is this: when the capacitor has been charged to its full potential V_o, it has an energy $\frac{1}{2}\mathrm{C}V_o^2$ stored in it. Thus an energy $\frac{1}{2}\mathrm{C}V_o^2$ has been dissipated while charging in the resistive parts of the circuit.

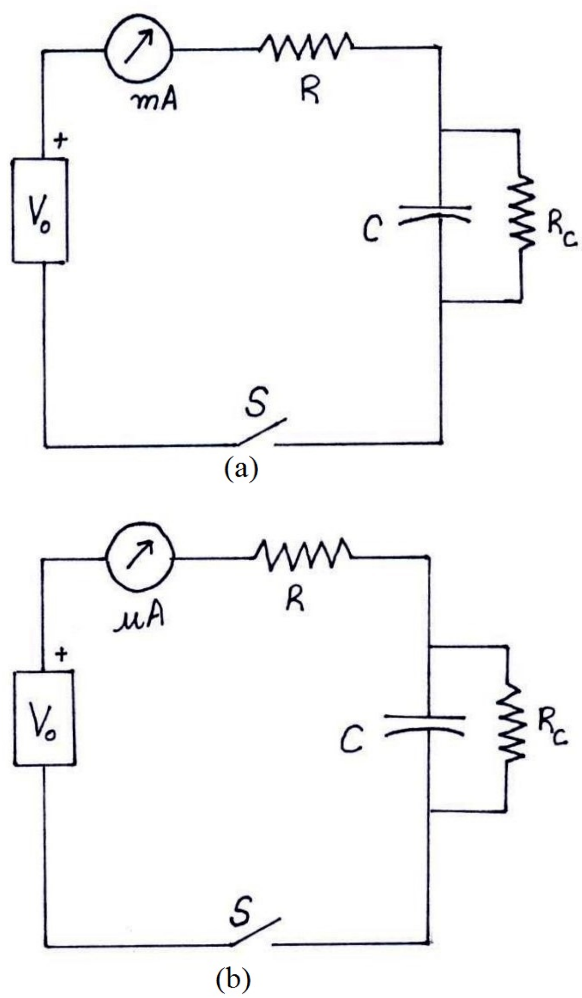


Figure 5.15:

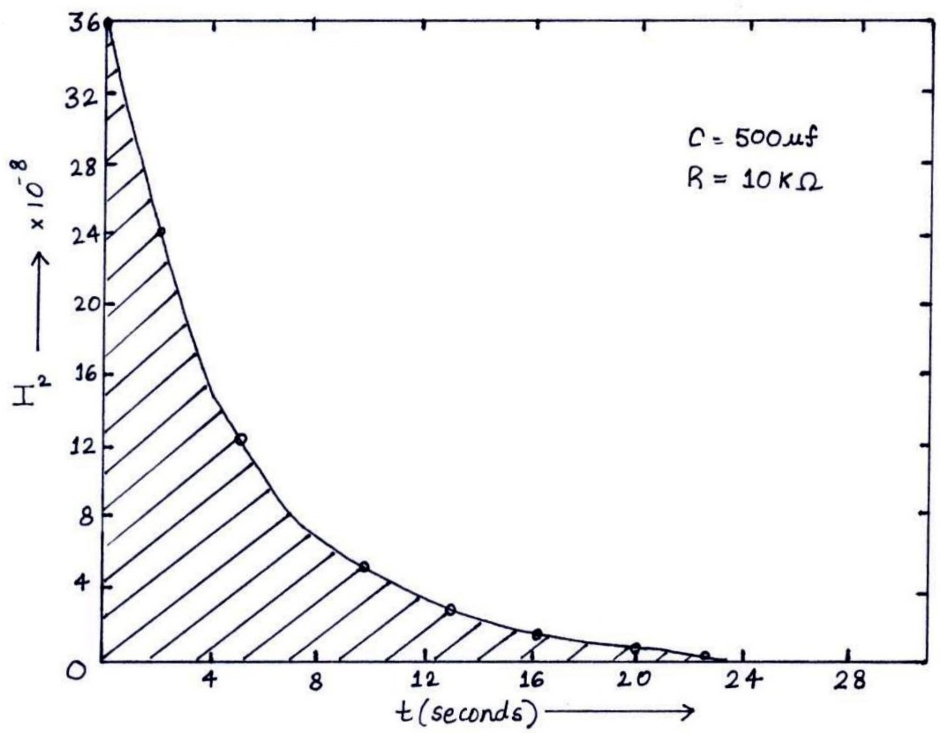


Figure 5.16: R times the shaded area gives the energy dissipated

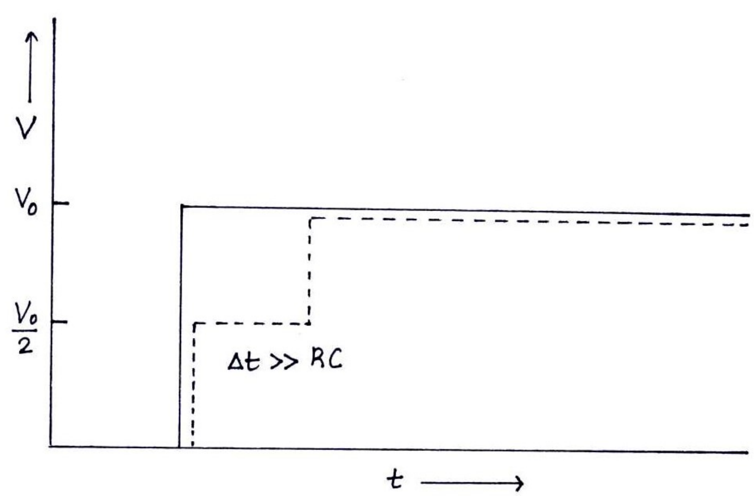


Figure 5.17: One step and two step charging voltage

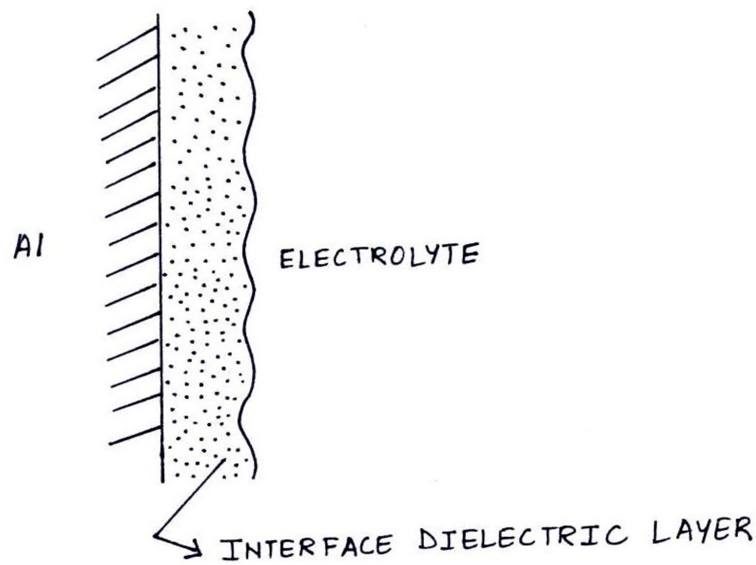


Figure 5.18:

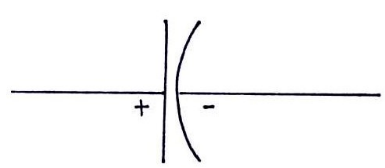


Figure 5.19:

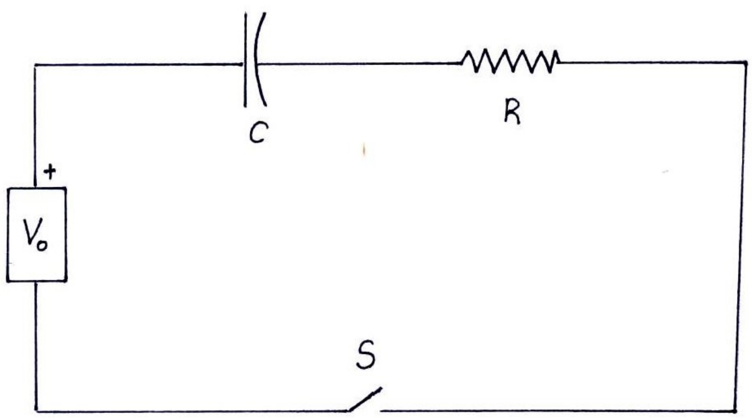


Figure 5.20:

6.

BH curve tracing

Magnetic characterization of the given materials using Hysteris loop tracer

1. Analysis of the given Ferromagnetic Materials in terms of coercivity, retentivity and saturation magnetization.
2. Identification of magnetic phase.

A note on Magnetic Hysteresis

Magnetic Hysteresis relates to the magnetization properties of a material in which the material becomes magnetized and then de-magnetized. We know that the magnetic flux generated by an electromagnetic coil is the amount of magnetic field or lines of force produced within a given area and that it is more commonly called "Flux Density". The flux density is denoted by the symbol B and its unit is Tesla. We also know that the magnetic strength of an electromagnet depends upon the number of turns of the coil, the current flowing through the coil or the type of core material being used, and if we increase either the current or the number of turns we can increase the magnetic field strength (denoted by symbol H).

The relative permeability symbol μ_r, is defined as the product of μ(absolute permeability) and μ_o, the permeability of free space. The relationship between B and H can be defined by the fact that the relative permeability, μ_r is not a constant but a function of the magnetic field intensity thereby giving magnetic flux density as $B = \mu H$.

So for ferromagnetic materials the ratio of flux density to field strength(B/H) is not constant but varies with flux density. However, for air cored coils or any non-magnetic medium core such as wood or plastic, this ratio can be considered as a constant and this constant is known as μ_o,the permeability of free space. By plotting values of flux density, (B) against field strength, (H) we can produce a set of curves known as magnetization curves or magnetic hysterisis curves or simply BH curves.

Retentivity

Lets assume that we have an electromagnetic coil with a high field strength due to the current flowing through it, and that the ferromagnetic core material has reached its saturation point, maximum flux density. If we now open a switch and remove the magnetizing current flowing through the coil we would expect the magnetic field around the coil to disappear as the magnetic flux is reduced to zero. However, the magnetic flux does not completely disappear as the electromagnetic core material still retains some of its magnetism even when the current has stopped flowing in the coil. This ability to retain some magnetism in the core after magnetization has stopped is called Retentivity or Remanence while the amount of flux density still present in the core is called Residual Magnetism B_r.

The reason for this is that some of the tiny molecular magnets do not return to a completely random pattern and still point in the direction of the original magnetizing field giving them a sort of "memory". Some ferromagnetic materials have a high retentivity(magnetically hard) making them excellent for producing permanent magnets. While other ferromagnetic materials have low retentivity(magnetically soft) making them ideal for use in electromagnets,solenoids or relays. One way to reduce this residual flux density to zero is to reverse the direction of current flow through the coil making the value of H, the magnetic field strength negative and this is called a Coersive Force.

If this reverse current is increased further the flux density will also increase in the reverse direction until the ferromagnetic core reaches saturation again but in the reverse direction from before. Reducing the magnetizing current once again to zero will produce a similar amount of residual magnetism but in the reverse direction. Then by constantly changing the direction of the magnetizing current through the coil from a positive direction to a negative direction,as would be the case in an AC supply, a Magnetic Hysteresis loop of the ferromagnetic core can be produced.

The effect of magnetic hysteresis shows that the magnetization process of a ferromagnetic core and therefore the flux density depends upon the circuit's past history giving the core a form of memory. Then ferromagnetic materials have memory because they remain magnetized after the external magnetic field has been removed. However, soft ferromagnetic materials such as iron or silicon steel have very narrow magnetic hysteresis loops resulting in very small amounts of residual magnetism making them ideal for use in relays and solenoids as they can be easily magnetized and demagnetized.

Hysteresis Loop Tracer

6.1 Introduction

A precise knowledge of various magnetic parameters of ferromagnetic substances and the ability to determine them accurately are important aspects of magnetic studies. These not only have academic significance but are also indispensable for both the manufacturers and users of magnetic materials.

The characteristics which are usually used to define the quality of the substance are coercivity, retentivity, saturation magnetization and hysteresis loss. Furthermore, the understanding of the behaviour of these substances and improvement in their quality demand that the number of magnetic phases present in a system is also known.

The information about the aforementioned properties can be obtained from a magnetization hysteresis loop which can be traced by a number of methods in addition to the slow and laborious ballistic galvanometer method. Among the typical representatives of AC thin films, wires or even rock and mineral samples. Toroidal or ring form samples are more convenient because of the absence of demagnetizing effect due to closed magnetic circuits,but are not practicable to make all test samples in toroidal form with no free ends. Further every time the pickup and magnetizing coils have to be wounded on them and hence are quite inconvenient and time consuming. In the case of open circuit samples, the free end polarities give rise to the demagnetizing field which reduces the local field acting in the specimen and also makes the surrounding field non-uniform. Therefore, it becomes necessary to account for this effect lest the hysteresis loop is sheared. In case of conducting ferromagnetism, several additional problems arises due to eddy currents originating from the periodic changes in applied magnetic field. These currents give rise to a magnetic field in the sample which counteracts the variation of the external field and, in turn, renders the field acting in it non uniform and different from the applied field,both in magnitude and phase. Thus apart from resistive heating of the samples, because of the eddy currents the forward and backward paths traced near saturation will be different, which will lead to a small loop instead of a horizontal line in the magnetic polarization(J) against field(H) plot. The intercept of the magnetic polarization axis, which corresponds to retentivity and saturation magnetic polarization tip will continue to increase with the applied field upto very high values.

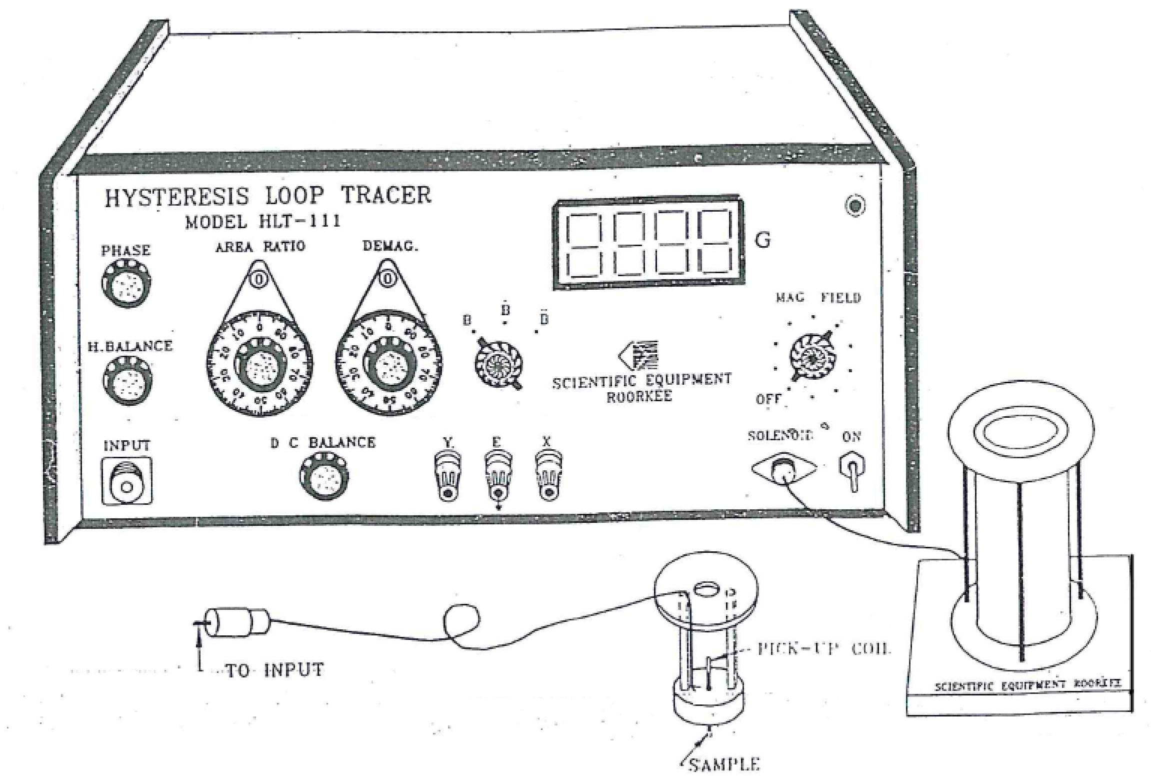


Figure 6.1: Hysteresis Loop tracer

Accordingly,retentivity(J_r) and saturation magnetic polarization(J_s) will be asymptotic values of the J-intercept and tip height respectively against H plots. Furthermore, the width of the loop along the direction of the applied field will depend on its magnitude and will continue to increase because shielding due to eddy currents is proportional to the external field. Therefore, the true value to coercivity (JH_c) corresponding to no eddy currents situation, will be obtained by extrapolating the half loop width against field line to the H=0 axis. Obviously the effect of eddy currents will be more pronounced in thicker samples than in thin ones.

6.1.1 DESIGN PRINCIPLE

When a cylindrical sample is placed coaxially in a periodically varying magnetic field (say by the solenoid) the magnetization in the sample also undergoes a periodic variation. This variation can be picked up by a pick up coil which is placed coaxially with the sample. Normally, the pick up coil is wound near the central part of the sample so that the demagnetization factors involved are ballistic rather than the magnetometric.

For the uniform field H_a produced, the effective field H acting in the cylindrical sample will be

$$H = H_a - NM \tag{6.1}$$

$$H = H_a - \frac{NJ}{\mu_o} \tag{6.2}$$

where N is the normalized demagnetization factor including 4π and J is the magnetic polarization defined by

$$B = \mu_o H + J \tag{6.3}$$

with $B = \mu H$ or $\mu_o(H+M)$ as magnetic induction. The signal corresponding to the applied field, H_a,can be written as

$$e_1 = C_1 H_a \tag{6.4}$$

where C_1 is a constant.

Further the flux linked with the pickup coil of area A_c due to sample of area A_s will be

$$\phi = \mu_o(A_c - A_s)H' + A_s B \tag{6.5}$$

Here H' is the magnetic field, in the free from sample sample area of the pickup coil, will be different from H and the difference will be determined by the magnitude of demagnetizing field. However, when the ration of length of the sample rod to the diameter of the pickup coil is more than 10, the difference between H and H' is too small, so that

$$\dot{\phi} = \mu_o(A_c - A_s)H + A_s B = \mu_o A_c H + A_s(B - \mu_o H) \tag{6.6}$$

$$\phi = \mu_o A_c H + A_s J \tag{6.7}$$

The signal e_2 induced in the pick up coil will be proportional to $\frac{d\phi}{dt}$. After integration the signal(e_3) will, therefore be

$$e_3 = C_3\phi = C_3\mu_o A_c H + C_3 A_s J \tag{6.8}$$

Solving equations(1.1),(1.4) and (1.8) for J and H give

$$C_1 C_3 A_c(\frac{A_s}{A_c} - N)J = C_1 e_3 - \mu_o C_3 A_c e_1 \tag{6.9}$$

and

$$C_1 C_3 A_c(\frac{A_s}{A_c} - N)H = C_3 A_s e_1 - \frac{N C_1 e_3}{\mu_o} \tag{6.10}$$

Based on these equations an electronic circuits may be designed to give values of J and H and hence the Hysteresis loop.

In case the sample contains a number of magnetically different constituents, the loop obtained will be the algebraic sum of individual loops of different phases. The separation of these is not easy in a J-H loop while in a second derivative of J, $\frac{d^2J}{dt^2}$, the identification can be made very clear.

6.1.2 EXPERIMENTAL DESIGN AND ANALYSIS

The aim is to produce electrical signals corresponding to J and H as defined in Eqs.(1.9) and (1.10) so that they can be displayed on CRO(cathode ray oscilloscope). Moreover, it should be able to display $\frac{d\phi}{dt}$ and $\frac{d^2\phi}{dt^2}$ as a function of H or usual time base of the CRO.

A detailed circuit diagram is shown in Fig. 2. The magnetic field has been obtained with a multi-layered solenoid driven by the AC mains at 50Hz and supplied through a variable transformer arrangement. The magnetic field has been calibrated with a Hall probe and is found to be within $\pm 3\%$ of the maximum value over a length of 5cm across the central region. The instantaneous current producing the field is passed through a resistor R_1, in series with the solenoid and measured with an AC ammeter. The resulting signal E_1 is applied across a 500Ω heliopot and an adder amplifier through a 100KΩ resistance.

The signal e_2 corresponding to the rate of change of flux is obtained from a pickup coil wound on a non conducting tube. Necessary arrangements have been made to place the sample coaxially with the pickup winding and in uniform magnetic field. The pickup coil is connected to point B(fig2) through

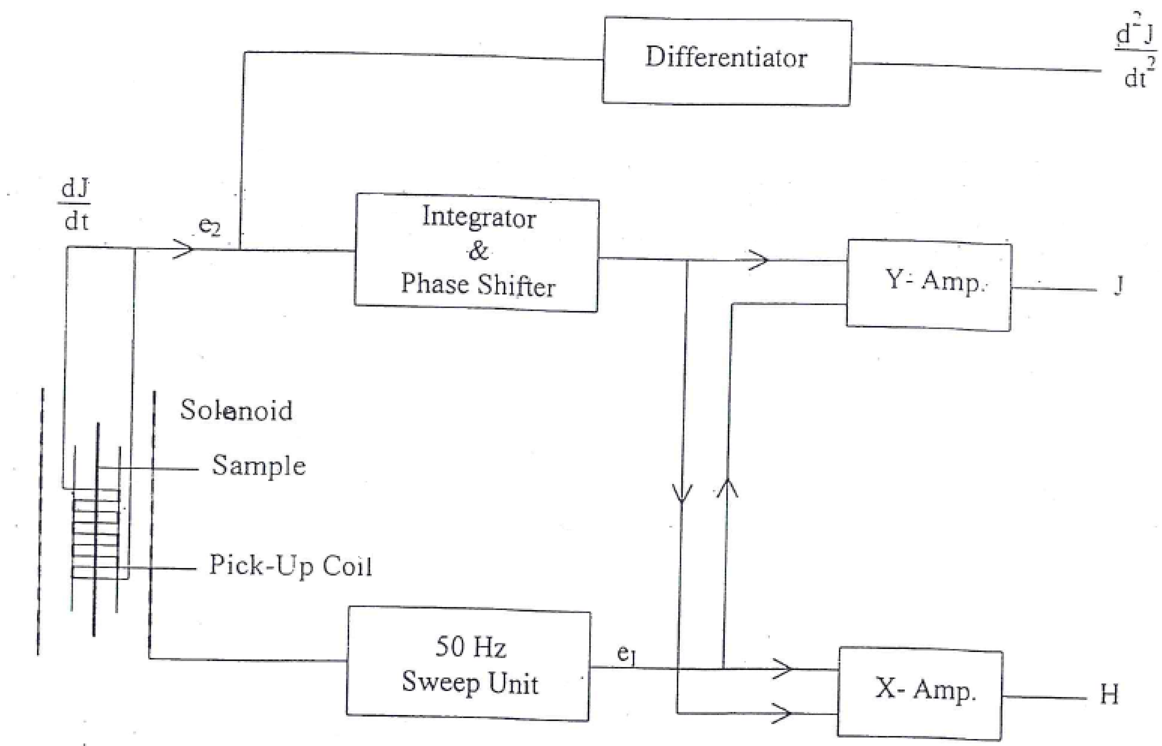


Figure 6.2: Hysteresis Loop tracer

twisted wires, where e_2 constitutes the input for further circuit. To obtain J, $e - 2$ is fed to an adjustable gain integrator. Because of capacitive coupling of pickup coil and solenoid, self inductance of pickup coil and integration operation an additional phase will be introduced in the output signal e_3, whose sign can be made negative with respect to e_1 by interchanging the ends of the pickup coil. To render e_3 completely out of phase with e_1,a phase shifter consisting of a 1KΩ potentiometer and 1μF capacitor has been connected at the output of integrator. Amplitude attenuation due to this network is compensated by the gain of the integrator and is not important as addition of signals is performed afterward.

The out of phase signals e_1 and e_3 are added at the input of a unity gain adder amplifier and its output is proportional to J is applied to Y-input of a CRO. Fractions of these signals corresponding to the demagnetization factor and area ration form the input of another adder amplifier with gain 10 whose output after further amplification of 10 is fed to the X-input of CRO and gives H. It may be mentioned that the gains of the amplifier can be adjusted but should always be such that the operational amplifiers are not loaded to saturation.

The selector switch(SW) can change the Y-input of CRO to J, $\frac{d\phi}{dt}$, or $\frac{d^2\phi}{dt^2}$. The $\frac{d\phi}{dt}$ signal is taken directly from the pickup while $\frac{d^2\phi}{dt^2}$ is obtained through an operational amplifier differentiator.

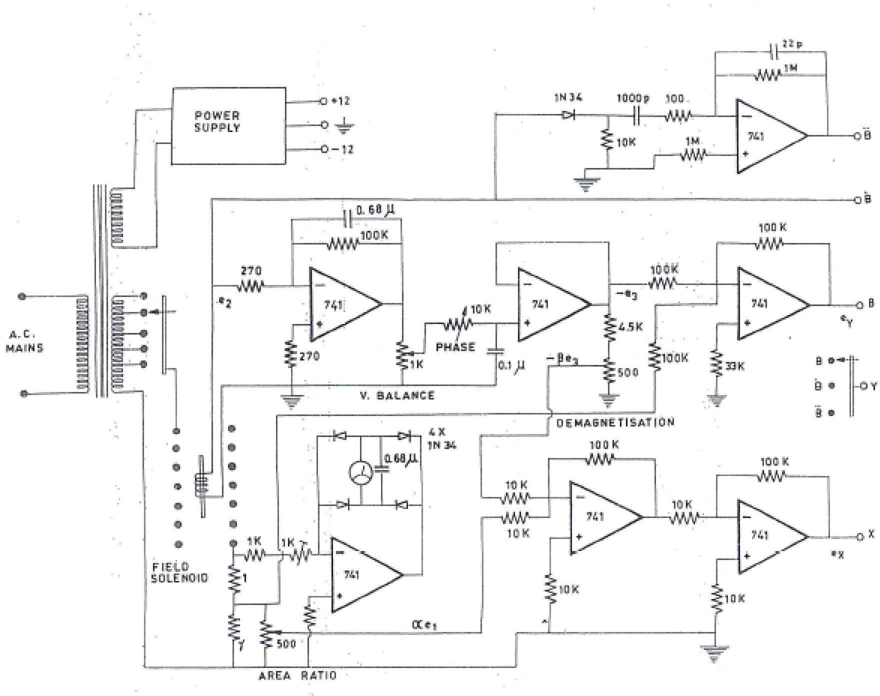


Figure 6.3: Hysteresis Loop tracer

Let us now analyze the circuit.

The magnetic field at the centre of the solenoid for current i flowing through it will be

$$H_a = Ki \tag{6.11}$$

also

$$e_1 = R_1 i \tag{6.12}$$

with symbols defined above. Equation(1.12) reduces to equation(1.4) with $C_1 = R_1/K$. Further, when the sample is placed in a pickup coil of n turns

$$e_2 = n(\frac{d\phi}{dt}) = n\mu_o A_c(\frac{dH}{dt}) + nA_s(\frac{dJ}{dt}) \tag{6.13}$$

by substituting ϕ from equation(1.7), we get

$$-e_3 = -g_1 \int e_2 dt = -g_1 n\mu_o A_c H - g_1 n A_s J \tag{6.14}$$

where g_1 is the gain of the integrator and phase shifter combination. The sum of e_1 and $-e_3$ after amplification becomes

$$e_y = -g_y(e_1 - e_3) = -g_y(C_1H - g_1n\mu_oA_cH + C_1\frac{NJ}{\mu_o} - g_1nA_sJ) \tag{6.15}$$

Using equations(1.1),(1.4) and (1.14), g_y is the gain of this amplifier. If we adjust $C_1 = g_1n\mu_oA_c$then

$$e_y = g_yg_1nA_c(\frac{A_s}{A_c} - N)J \tag{6.16}$$

Fraction α and β of e_1 and $-e_3$ respectively , are added together at the input of the first amplifier for the X-input. If g_x be the total gain of both amplifiers we get

$$e_x = g_x(e_1 - Be_3) = g_xg_1n\mu_oA_c(-B)H + g_xg_1nA_c(N - B\frac{A_s}{A_c})J \tag{6.17}$$

After substituting $C_1 = g_1n\mu_oA_c$, J will be eliminated from the right hand side of equation(1.17). By adjusting α and β such that

$$\alpha = \frac{A_s}{A_c} \tag{6.18}$$

and

$$\beta = N \tag{6.19}$$

we get

$$e_x = g_xg_1n\mu_oA_c(\frac{A_s}{A_c} - N)H \tag{6.20}$$

Equation(1.16) and (1.20) can be written as

$$H = G_o\frac{e_x}{(\frac{A_s}{A_c} - N)} \tag{6.21}$$

and

$$J = \frac{G_o\mu_og_xe_y}{g_y(\frac{A_s}{A_c} - N)} \tag{6.22}$$

where

$$\frac{1}{G_o} = g_xg_1n\mu_oA_c \tag{6.23}$$

Equations(1.21) and (1.22) define the magnetic quantities H and J in terms of electrical signals e_x and e_y respectively.

6.1.3 Method

CALIBRATION

When an empty pick up coil is placed in the solenoid field, the signal e_2 will only be due to the flux linking with coil area. In this case J=0,$\alpha = 1$,N=0, so that $H = H_a$ and Eqs.(1.16) and (1.20) yield

$$e_y = 0 \tag{6.24}$$

and

$$e_x = G_o^{-1} H_a \tag{6.25}$$

i.e. on CRO it will be only a horizontal straight line representing the magnetic field H_a. This situation will, obviously, be obtained only when the condition for (1.16) is satisfied. Thus without a sample in the pickup coil a good horizontal straight line is a proof pf complete cancellation of signals at the input of the Y-amplifier. This can be achieved by adjusting the gain of the integrator and also the phase with the help of network meant for this purpose. From known values of H_a and the corresponding magnitude of e_x, we can determine G_o and hence calibrate the instrument. The dimensions of a given sample define the values of demagnetization factor and the area ratio pertaining to the pickup coil.The demagnetization factor can be obtained from the Appendix. These values are adjusted with the value of 10turn heliopots provided for this purpose. The value of the area ratio can be adjusted upto three decimal places whereas that of N upto four(zero to 0.1max). The sample is now placed in the pickup coil. The plots of J,$\frac{dJ}{dt}$ and $\frac{d^2J}{dt^2}$ against H can be studied by putting the selector switch at appropriate positions. The graph of these quantities can also be obtained from time base by using the internal time base of CRO.

Since eddy currents are present in conducting ferromagnetic materials, the resulting J-H loop has a small loop in the saturation portion due to differences in phases for the forward paths. Moreover, these plots do not show horizontal lines at saturation and hence their shapes can't be employed as a criterion to adjust the value of demagnetization factor.

The values of loop width, intercept on the J-axis and saturation position are determined in terms of volts for different applied fields. Plots of these against magnetic field are then used to extract the value of coercivity, retentivity and saturation magnetic polarization. The first corresponds to the intercept of the width against currents straight line on the Y-axis and it is essentially the measure of the width under no shielding effects. On the other hand, the remaining two parameters are derived from asymptotic extensions of the corresponding plots because these refer to the situation when shielding effects are insignificant. caution is necessary in making the straight line fit for loop widths as function of current data as the points for small values of magnetic current have some what lower magnitudes. This is due to the fact that incomplete saturation produces lower coercivity values in the material. The geometrically obtained values of potential are,in turn, used to find the corresponding magnetic parameters through equations(1.21) and (1.22).If the area ratio for a particular sample is so small that the loop does not exhibit observable width, the signal e_x can be enhanced by multiplying α and β by a suitable factor and adjusting the two heliopots accordingly. The ultimate value of the intercept can be normalized by the same factor to give the correct value of coercivity.

6.1.4 Observations

For this equipment diameter of pickup coil=3.21mm
g_x=100
g_y=1

Sample: Commercial Nickel
Length of sample=39mm
Diameter of sample=1.17mm

Therefore,
Area ratio ($\frac{A_s}{A_c}$) =0.133
Demagnetization factor(N)=0.0029(Appendix)

Calibration
Settings:Without sample. Oscilloscope at D.C. Bal. adjusted for horizontal straight line in the centre. Demagnetization at zero and Area ratio 0.40 at magnetic field 200 Gauss(rms)
e_x=64mm, or
e_x =7.0V(if read by applying on Y input of CRO)

For Area ratio 1
e_x=160mm or e_x=17.5V

Table 6.1: Coercivity

S.No.	**Mag. Field (rms) (Gauss)**	**2xLoop width (mm)**
1.	30	7.0
2.	62	9.0
3.	94	11.0
4.	138	12.5
5.	179	14.0
6.	226	15.5
7.	266	16.75
8.	302	18.0
9.	336	18.75

From equation(1.25)
G_o(rms)=$\frac{200}{160}$=1.25gauss/mm
G_o(peak to peak)=1.25x2.82=3.53gauss/mm,

also
G_o(rms)=$\frac{200}{17.5}$=11.43gauss/volt
G_o(peak to peak)=11.43x2.82=32.23gauss/volt

By adjusting N and $\frac{A_s}{A_c}$ as given above the J-H loop width is too small. Thus both are adjusted to three times i.e. 0.0087 and 0.399 respectively.

The measurements for Coercivity, Saturation Magnetization and Retentivity are given in table 1.1 ,1.2 and 1.3.

Table 6.2: Saturation Magnetization

S.No.	**Mag. Field (rms) (Gauss)**	**Tip to Tip height(mV)**
1.	29	205
2.	61	370
3.	96	400
4.	137	420
5.	176	430
6.	223	440
7.	264	445
8.	298	450
9.	331	450

Table 6.3: Retentivity

S.No.	**Mag. Field (rms) (Gauss)**	**2xIntercept (mV)**
1.	29	170
2.	61	260
3.	95	265
4.	136	270
5.	175	270
6.	219	275
7.	263	275
8.	302	275
9.	335	275

From the graphs Fig(5) and Fig(6), we have
Loop width=2.9mm(after dividing by the multiplying factor 3)
2xIntercept=280mV
Tip to tip height=457.5mV

(a)Coercivity Since $e_x = \frac{1}{2}\times$ loop width $=\frac{1}{2} \times 2.9 = 1.45$mm

$H = \frac{G_o e_x}{(\frac{A_s}{A_c} - N)} = \frac{3.53 \times 1.45}{0.133 - 0.0029} = 39.30$ from equation(1.21)

(b)Saturation magnetization

$\mu_s = \frac{J_s}{4\pi}$ from equation(1.3)

$(e_y)_s = \frac{1}{2}\times$tip to tip height =457.5/2=228.75mV

$\mu_s = \frac{J_s}{4\pi} = \frac{G_o \mu_o g_x (e_y)_s}{g_y (\frac{A_s}{A_c} - N) \times 4\pi}$ from equation(1.22)

$\mu_s = \frac{32.23 \times 1 \times 100 \times 0.229}{1 \times (0.133 - 0.0029) \times 12.56} = 452$ gauss

(c)Retentivity

$\mu_r = \frac{J_r}{4\pi}$ from equation(1.3)

$(e_y)_r = \frac{1}{2} \times (2\times$ Intercept$)=\frac{1}{2} \times 280 = 140$mV

$$\frac{J_r}{4\pi} = \frac{G_o \mu_o g_x (e_y)_r}{g_y (\frac{A_s}{A_c} - N) \times 4\pi} = \frac{32.23 \times 1 \times 100 \times 0.140}{1 \times (0.133 - 0.0029) \times 12.56} = 276 \text{ gauss}$$

QUESTIONS

1. Explain the difference in J-H loop of hard and soft iron samples?
2. Why the loop width graph was extrapolated to zero magnetic field?
3. Why the asymptotes were drawn for finding J_s and J_r ?

APPENDIX

Demagnetizing Factors for Ellipsoids of Revolution For Prolate Spheriods, c is the polar axis

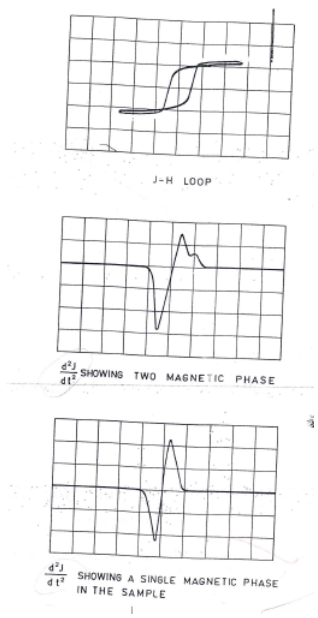


Figure 6.4: Different curves J-H and $\frac{dJ}{dt^2}$ for two and single magnetic phase

C/a	$N_c/4$	**C/a**	$N_c/4$	**C/a**	$N_c/4$
1.0	0.333333	4.0	0.075407	20	0.006749
1.1	308285	4.1	72990	21	6230
1.2	286128	4.2	70693	22	5771
1.3	266420	4.3	68509	23	5363
1.4	248803	4.4	66431	24	4998
1.5	0.232981	4.5	0.064450	25	0.004671
1.6	218713	4.6	62562	30	3444
1.7	205794	4.7	60760	35	2655
1.8	194056	4.8	59039	40	2116
1.9	183353	4.9	57394	45	1730
2.0	0.173564	5.0	0.050821	50	0.001443
2.1	164585	5.5	48890	60	1053
2.2	156326	6.0	43230	70	0.805
2.3	148710	6.5	38541	80	0.637
2.4	141669	7.0	34609	90	0.518
2.5	0.135146	7.5	0.031275	100	0.000430
2.6	129090	8.0	28421	110	363
2.7	123455	8.5	25958	120	311
2.8	118203	9.0	23816	130	270
2.9	113298	9.5	21939	140	236
3.0	0.108709	10	0.020286	150	0.000209
3.1	104410	11	17515	200	125
3.2	100376	12	15297	250	083
3.3	096584	13	13490	300	060
3.4	093015	14	11997	350	045
3.5	0.089651	15	0.010749	400	0.000036
3.6	86477	16	09692	500	24
3.7	83478	17	08790	600	17
3.8	80641	18	08013	700	13
3.9	77954	19	07339	800	10

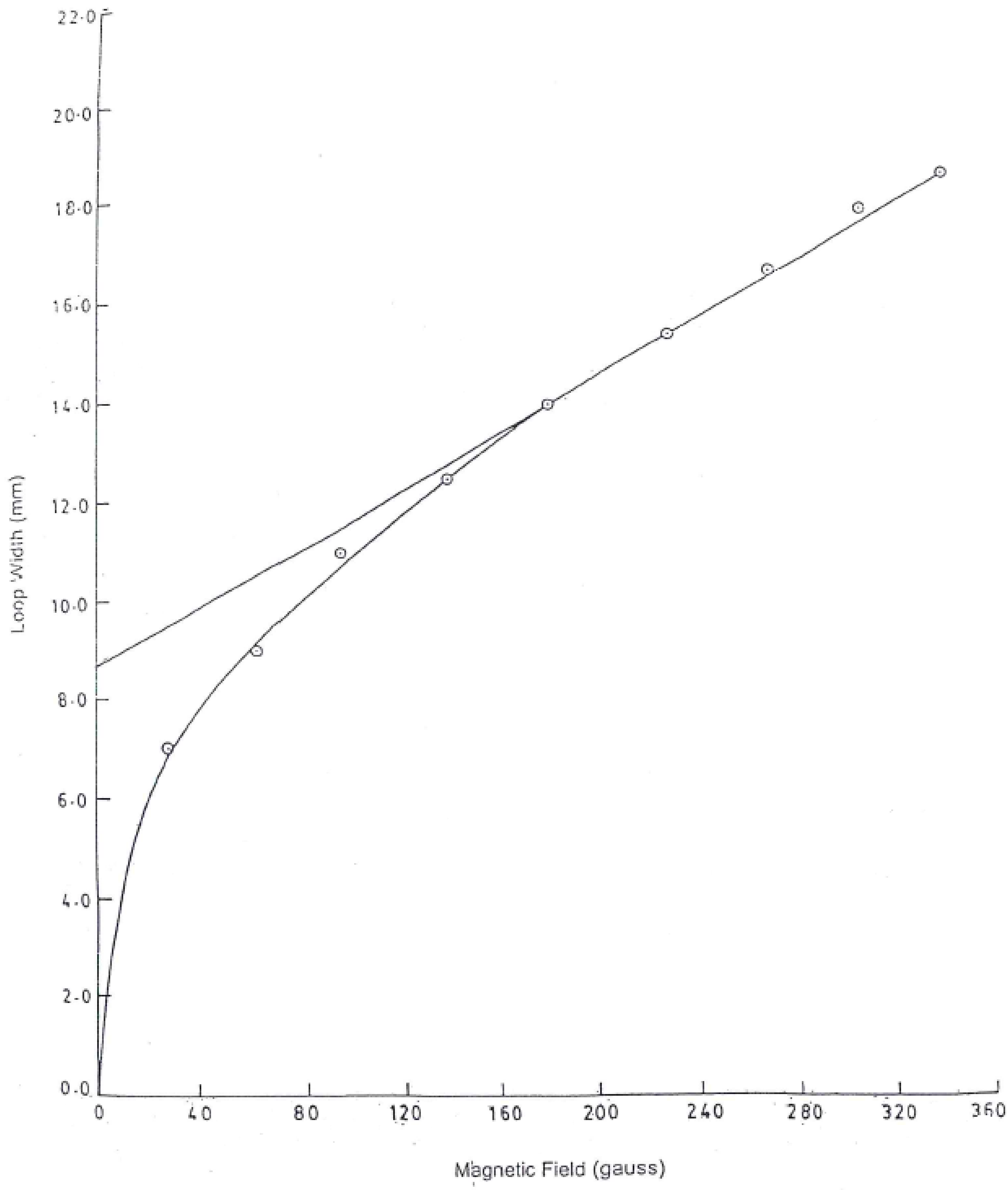


Figure 6.5: Dependence of loop width on magnetic field. The intercept of straight line fit gives coercivity from equation.

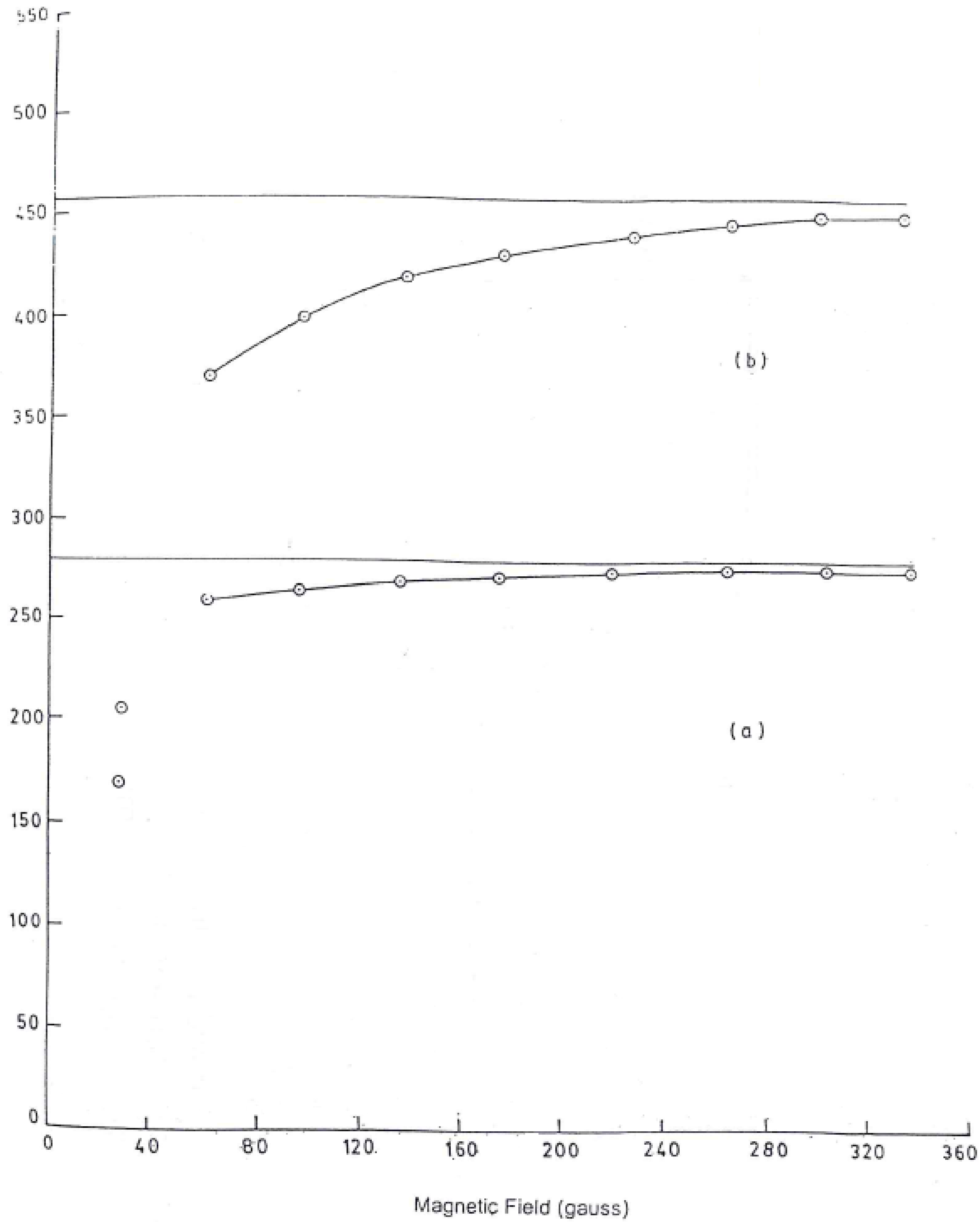


Figure 6.6: Dependence of (a) Twice the Intercept on the Y-axis, and (b) Tip to tip separation of J-H Plot for commercial Nickel on Magnetic Field.

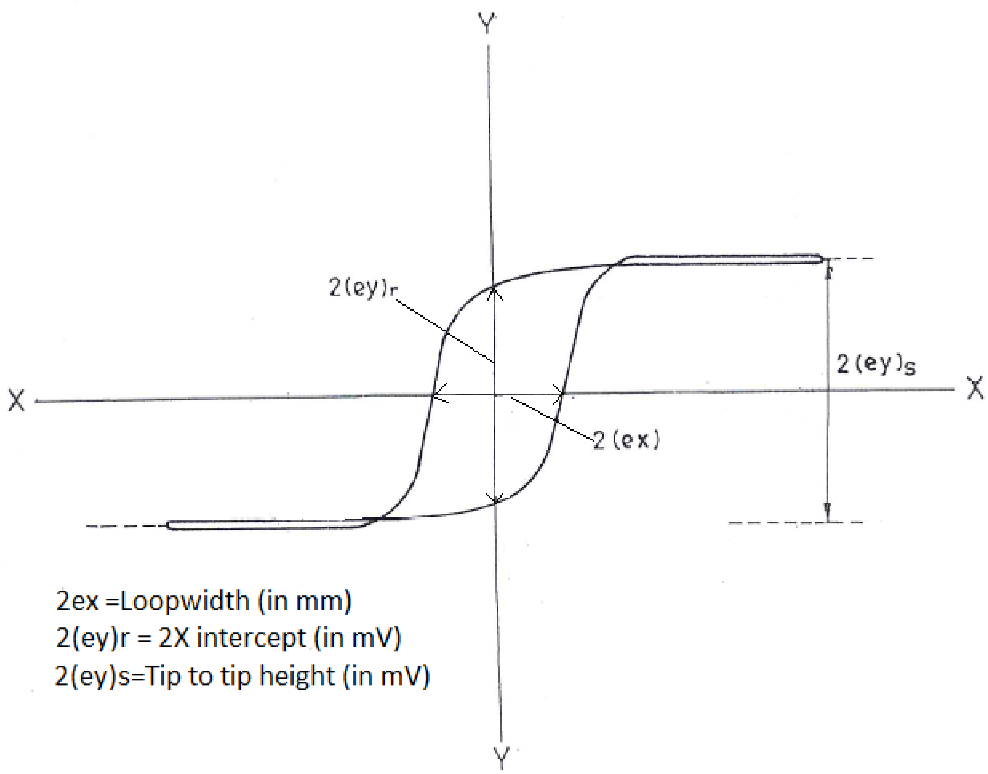


Figure 6.7: The hysteresis Loop

7.

Study of Electromagnetic Induction

7.1 Introduction

The basic principle of generation of alternating emf is electromagnetic induction* discovered by Michael Faraday. This phenomenon is the production of an induced emf in a circuit(conductor) caused by a change of the magnetic flux linking the circuit. Faraday's law of induction tells us that the induced emf E is given by

$$E = -\frac{d\phi}{dt} \tag{7.1}$$

where dϕ/dt represents the rate of change of flux linkng the circuit. If you use mks units, E will be in volts, $\vec{B}$ in webers/meter^2, the flux ϕ in webers and t in sec. If, on the other hand you use Gaussian units, $\vec{B}$ in gauss, ϕ in guass cm^2, then Eq.7.1 will

*It is said that when Faraday was asked about the use of his discovery he replied "what is the use of a new born baby?" Had faraday made the discovery in modern days, he would have been probably asked "What is the relevance of your discovery?" indicating the great progress we have made in the nuances of language; we are, however, not quite sure what Faraday would have replied.

read

$$E = -\frac{1}{c}\frac{d\phi}{dt} \tag{7.2}$$

where c is the speed of light in cm/sec and E will then be in ab volts.

For a discussion of the concept of flux and Faraday's law turn to Appendix I. The experiments described in this chapter will further help you to understand the phenomenon.

7.2 The Apparatus

It consists of a permanent magnet mounted on an arc of a circle of radius 50cm. The arc is part of a rigid frame of aluminium and is suspended at the centre of the arc so that the whole frame can oscillate freely in its plane[figure 7.1]. Weights have been provided, whose positions can be altered so that the time period of oscillation can be varied from about 1.5 to 3 sec. Two coils of about 10,000 turns of copper wire loop the arc so that the magnet can pass freely through the coil.

The two coils are independent and can be connected either in series or in parallel. The amplitude of the swing can be read from the graduations on the arc. When the magnet moves through and out of the coil, the flux of the magnetic field through the coil changes, inducing the emf.

In order to measure this emf, we resort to the now familiar trick of charging a capacitor through a diode and measuring the voltage developed across the capacitor, at leisure.[figure 7.2].

R represents the coil resistance(about 500ohms) plus the forward resistance of the diode. (If you introduce an additional resistance, that will also have to be included in R). The capacitors used are in range of 100μf and the charging time RC is of

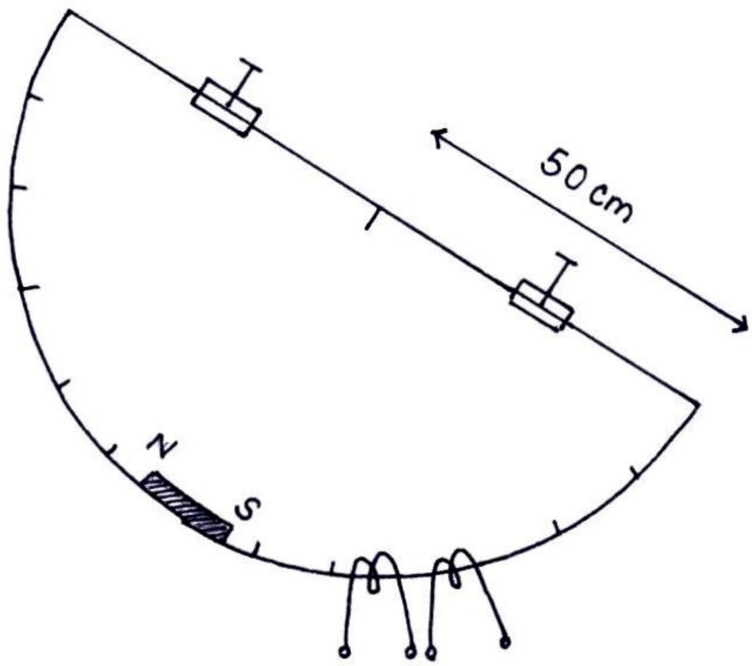


Figure 7.1:

the order of 40msec. It will turn out that this time is somewhat larger than the time during which the emf in the coil is generated so that the capacitor does not charge up to the peak value in a single swing and may take about 10oscillations to do so. This may be checked by the current meter in the circuit which will tell you when the charging current ceases to flow.

The peak value of the emf generated may also be measured by using null method in which one compares the varying emf with a d-c voltage. The arrangement is shown in figure 7.3. The voltmeter will record a 'kick' if the voltage across AB(potential divider) is smaller than the peak voltage developed across the coil so that all that is required is to increase the d-c voltage until the meter ceases to show any deflection. The part played by the capacitor is purely nominal. See if there is any difference in the

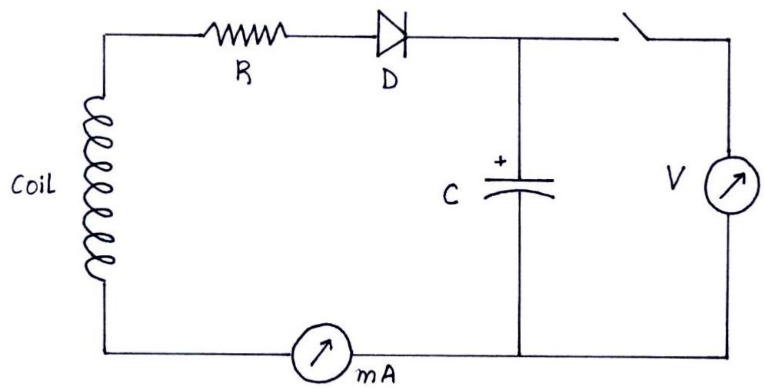


Figure 7.2:

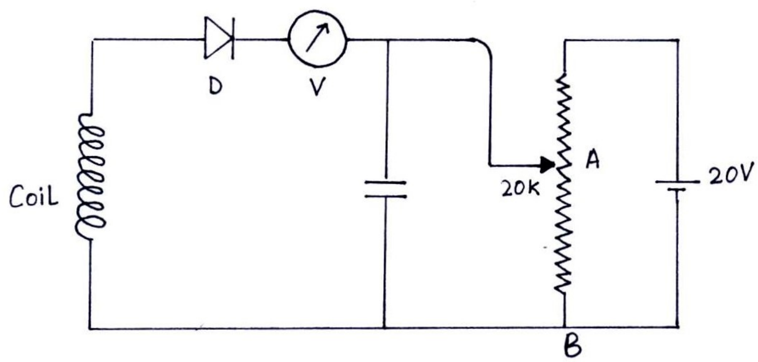


Figure 7.3:

performance without it.In the experiments, try to measure the induced emf by both the methods suggested above.

7.3 Experiment A

To study the emf induced as a function of the velocity of the magnet.

The magnet is placed at the centre of the arc. As the magnet

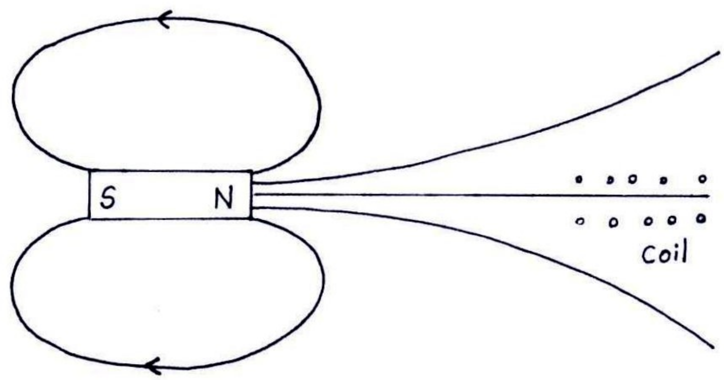


Figure 7.4: The magnetic field at the coil increases as the magnet approaches the coil

starts far away from the coil, moves through it and recedes, the magnetic field through the coil changes from a small value, increases to its maximum and becomes small again thus inducing an emf(Appendix I).

Actually, there is a substantial magnetic field at the coil only when it is very near the magnet; moreover, the speed of the magnet is largest when it approaches the coil since it is approximately in the mean position of the oscillation. Thus the magnetic field changes quite slowly when the magnet is far away and rapidly as it approaches the coil.Roughly, this is the way we expect $\vec{B}$ (at the coil) to change with time.

The flat portion at the top, in figure 7.5 corresponds to the finite length of the magnet.Actually, the curve in figure 7.5 also tells us the way the flux ϕchanges with time since, with a stationary coil, it behaves the same way as $\vec{B}$. The induced emf will be negative time derivative of ϕ and will look like this:

The times t_1 and t_2 in figure 7.5 are the points of inflection of the curve and in figure 7.6 are obviously a minimum and

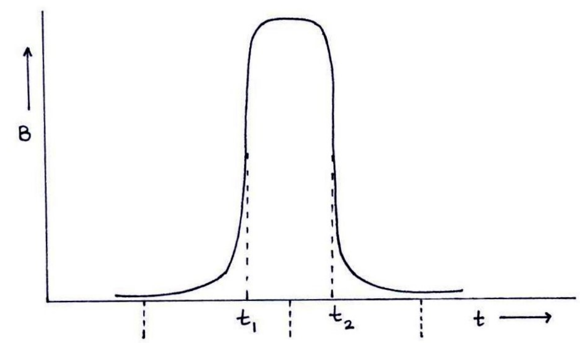


Figure 7.5: Variation of B at the coil with time

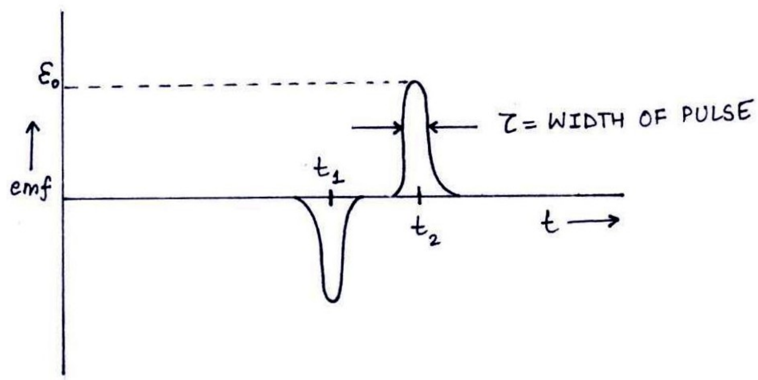


Figure 7.6: Variation of induced emf with time

maximum, respectively.

Remember, this sequence of two pulses, one negative and one positive, occurs during just half a cycle. On the return swing of the magnet, they will be repeated. (Which one will be repeated first, the negative or the positive pulse?)

Consider now the effect of these pulses on the charging circuit of figure 7.2. The diode will conduct only during the positive pulse; at the first half swing, the capacitor charges up to a potential, say about $0.5E_o$. During the next half swing, the diode will be cut off until the positive pulse reaches $0.5E_o$ and then the capacitor will be allowed to charge up to a slightly higher potential. Thus, in a few oscillations the capacitor will be charged up to the peak value E_o.

The rate of change of flux through the coil is, essentially, proportional to the velocity of the magnet as it passes through the coil. By choosing different amplitudes of oscillation of the magnet, we can alter this velocity. Suppose the angular velocity of the magnet at any point is ω and the moment of inertia of the system about the axis of rotation is K. The kinetic energy of the system is $\frac{1}{2}\mathrm{K}\omega^2$ and the potential energy(referred to the lowest position of the magnet) is Mgr(1-cos θ) where M is mass of the system and r the distance of the centre of gravity from the point of suspension. The maximum value ω_{max} is given by

$$\frac{1}{2}K\omega_{max}^2 = Mgr(1 - cos\theta_o) \tag{7.3}$$

or,

$$\omega_{max}^2 = \frac{2Mgr}{K}(1 - cos\theta_o) \tag{7.4}$$

where θ_0 is the angular amplitude. In order to eliminate the constants (Mgr/K) we note that the motion is approximately simple harmonic with a time period.

Conservation of energy gives
$\frac{1}{2}K\dot{\theta}^2 + Mgr(1 - cos\theta)$=constant
where we have written ω for $\dot{\theta}$; for small θ this gives
$\frac{1}{2}K\dot{\theta}^2 + \frac{1}{2}Mgr\theta^2$=constant
Differentiating this we obtain
$\ddot{\theta} + \frac{Mgr}{K}\theta = 0$
from which the time period given by eq7.5 is readily written.

$$T = 2\pi\sqrt{\frac{K}{Mgr}} \tag{7.5}$$

From eqs.(7.4) and (7.5) we obtain

$$\omega_{max} = \frac{4\pi}{T} \sin \frac{\theta_o}{2} \tag{7.6}$$

The velocity of the magnet is given by

$$v_{max} = R\omega_{max} = R\frac{4\pi}{T} \sin \frac{\theta_o}{2} \tag{7.7}$$

where R is the distance of the magnet from the point of suspension.

The angular amplitude θ_o is determined by measuring the initial displacement S_o of the centre of the magnet from the mid-point of its oscillation since

$$\theta_o = \frac{S_o}{R} \tag{7.8}$$

Measure the length R directly. Fix the amplitude S_o at a certain value measured on a scale which is fixed on the arc housing the magnet and set the magnet in oscillation. The velocity of the magnet through the coil is readily commuted from Eqs.(7.7) and (7.8).

As the capacitor in figure 7.2 charges up, watch the ammeter and as soon as it shows that there is no more charge current, connect the voltmeter and measure the peak voltage V. (Alternatively, you may use the null method discussed).

Vary the velocity of the magnet v_{max} by choosing different values for S_o. For each velocity determine the peak voltage of the capacitor which is obviously a measure of the induced emf. A graph of the peak voltage vs v_{max} will yield a straight line in accordance with Faraday's law. Try with a number of values for S_o. You may also change the capacitor and observe the difference in the charging rate. In figure 7.7, we display the typical results of a measurement.

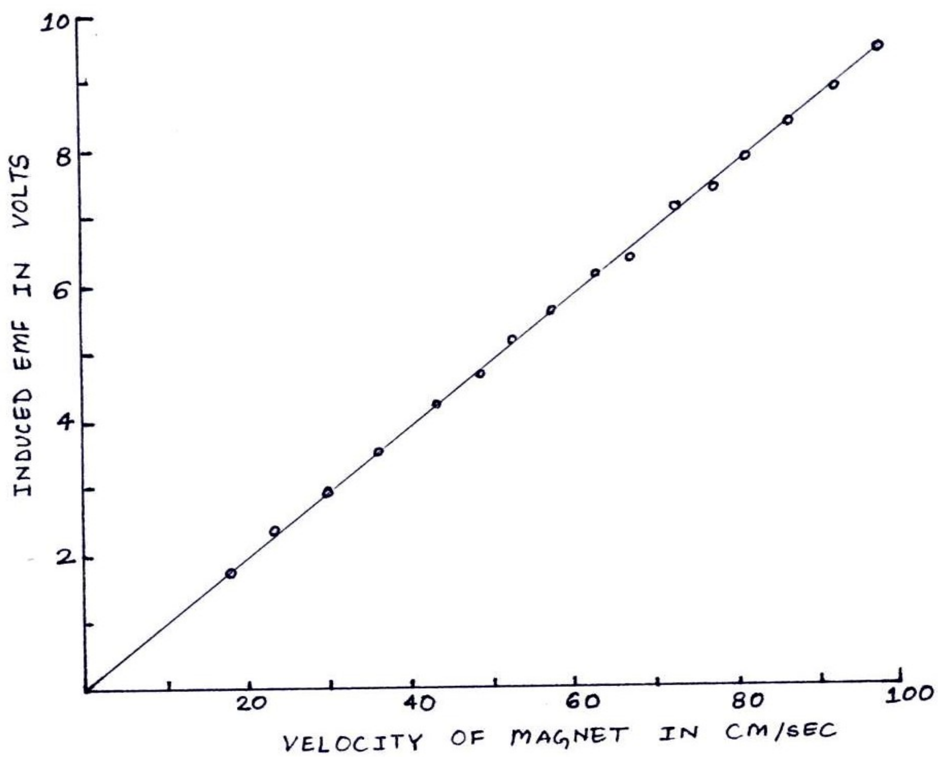


Figure 7.7:

7.4 Experiment B

To study the charge delivered due to induction

When the charging time (RC) of the capacitor is large, the charge collected over a small interval of time t≪RC is given by

$$Q(t) = \frac{1}{R}\int_0^t E(t)dt = -\frac{1}{R}\int_0^t \frac{d\phi}{dt}dt \tag{7.9}$$

$$Q(t) = \frac{1}{R}[\phi(0) - \phi(t)] \tag{7.10}$$

During each oscillation, the magnetic field at the coil changes from practically zero to its maximum value $\vec{B_{max}}$ when the magnet passes through the coil. The change in flux is approximately $\vec{B_{max}}$Am where m is the number of turns and A the area of the coil, the charge Q is given by $Q = CV$ where V is the voltage acquired by the capacitor whose capacitance is C. Thus, Q can be readily measured. Eq(7.10) then will enable you to make a rough estimate of $\vec{B_{max}}$.

Try using different resistors R in charging circuit and see how far Eq(7.10) is obeyed. The change in the flux ought to be the same so that the charge collected should be smaller the larger the value of R. If you find that the voltage of the capacitor is too small to be measured for a single swing, you may average over a small number of oscillations(why only a small number of oscillations?).

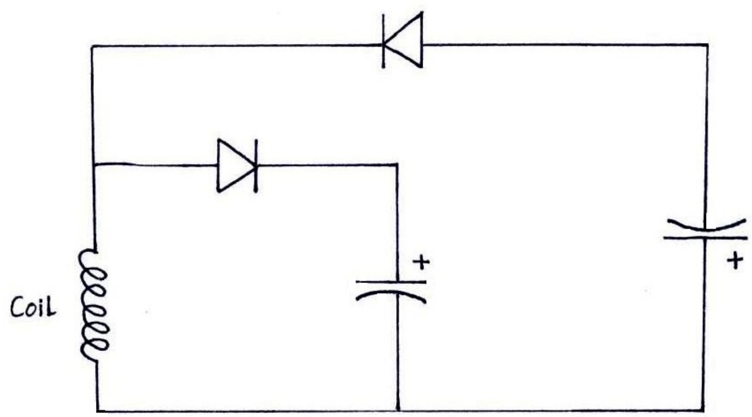


Figure 7.8:

As mentioned in Experiment A , the diode allows the capacitor to charge only for positive pulse [Figure 7.6]. You may arrange two sets of charging circuits as in [Figure 7.8] so that one capacitor charges up on the positive pulse and the other on the negative pulse. Verify that the charges on the capacitor are nearly the same. (What will the voltages on the capacitor depend on?)

If you stop the oscillation (by hand) after a quarter oscillation (from the extreme position of the magnet to its mean position), only one capacitor will charge up. Try and find out if the sign of the emf induced is as should be according to Faraday's law.

7.5 Experiment C

To study electromagnetic damping

We have. so far, neglected damping of the oscillations of the magnet. Successive oscillation will not be of the same amplitude as you check from a rough measurement of the amplitude after, say 10 oscillations.

There are many reasons for this damping. There is always some air resistance; then again the system is not nearly free from friction at the point of suspension. But the most important (and interesting!) source is that the induced emf in the coil itself introduces a damping through a mechanism which goes by the name of Lenz's law. This law states that the direction of the induced emf is always such as to oppose the change that causes it. (See Appendix II for a discussion)

The energy dissipation will not be same after each oscillation; in fact as a rule in oscillatory systems, the fractional loss of energy turns out to be roughly constant. That is to say, suppose the energy of the system is E_n after n oscillations. Then

$$\frac{E_n}{E_{n-1}} = \alpha \tag{7.11}$$

where α is nearly independent of n. It is easy to see that this implies

$$\frac{E_n}{E_o} = \alpha^n \tag{7.12}$$

where E_o is the energy at the beginning.

Since the energy is proportional to the square of the amplitude, Eq.(7.12) gives

$$\frac{S_n}{S_o} = \sqrt{\frac{E_n}{E_o}} = \alpha^{n/2} \tag{7.13}$$

Thus if you plot a graph of $\log S_n$ as a function of n you ought to get a straight line. In practice, you will find that this is only approximately true.

First, keep the coil open circuited. Fix the amplitude of the magnet and measure the amplitude S after a number of oscillations. You will find that the amplitude is still considerable even after 200 oscillations, since in this case there is no electromagnetic damping at all. Plot log S as a function of n.

Next, try the same with a short circuited coil. This time the amplitude diminishes rapidly and about 20 oscillations or so are all that give measurable amplitudes. Again plot log S vs n. You may also connect a finite load such as a 500ohm resistor and make the same measurements. Finally, try also a big capacitor, say 2000μf, as a load. At each swing the capacitor keeps charging up and energy has to be supplied to build up this energy as well as the energy that will be lost through leakage. Try and interpret the graphs that you obtain in these cases; the case of a capacitative load is somewhat complicated. (Figure 7.9 shows these curves plotted from experimental data)

APPENDIX-I
Flux Of The Field And Faraday's Law

As pointed out at the beginning of this chapter, the concept of flux of the field is vital to the understanding of Faraday's Law.

Consider a small element of area $\vec{d\sigma}$. We assign a direction to this element taking it to be the normal to the plane of the area directed such that if it is bounded by a curve as shown in [Figure 7.10], then the normal comes out of the plane of the paper towards you, the reader. In other words, it is the same direction as the movement of the axis of a right handed screw rotated in the sense of the arrow on the curve.

Suppose, now this element of area is situated in a magnetic field $\vec{B}$. Then the scalar quantity

$$d\phi = \vec{B}\vec{d\sigma} = \mid B \mid\mid d\sigma \mid \cos(\theta) \tag{7.14}$$

is called the flux of $\vec{B}$ through the area $\vec{d\sigma}$, where θ is the angle between the direction of the magnetic field and the direction assigned to the area $\vec{d\sigma}$.

We can generalize this to define the flux over a finite area $\vec{S}$. In doing this, we must remember that the magnetic field $\vec{B}$ will not, in general, be the same at different points within the finite area. We therefore divide up the area into small pieces, calculate the flux over each piece and integrate. Thus, the flux is

$$\phi = \int_s \vec{B}\vec{d\sigma} \tag{7.15}$$

where the symbol s signifies that we are to integrate over the entire area $\vec{S}$.[Figure 7.11] Obviously, you cannot take $\vec{B}$ out of the integral in Eq.(3.15) unless $\vec{B}$ is same everywhere in $\vec{S}$.

If the magnetic field at every point changes with time as well, then the flux will also change with time.

$$\phi = \phi(t) = \int_s \vec{B(t)}.\vec{d\sigma} \tag{7.16}$$

Faraday's discovery was that the rate of change of flux $d\phi/dt$ is related to the work done on taking a unit positive charge around the contour C[Figure 7.11] in reverse direction. This work done is just the emf. Accordingly, we can state Faraday's law in its usual form that the induced emf is given by

$$E = -\frac{d\phi}{dt} \tag{7.17}$$

If you look at Eq(3.16),you will see that even if $\vec{B}$ does not change with time the flux may still vary if the surface S is somehow changing with time. Consider, for example, a frame of wires ABCD, as drawn in figure 7.12, situated in a constant magnetic field. If the side BC is moved out thus increasing the area of the loop ABCD, the flux of $\vec{B}$ through the loop increase with time. Here also Faraday's law will apply as stated in Eq(3.17)***.

*** There are, however, a number of situations in which Faradays' law would not hold. For a beautiful discussion, read Feynman's Lectures in Physics, CH 17, Vol. II

APPENDIX-II

Lenz's Law

This law is just the statement of the tendency of a system to resist change as applied to the phenomenon of electromagnetic induction. Let us understand the origin of the law.

Suppose we have q steady current I in a circular loop as in figure 7.13. Then there is a magnetic field $\vec{B}$ associated with this current, the lines of force going through the face of the coil and out is shown in the figure. The lines o force close upon themselves outside the coil. (The lines of force representing $\vec{B}$ always close upon themselves). Note particularly the direction of these lines. The way to remember this is to ask yourself how the axis of a right handed screw, rotated in the direction of the arrow on the coil, will move. This is the direction of the magnetic field.

Suppose you increase the current. This will increase the magnetic field in the direction drawn and the flux will increase. But according to Faraday's law this increase in flux will set up an induced emf given by the rate of change of this flux, i.e.

$$E = -\frac{d\phi}{dt} \tag{7.18}$$

Note the negative sign. This means that the direction of the emf in the coil will be opposite the sense of rotation of a right handed screw. Thus the induced emf will try to restore the original current. This is why we have, on occasion, called it the back emf. If, therefore, the current in the coil has to be increased, one has to supply energy to overcome this opposing emf.

It is quite easy to see how much energy is required without going into details of this opposing field. Recall that a coil of self inductance L carrying a current I has an energy $\frac{1}{2}\mathrm{L}I^2$. If, therefore, the increased current is I_o, the extra energy to be supplied is $\frac{1}{2}\mathrm{L}I_o^2$ -$\frac{1}{2}\mathrm{L}I^2$. You must now be able to argue why the open circuited coil in Experiment C is damped much less than a short circuited one.

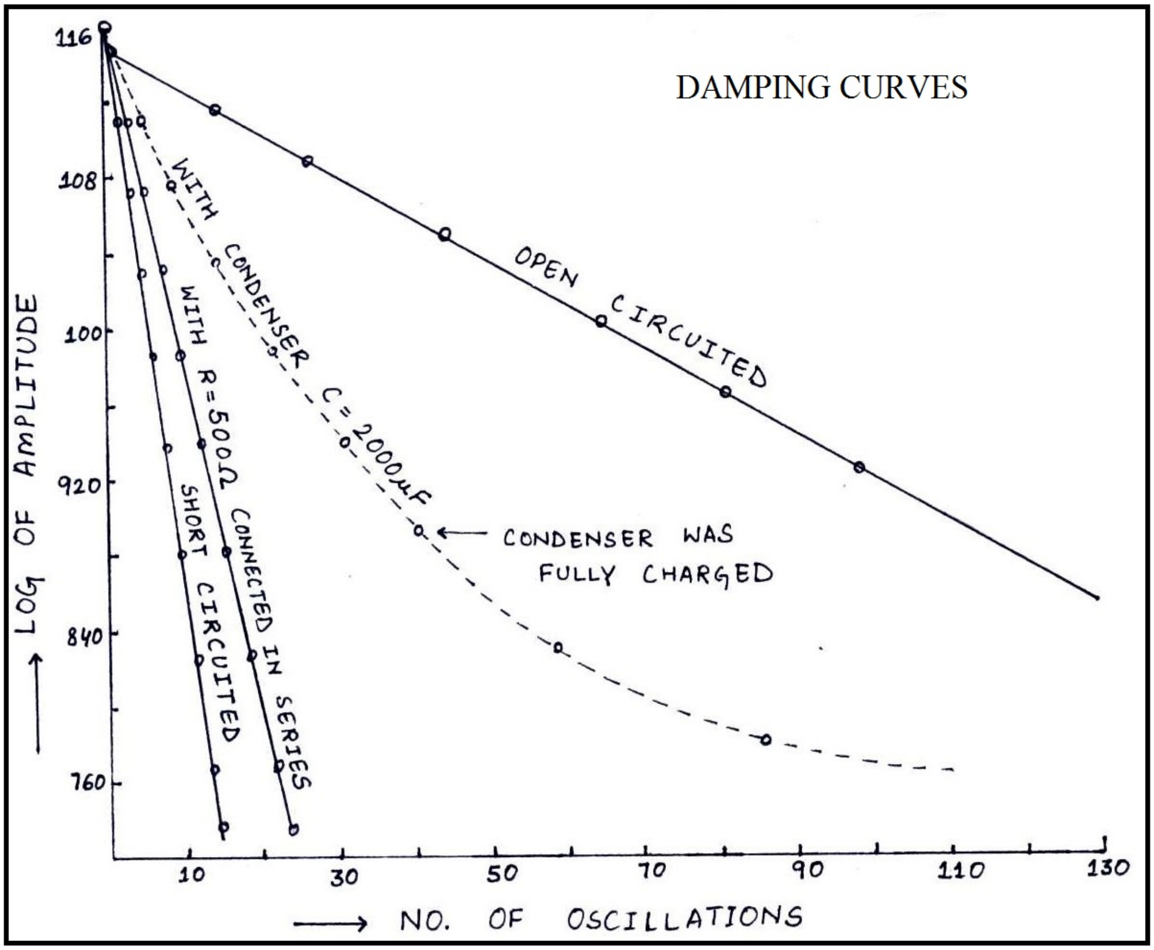


Figure 7.9:

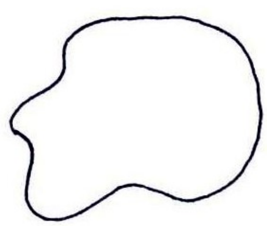


Figure 7.10:

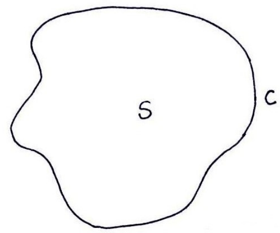


Figure 7.11:

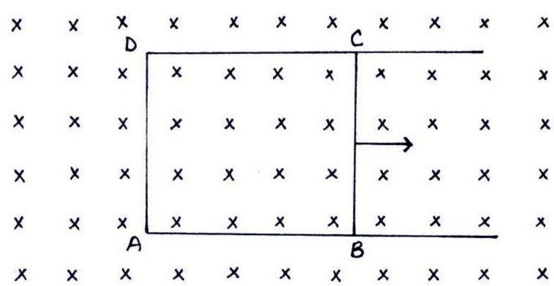


Figure 7.12:

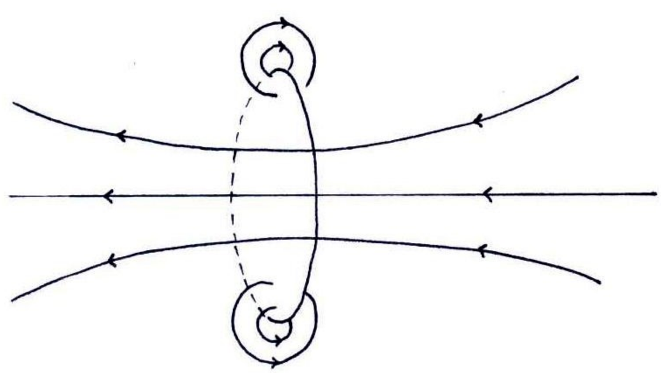


Figure 7.13: Field due to a circular coil carrying current

8.

Determination of Cauchy's Contants

8.1 Objective:

To determine Cauchy's Constants using a prism and spectrometer.

Apparatus:

Glass prism, spectrometer and mercury vapour lamp.

8.2 Theory:

The wavelength dependence of refractive index of a dielectric medium can be approximated by

$$\mu = A + \frac{B}{\lambda^2} \tag{8.1}$$

where μ represents the refractive index at wavelength λ and A and B are constants. The Eq.(8.1) is known as Cauchy's formula and A and B are known as Cauchy's constants. As is

obvious from the above formula, a curve between μ and $1/\lambda^2$ is a straight line whose intercept with the y axis gives A and slope with respect to the x-axis gives B. Thus we can easily find Cauchy's constants as discussed below.
A parallel beam of white light from a source (mercury lamp) is passed through a prism. One would observe a spectrum on the other side of the prism (Fig.8.3). The prism is then set in the position of minimum deviation and the angle of minimum deviations corresponding to different colors are measured with the help of the spectrometer. The refractive index at different wavelengths can be calculated using the following well known formula:

$$\mu = \frac{sin\frac{A_0+D_m}{2}}{sin\frac{A_0}{2}}$$

Here A_0 is the angle of the prism and D_m is the angle of minimum deviation. [Note: The wavelengths of various lines observed in light from mercury vapour lamp are provided in the laboratory.]

8.3 Experiment:

A spectrometer consists of a collimator which is mounted on the rigid arm and a telescope mounted on the rotation table arm which can rotate in a horizontal plane about the axis of the instrument. A prism table of adjustable height is mounted along the axis of rotation of the telescope. A circular scale and vernier arrangement is provide to enable measurement of the angle through which the telescope arm or the prism table is rotated.

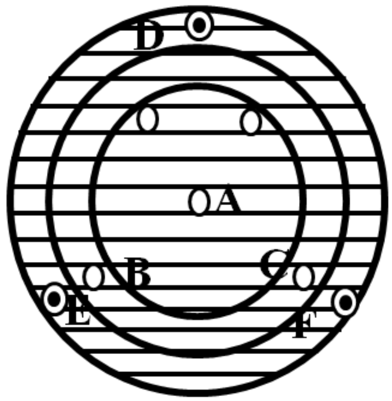


Figure 8.1: Top view of the prism table showing relevant details. A - rotation axis of the prism table. B,C - Threaded screw holes to fix grating stand. D,E,F - Leveling screws.

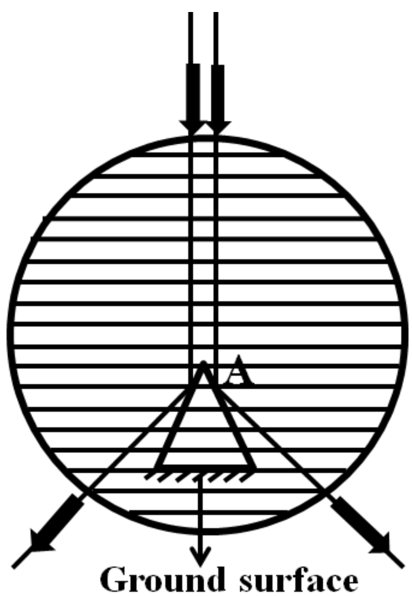


Figure 8.2: Positioning of the prism for optical alignment.

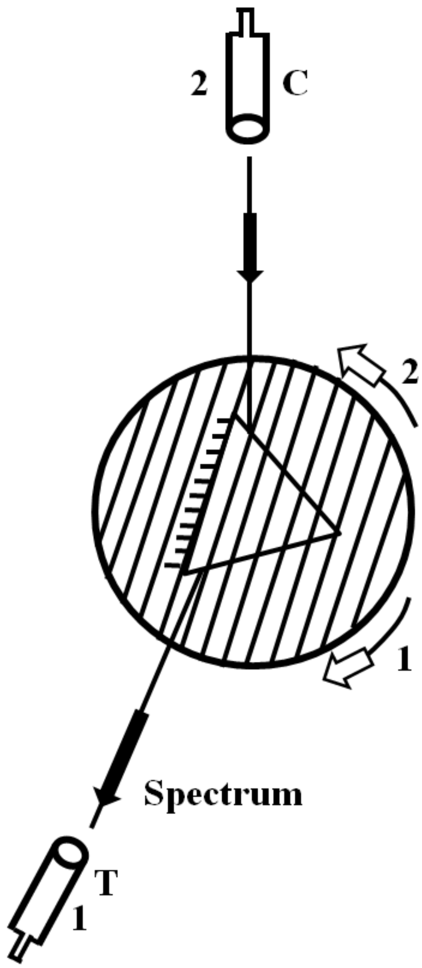


Figure 8.3: Top view of the set up for Schuster's method.

1. Setting the prism table

The prism table AB is made horizontal with the help of a spirit-level by adjusting the leveling screws D,E,F (see Fig.8.1). To start with, the prism table is rotated about its axis and adjusted in such a way that the parallel straight lines along with the two screw E and F are perpendicular to the axis joining the collimator and the telescope pointing directly opposite. A three way spirit level is kept on the prism table with its edge XY along the parallel lines

Further adjustment of the prism table is done using the method of optical alignment. The given prism is placed such that the ground surface is facing towards the telescope and is perpendicular to the axis of the collimator. Adjust the position of the prism such that the edge of the prism opposite to the ground surface lies approximately along the axis of the prism table as shown in Fig.8.2. If you now rotate the telescope arm, you would be able to see the reflected images of the slit appears symmetrically placed about the horizontal cross wire when viewed from both sides. The prism table adjustments are complete now.

2. **Schuster's method of focusing a spectrometer for parallel light:**

When a distant object is not available or the spectrometer is too heavy to be carried outside the dark room where the experiment is being performed, the setting of the spectrometer is done by the Schuster's method. the slit is kept facing the brightest portion of the mercury lamp and its width adjusted to permit a thin line of light to act as incident light.

Prism is now kept on the prism table with its ground face along the parallel lines ruled on the prism table. The prism table is rotated so as to obtain mercury light incident from the collimator on the prism. Telescope arm is moved to a suitable position to see the spectrum through it. the prism table is rotated to achieve the position of minimum deviation (of course, you will have to rotate the telescope arm also, as you rotate the prism table, to retain the spectrum in the field of view of the telescope). At this position, the spectrum which appeared to be moving in the telescope in one direction (say left to right) reaches an extreme limit and retraces its path on further movement of the prism table in the same direction.

Prism table is rotated away from this position of minimum deviation. bringing the refracting angle towards the telescope and the telescope is now focused on the image as distinctly as possible. Prism table is then rotated to the other side of the minimum deviation position towards the collimator and the collimator is focused to obtain a sharp image of the spectrum. The process is repeated till the motion of the prism does not affect the focus of the spectrum (please see Fig.8.3). The collimator and the telescope are then set for parallel light and their settings are not to be disturbed during the course of the experiment.

Measurements of angle of minimum deviation D_m and prism angle A_0:

The prism is again set in the position of minimum deviation as discussed above. Now measure the positions of various lines (colors) of the spectrum on the circular scale without disturbing the prism table. Now remove the prism from prism table and rotate the telescope to see the slit directly and measure its position. The difference between this last reading and the readings corresponding to various colors in the position of minimum deviation will give us the angles of minimum deviations for different colors.

This given prism is now again placed on the prism table such that the ground surface is facing towards the telescope and is perpendicular to the axis of collimator. Adjust the position of the prism such that the edges of the prism opposite to the ground surface lies approximately along the axis of the prism table as shown in Fig.8.3. Rotate the telescope arm and measure the position of reflected images of the slit on both sides of incident beam. The difference between the two readings is equal to angle $2A_0$.

8.4 Observations:

Least count of the spectrometer=

Readings for the measurement of angle of minimum deviation:

Reading of telescope position for direct image of the slit:
Left scale (θ_L):
Right scale (θ_R):

Sr. No.	color of light	Reading for telescope position	$D_1 = \theta_L \sim \theta_1$	$D_2 = \theta_R \sim \theta_2$

		Left scale θ_1	Right scale θ_2		
1.	Violet I				
2.	Violet II				
3.	Blue				
4.	Green				
5.	Yellow I				
6.	Yellow II				
7.	Red				

Readings for measurement of prism angle A_0:

Sr. No.	Position of telescope for reflected slit from		$A_0 = \frac{a \sim b}{2}$
	Left face (a)	Right face (b)	

Calculations:

Sr. No.	Color	$D_m = \frac{D_1+D_2}{2}$	$\mu = \frac{sin\frac{A_0+D_m}{2}}{sin\frac{A_0}{2}}$	$1/\lambda^2$

Using the above values draw a graph between μ and $1/\lambda^2$ and determine A and B.

Precautions: Care should be taken to ensure proper setting of the spectrometer. It should be ensured that the settings of the telescope and collimator are not touched during the course of taking the various readings.

Source of errors: Think and find out yourself after doing the experiment.

9.

Millikan's oil drop experiment

9.

Millikan’s oil drop experiment

9.1 Objective:

To determine the total charge on an oil drop and estimate the value of elementary charge of an electron.

9.2 Theory:

If electrically charged oil droplets (or small drops) are made freely fall through air in presence of an externally applied electric field E such that the field forces the droplets move opposite to the direction of free motion downwards, one can calculate the total charge on the droplet. By doing these measurements on the same drop a few times and repeating on many drops, one is able to estimate the value of the elementary charge of an electron.

Consider a spherical drop of radius r and material density ρ. The weight of the drop is given by

$$W = \frac{4\pi}{3} r^3 \rho g \tag{1}$$

Where g is the gravitational acceleration. In air (density = ρ_{air}) the drops falls downwards due to gravity. The apparent weight of the drop can be written as

$$W_a = \frac{4\pi}{3} r^3 (\rho - \rho_{air}) g \tag{2}$$

Now, for a drop that is moving in a medium, there acts a drag force that is opposite to the direction of motion. The magnitude of the drag force keeps increasing with the speed in the forward direction. For a drop falling under gravity, there comes a situation when the drag force balances the weight and there is no net force on the drop. In that case the drops falls freely with a constant velocity v_1 downwards called the terminal velocity. If η is the viscosity of the air (fluid) then according to Stokes’ law, drag force on the drop is given by the relation,

$$F_d = 6\pi\eta r v_1 \tag{3}$$

Since for the freely falling drop, $F_d = W_a$, we can derive an expression relating the radius of the drop to the terminal velocity v_1 given as

$$r^2 = \frac{9\eta v_1}{2g(\rho - \rho_{air})} \tag{4}$$

Stokes' law, however, becomes incorrect when the velocity of fall of the droplets is very small (less than 0.1 cm/sec). Since the velocities of the droplets used in the current experiments will be much smaller than 0.1 cm/sec, the viscosity must be corrected by multiplying by a correction factor. The resulting effective viscosity that should be used is given by

$$\eta_{eff} = \eta \Big/ \left(1 + \frac{b}{Pr}\right), \tag{5}$$

where parameter b is a constant (typical value ~ 8.2×10^{-3} Pascal) and P is the atmospheric pressure. Solving Eqs. (4) and (5) together for the radius of the drop we obtain

$$r = \sqrt{(b/2P)^2 + 9\eta v_1 / 2g(\rho - \rho_{air})} - (b/2P) \tag{6}$$

Now, an electric field is applied such that it can counter the downward force, i.e., the weight of the drop. Assuming that the charge on the oil drop is q and electric field E is applied between to charging plates kept at potential difference V and distance d between them. Clearly, for a specific value of the electric field, the electrical force $F_E = qE = qV/d$ on the drop just balances the weight, i.e., $F_E = W_a$. In this situation, one would observe that the oil drop remains steady. Because of the practical problems in determining the exact weight of the oil drop and the electric force, it is recommended that the electrical force upwards is slightly higher than the weight so that the action of the Stokes' law can be brought in because the oil drop starts moving upwards. Due the drag force, the upward movement quickly attains a terminal velocity v_2. In this situation, from the force balance equation, one can write

$$F_E - W_a = 6\pi\eta r v_2 \tag{7}$$

After simplification, we get the following expression for the electrical charge on the oil drop,

$$q = \left(1 + \frac{v_2}{v_1}\right)\frac{d}{V}\frac{4}{3}\pi r^3(\rho - \rho_{air}) \tag{8}$$

To determine the elementary charge 'e' on an electron, it must be the case that the oil drop has charge 'q' that is integer multiples of 'e'. Therefore, for the estimation of 'e', measurements on many drops should be carried out. Various values of the charges (q_1, q_2, q_3, ….) and a little bit of calculus will help determine the value of 'e'.

9.3 Experimental setup

The complete setup is shown in Fig. 1. The various parts include (a) atomizer, (b) oil drop spray chamber, (c) drift chamber, (d) imaging assembly, (e) LED source, (f) the main control panel, and (g) computer.

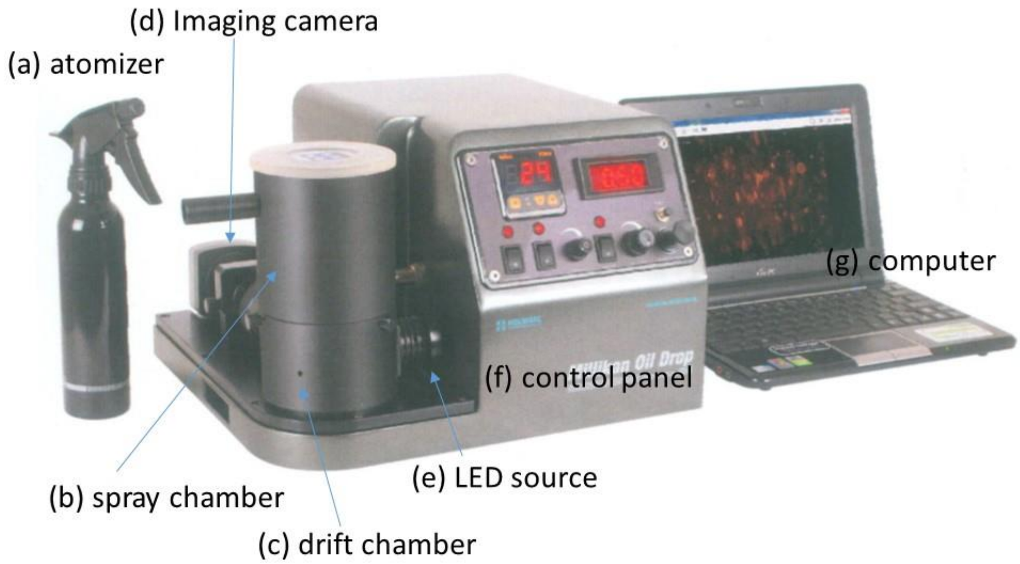


Figure 1: Various parts of the experimental setup.

A closer view of the drift chamber is shown in Fig. 2. In this section, the oil drops are imaged using the CCD camera by shining light from a LED source and in the presence of an electric field applied between two charging plates.

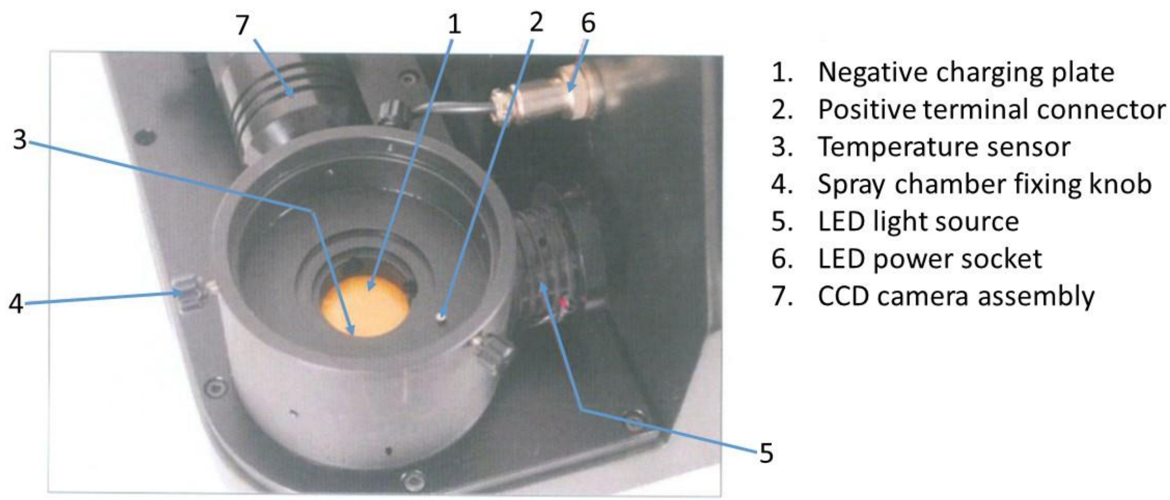


Figure 2: Closer view of the drift chamber and accessories.

Figure 3 describes various control switches/knobs and displays of the control panel. Figure 4 display the procedure of attaching the positive charging plate into the drift chamber.

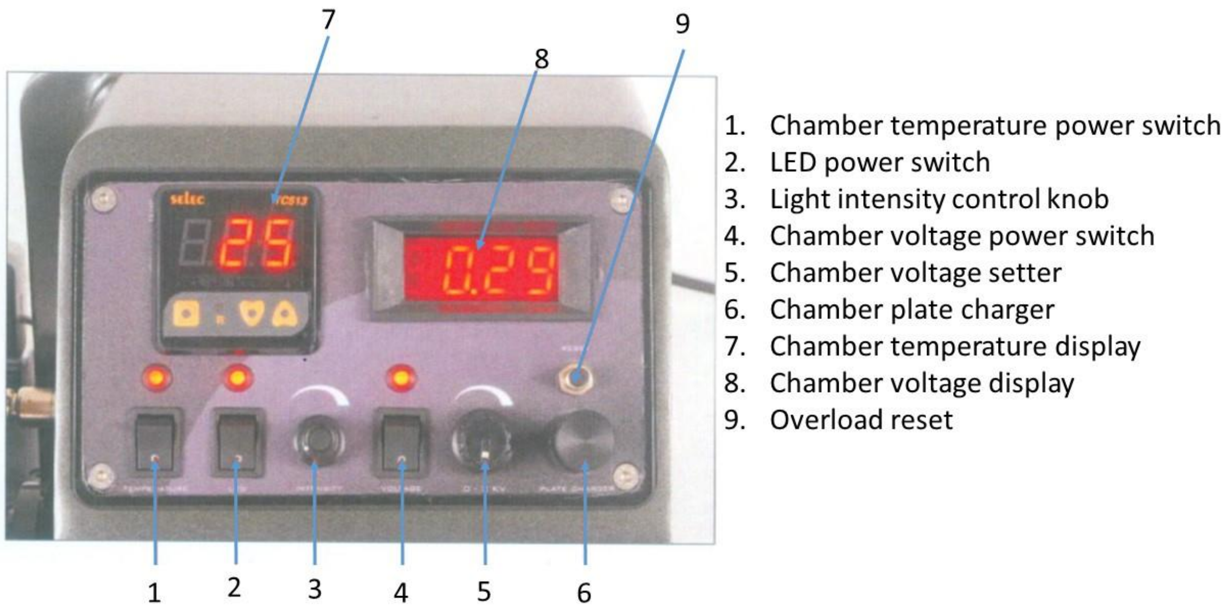


Figure 3: Closer view of the control panel.

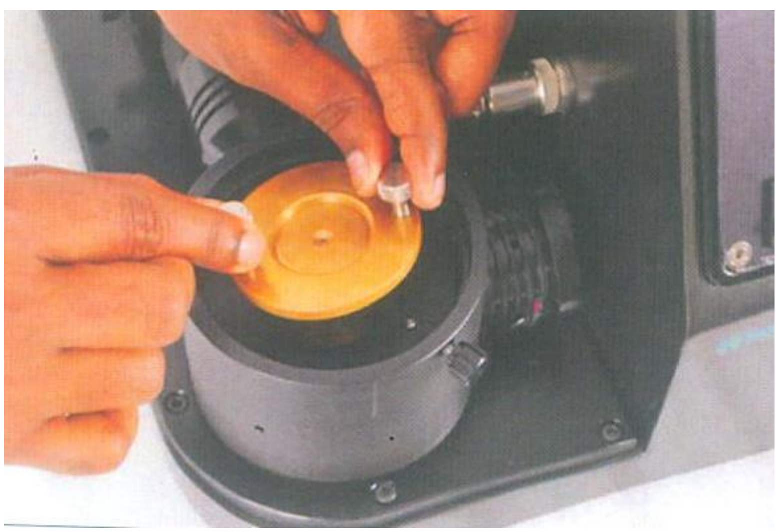


Figure 4: Attaching the positive charging plate in the drift chamber.

9.4 Experimental procedure

The CCD camera assembly provided in the experimental set up as described above is used for observing the movement of the oil droplets between the two charging plates with the help of an imaging software in the computer. This helps to measure the approximate size of the oil drops and also their velocities while falling down under gravity and moving against it in absence and in presence of an applied electric field, respectively. The potential difference between the plates can be controlled and monitored between 0 to 2 KV. The following procedure will help in performing the measurements.

- Power up the system including the computer and the main control panel.
- Turn on temperature, LED and voltage control switches. The displays for the temperature and the voltage should start displaying the current values of the temperature and voltage.
- Keep the atomizer in the upright position (vertically standing) on the table and only then apply pressure by pressing the nozzle cap.
- Press the nozzle cap a few times to generate good pressure inside the atomizer.
- Give a small puff of oil drops through the hole in the spraying chamber using atomizer and wait (few minutes) for some drops to appear on the screen. It is quite easy to get nice spray of very small drops if the above mentioned steps are done properly.
- The LED intensity should be kept at bare minimum only to observe the droplets in the screen.
- Observe the drops on the screen of the software panel. Increase the value of the voltage in steps and don’t jump to very high values. It is recommended that experiments are done at voltages below 1 kV. Once you select a voltage, say 0.3 kV using the variable power supply at the front panel, notice if some drops have stopped falling down and started moving upwards as soon as the chamber plate charger knob is pressed.
- If no drop is seen moving upwards in the presence of the electric field then increase the voltage on the plate from 0.3 to 0.35 kV and repeat the above method. You may need to repeat this a few times until you find some drops moving upwards.
- Select one drop which started moving upwards. For this drop, take multiple measurements for the time taken in freely falling a fixed distance under gravity and time taken in traveling a fixed distance upwards in the presence of the electric field. You can use your own timer or a timer provided in the software.

Important points to be noted:

- The lid/cover of the spray chamber should be removed for cleaning only when the system is off.
- LED should not be operated at high intensity for more than 2 minutes. Start and try to perform the whole experiment at low intensity.
- The imaging software is already calibrated for measuring the distances travelled by the droplets. Generally, travel distance of 1 mm is good enough.
- Avoid applying voltages more than 1.5 kV. This is not good for the capacitors inside.
- One spray (or maximum two) is enough to perform the whole experiment.
- One needs to take multiple measurements (at least three) on a single drop.
- Measurements on multiple drops (5 to 10) have to be taken.
- From the values of the electrical charge on the drops, you should find the common factor among all those such that the amount of charge is only an integral multiple of this factor. This is the elementary charge on the electron.

- After completing the measurements, ensure that the LED intensity and the voltage levels have been returned to the minimum before you switch off the device.
- Ensure that the working area is neat and clean all the time.
- Ensure, the spray chamber and the drift chamber including the charging plate are cleaned up thoroughly before and after the experiments.
- The control panel and every other accessory should not be moved from its original place. The instruments should be handled very carefully and gently.
- For any mishandling of the instrument and its parts, the student will be penalized.

9.5 Observations

(a) Temperature of the chamber in ^{o}C :
(b) Viscosity η of air at above temperature :
(c) Density of air ρ_{air} at the above temperature :
(d) Density of oil drop ρ :
(e) Acceleration due to gravity g :
(f) Atmospheric pressure P :
(g) Distance between the charging plates d :

Observation table for the oil drops

i. Distance travelled downwards l_1:
ii. Distance travelled upwards l_2 :

S. No.	Voltage between the plates	Time taken (down) t_1	Time taken (up) t_2
	Drop 1		
1			
2			
3			
.			
.			
	Drop 2		
1			
.			
	Drop 3		
.			
	Drop 4		
.			
	…		

9.6 Calculations

(a) Determination of ‘q’

Drop 1:

i. Average time taken (down) t_1 =
ii. Velocity of falling drop, $v_1 = l_1/t_1$ =
iii. Average time taken (up) t_2 =
iv. Velocity of rising drop, $v_2 = l_2/t_2$ =
v. Radius of the drop r =
vi. Voltage on the charging plate V =

Therefore, charge on the oil drop

$$q = \left(1 + \frac{v_2}{v_1}\right)\frac{d}{V}\frac{4}{3}\pi r^3(\rho - \rho_{air}) =$$

Drop 2:

……

(b) Determination of ‘e’

Drop number	Charge on the drop	
1	q_1	
2	q_2	
3	q_3	

Analysis:

10.

To determine the wavelength of laser light using single slit diffraction pattern.

10.1 Apparatus:

Helium-Neon laser or diode laser, a single slit with adjustable aperture width, optical detector and power meter

10.2 Theory:

It is generally assumed that light travels in a straight line but it suffers some deviation from its straight path in passing close to edges of opaque obstacles and narrow slits. Some of the light does bend into the region of geometrical shadow and its intensity falls off rapidly. This bending of light which is not due to reflection/refraction is called as DIFFRACTION:

Two main classes of diffraction are:
i) Fresnel diffraction: In this case, the source of light or the

screen or both are at a finite distance from obstacle. Here no lenses are employed for rendering the rays parallel or convergent. Therefore the incident wave front is spherical or cylindrical instead of being plane.

ii) Fraunhoffer diffraction: In this case, the source of light and the screen are effectively at infinite distance from the obstacle (or aperture) causing diffraction. This means that the wave front incident on the obstacle is plane and all the secondary wavelets at every point of aperture are in phase. This can be achieved by placing the source on the focal plane of a convex lens and placing the screen on the focal plane of another convex lens. Alternatively, using a laser, this can be achieved by placing the obstacle/aperture in the parallel beam and observing the pattern on a screen placed at sufficiently large distance($D >> \frac{d^2}{\lambda}$, where D is the distance between the screen and the aperture, d is the slit width and λ is the wavelength of light used).

Fraunhoffer diffraction due to single slit:

Let AE represents a long narrow slit of width d as shown in fig.10.1. A plane wave front WW of monochromatic light of wavelength λ propagating normally to the slit is incident on it. To calculate diffraction pattern due to this slit, it is assumed that the slit consist of a large number of equally spaced point sources and that each point on the slit is a source of Huygen's secondary wavelets which interfere with the wavelets emanating from other points. The resultant field amplitude produced by these N sources at some arbitrary point P on the screen is given

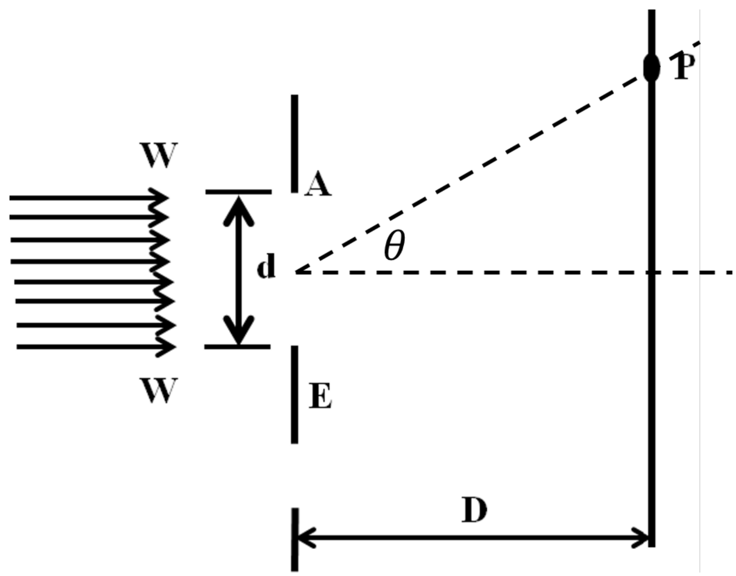


Figure 10.1: Geometry of the single slit diffraction setup.

by

$$R = a[\frac{\sin\left(\frac{N\pi}{N-1}\frac{d\sin\theta}{\lambda}\right)}{\sin\left(\frac{\pi}{N-1}\frac{d\sin\theta}{\lambda}\right)}]$$

Here θ is the angle made by the line joining center of the slit and observation point P with the direction of incident beam. In the limiting case of N tending to infinity and distance between two consecutive points on the slit tends to zero then we have

$$R = a[\frac{\sin\left(\frac{\pi d\sin\theta}{\lambda}\right)}{\left(\frac{\pi d\sin\theta}{N\lambda}\right)}] \qquad (10.1)$$

Rewriting eqn.10.1

$$R = A(\frac{sin\alpha}{\alpha}) \qquad (10.2)$$

Where $A = Na$ and $\alpha = \frac{\pi dsin\theta}{\lambda}$.
Since the intensity at P, being proportional to square of ampli-

tude can be given by

$$\begin{aligned} I &= \frac{A^2 sin^2\alpha}{\alpha^2} \\ I &= I_0 \frac{sin^2\alpha}{\alpha^2} \end{aligned} \tag{10.3}$$

Where $I_0 = A^2$, is the intensity at $\theta = 0$.

Central maximum intensity position:

For $\alpha = 0$, $\frac{sin\alpha}{\alpha} = 1$ and $I = I_0$, which corresponds to the maximum intensity. Therefore $\alpha = 0$ i.e. $\theta = 0$ is the central maximum position.

Minimum intensity positions:

In the diffraction pattern the intensity will fall to zero where $sin\alpha = 0$, which means $\alpha = \pm m\pi$ or

$$d\ sin\theta_m = \pm m\lambda \tag{10.4}$$

The value of $m = 0$ does not correspond to a minimum since $m = 0 \Rightarrow \theta = 0$, which is the central maximum.

Angular separation between consecutive minima:

From eqn.10.4,if θ is small, the angular separation between two consecutive minima is

$$\Delta\theta = \frac{\lambda}{d} \tag{10.5}$$

Thus by measuring the angular separation between two consecutive minima and the width of the slit one can find out the wavelength of light.

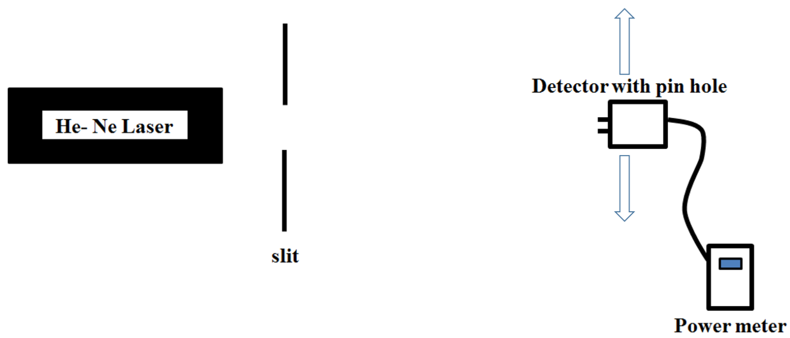


Figure 10.2: Schematic of experimental setup

10.3 Procedure:

The laser, slit and an optical detector with a pinhole are placed on an optical bench as shown in fig.10.2. It should be made sure that the distance between the slit and the detector should be sufficiently large ($>> \frac{d^2}{\lambda}$) to meet the Fraunhoffer diffraction condition. The light from the laser is allowed to fall on the slit and the diffraction pattern can be seen behind the slit. This diffraction pattern is made to fall on optical detector by laterally moving the position of the slit and the laser. Starting from one end of the diffraction pattern, the intensity is scanned by moving the pinhole detector along the entire length of the pattern. You need to measure the intensity profile up to 2 minima on either side of the central maximum. The corresponding power shown in the power mater at appropriate intervals is noted down. The plot between the position of detector and the power gives the diffraction pattern of the slit as shown in Fig.3. The position of the slit and that of the detector is also noted down; the difference between them gives the distance D. The slit is now observed

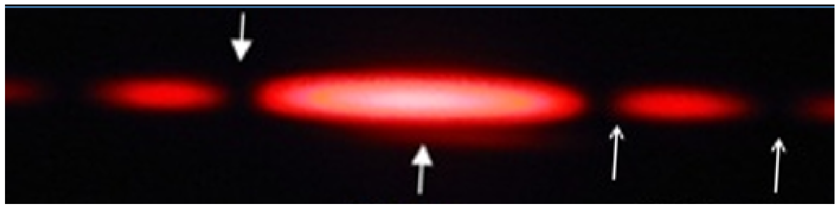


Figure 10.3: Typical single slit diffraction pattern observed on a screen. The arrows indicate positions of maxima and minima to be measured.

under a traveling microscope and the width of the slit d is found out.

Now from the plot of observed intensity vs. detector position, the distance 2L between the first minimum on the left and the first minimum on the right is measured. The angular separation $\Delta\theta_{\pm}$ between them can be calculated as follows (under the condition θ is very small)

$$\Delta\theta_{\pm 1} = \frac{2L}{D} \tag{10.6}$$

From eqn.10.4 the angular separation between +1 and -1 order minima can be given by

$$\Delta\theta_{\pm 1} = \theta_1 - \theta_{-1} = \frac{2\lambda}{d} \tag{10.7}$$

Using eqs.10.6 and 10.7 the wavelength of light can be determined.

10.4 Observations:

(a)Measurement of Intensity distribution of the Diffraction pattern

S. No.	Position of the detector (mm)	Power (mW)
1.		
2.		
3.		
. .		

(b) Measurement of the width of the slit

S. No.	Reading for right edge (a)	Reading for left edge (b)	d=$\|a-b\|$
1.			
2.			
3.			
. .			

Important Note: Never look into the laser beam directly, because it will damage your eyes permanently!

The main characteristics of a laser which distinguishes it from normal source like lamp, candle e.t.c are:

1) Directionality.
2) Monochromaticity.
3) High intensity and power.
4) High degree of coherence.

EFFECT OF LASER ON HUMAN BODY

The structures which are most affected by laser light are retina, cornea and skin. The retina can be damaged by light from visible (0.4-0.7 μ m) and near infrared (0.7-1.4 μ m) laser. The light from UV ($< 0.4\mu$ m) and far infrared ($< 1.4\mu$ m) lasers does not reach retina, but can harm cornea. Skin can be affected by lasers of any wavelength.

CLASSIFICATION OF LASERS BASED ON POWER:
1) CLASS-I: The emission of power accessible to human exposure is below levels at which harmful effects are known to occur.

2) CLASS-II: Low power visible lasers belongs to this class, its subclass II-A is for laser for which exposure for period less than 1000 sec should not be hazardous but exposure for period greater than this could be hazardous.

3) CLASS-III: Medium power lasers such that exposure to direct beam can be harmful but for which diffuse reflection are not harmful belong to this class.

4) CLASS-IV: High power lasers that can emit at levels such that harmful effects from diffuse reflections could occur belong to this class.

11.

To determine the wavelength of light from a Sodium Lamp by Newton's rings method.

11.1 THEORY

If we place a plano convex lens L on a flat glass plate G as shown in the figure, an air film of varying thickness is formed between the curved surface of the lens and the flat surface of the plate. Light from a Sodium lamp S falls on a flat glass plate P placed at 45° with respect to the incident beam. Some of this light is reflected at the plate and directed towards the lens and glass plate placed below. This light in turn is partially reflected upwards at all the four surfaces. Light reflected from the curved surface of the lens and light reflected from the adjacent surface of the glass plate then interferes to form a pattern of circular fringes.

Consider points lying close to the point of contact between the lens and the glass plate. We note that the path difference between the interfering beams is approximately 2t, where t is the thickness of the air gap. Since the light reflected from the glass plate G undergoes a further phase shift of π the condition for an interference maximum is,

$$2t = (n + \frac{1}{2})\lambda, n = 0, 1, 2, 3, ... \tag{11.1}$$

while the condition for a minimum is,

$$2t = n\lambda, n = 0, 1, 2, 3, ... \tag{11.2}$$

As the system is axially symmetric the resulting fringes are concentric circles with the center at the point of contact. If R is the radius of curvature of the curved surface of the lens, it can be shown from geometry that the diameter of the n^{th} dark ring is given by,

$$D_n^2 = 4 \cdot t \cdot (2R) = 4n\lambda R \tag{11.3}$$

Similarly for the $(n+m)^{th}$ ring,

$$D_{n+m}^2 = 4(n+m)\lambda R \tag{11.4}$$

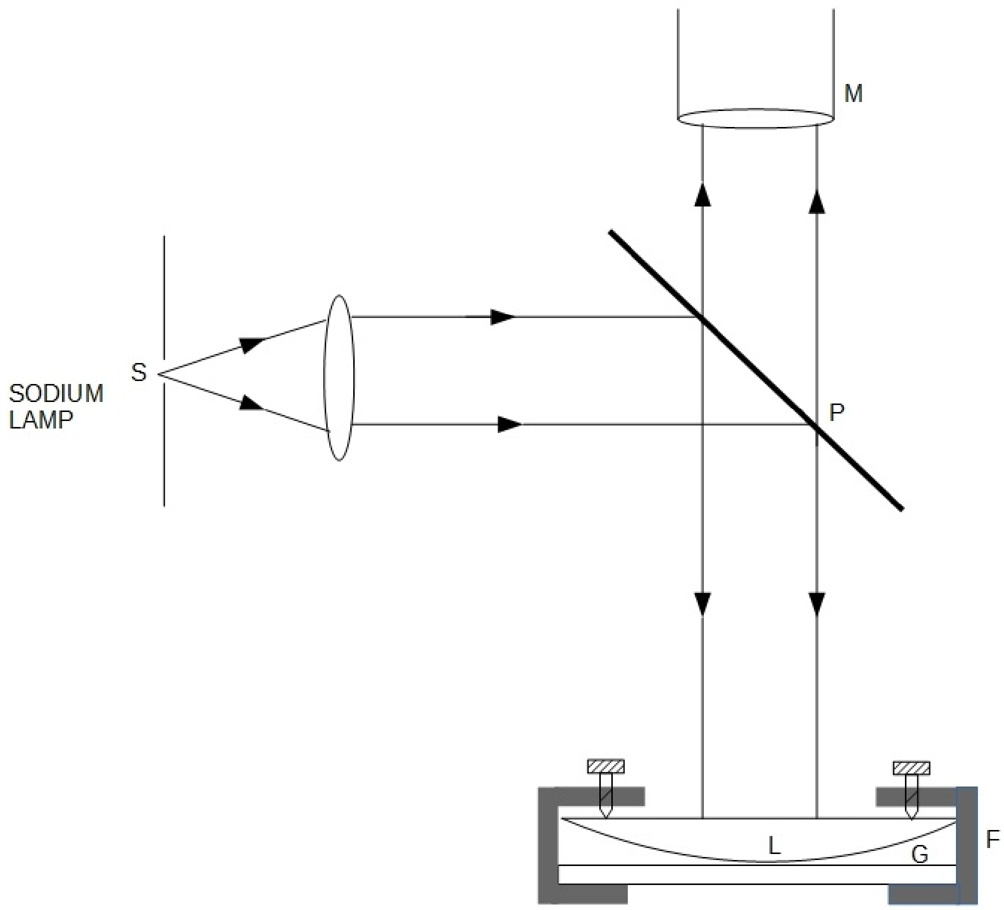
Subtracting equation 3 from equation 4 we get,

$$D_{n+m}^2 - D_m^2 = 4m\lambda R$$

i.e.

$$\lambda = \frac{D_{n+m}^2 - D_n^2}{4mR} \tag{11.5}$$

Thus measuring the diameter of the rings and the radius of curvature of the lens, we can find the wavelength of the light used.



PROCEDURE:

1. Clean both surfaces of the lens and glass plate with a tissue paper and ensure that there is no fingerprint or grease on either. Place the curved surface of the lens on the glass plate. Check that this is correct by gently pressing on one edge of the lens, it should rock because of the curved surface being in contact. Place this assembly in the frame supplied and slightly tighten the screws to ensure that the lens will not fall but can move slightly if needed. Make sure that you do not over-tighten the screws as this may break the lens or the glass plate.

2. Hold the lens-plate assembly horizontal while standing below any light on the ceiling of the laboratory. A circular pattern of interference fringes ($\sim$1-2 mm dia.) should be visible in the light reflected from the assembly. If no fringes are visible then the glass surfaces have not been cleaned properly. If the fringes are very irregular in shape then the flat and not the convex surface of the lens is in contact with the plate.

3. The frame containing the lens and plate is then placed in the Newton's rings apparatus so that the fringes are directly below the microscope. The microscope is then moved vertically until the fringes can be seen. If necessary, one of the three screws on the frame can also be tightened slightly to tilt the lens and ensure that the fringes are centered.

4. At this stage, the central fringe should be dark if this is not so, then the plate and lens are not clean, take them out, clean them and perform the same procedure as above. To ensure maximum contrast, move the Newton's ring apparatus of the lens in front of the lamp till the other dark fringes are also as black as possible.

5. Find the vernier constant of the traveling microscope. Then using the micrometer, move the microscope in the horizontal direction and check that it can be moved to more than 25 dark and bright fringes on either side of the center for taking readings.

6. Counting carefully from the center move out till the cross wire is on the 21^{st} fringe or 22^{nd} bright fringe. Now rotate the micrometer in the opposite direction till the 20^{th}..fringe of the same type is tangential to the cross-wire. Note the position of the traveling microscope from the micrometer.

The 21^{st} fringe must not be used as reversing the direction of the screw there gives a large backlash error.

7. Move the microscope using the micrometer to align the cross-wire tangential to the 18^{th} fringe and note the micrometer reading. Repeat this on the $16^{th}, 14^{th}, 12^{th}$ .... fringes, continue in the same fashion on the other side of the center till the 20^{th}

8. Remove the plano convex lens and plate from the frame and lay the lens with the flat surface downwards. Raise the central screw of the spherometer and place the spherometer on the convex surface of the lens. Rotate the screw until the tip just touches the lens and note the reading on the spherometer. Now without disturbing the reading, lift the spherometer and place it on the flat glass plate. Again lower the screw till it touches the plate and note the new reading. Repeat this process two or there times and obtain the mean value of 'h': which is the difference of the two readings.

9. In order to measure l the distance between any two legs of the spherometer, press the spherometer down on your notebook so that the three legs make marks on it. Trace out the triangle thus made by the spherometer, measure all the three sides and take the mean. Use this h and l to find the radius of curvature R of the lens by the formula.

$$R = \frac{l^2}{6h} + \frac{h}{2} \tag{11.6}$$

Observations:

Least count of micrometer on microscope =
Pitch (least count of main scale) of spherometer =
Least count of vernier (circular) scale of spherometer =

Table 11.1: Measurement of the diameter of the fringes

Serial No.	No. of Ring n	Microscope Reading		Diameter = D_n = |left hand side − right hand side|
		Left hand side	Right hand side	
1.	20	↓		
2.	18			
3.	16			
	:			
	:			↑

Calculations:

Serial No	Ring number n	D^2_{n+10} ($m = 10$)	D^2_n	$\lambda = \frac{D^2_{n+m} - D^2_n}{4mR}$
1	10			
2	8			
3	6			

Distance between two legs of the spherometer :
(1) (2) (3) Mean =

Serial No.	Spherometer Circular scale reading on lens	Spherometer Circular scale reading on plate	Difference of the two circular scale readings m	Number of complete rotations moved n	h = n×(pitch) + m×(least count of circular scale)
1					
2					
3					

(Calculate the maximum possible error and report the result as below)
The wavelength of light from the Sodium lamp was found to be $= \lambda \pm d\lambda$ nm.

Points to think about:

1. What happens to the light reflected from the upper surface of lens and lower surface of glass plate?
2. Why is the center of the fringe pattern dark even though the path difference between interfereing beams is zero?
3. What will you observe if white light is used in this experiment instead of sodium lamp?

12.

Determination of Planck's constant

11. Determination of Planck's Constant

<u>OBJECTIVES:</u> To Study the Planck's Constant

(i) Determination of the material constant 'η'

(ii) Determination of Planck's Constant, 'h'

<u>THEORY:</u>

The basic idea is that the photon energy (E_γ), which by Einstein's relation is $E_\gamma = h\nu$ is equal to the energy gap (E_g) between the valence and conduction bands of the diode. The energy gap, in turn, is equal to the height of the energy barrier, eV_o that the electrons have to overcome to go from the n-doped side of the diode junction to the p-doped side when no external voltage V is applied to the diode. In the p-doped side, they recombine with holes releasing the energy E_g as photons with $E_g = E_\gamma = eV_o$. Thus, a measurement of V_o indirectly yields E_γ and Planck's Constant if ν is known or measured. However, there are practical and conceptual problems in the actual measurement. Let us consider the LED diode equation:

$$I \propto exp\left(\frac{-V_o}{V_t}\right)\left[exp\left(\frac{V}{V_t}\right) - 1\right] \tag{1}$$

where,

$V = V_m - RI$

$V_t = \frac{\eta kT}{e}$

k = Boltzmann Constant

T = Absolute temperature

e = electronic charge

V_m is the voltmeter reading in the external diode circuit and R is the contact resistance. The constant η is the material constant, which depends on the type of diode, location of recombination region etc. The energy barrier eV_o is equal to the gap energy E_g when no external voltage V is applied. The quantities which are constant in a LED are impurity atom density, the charge diffusion properties and the effective diode area. The 'one' in rectifier is negligible if $I \geqslant 2$ nA, and the equation becomes

$$\begin{aligned} I &\propto exp\left[\frac{(V - V_o)}{V_t}\right] \\ &\propto exp\left[\frac{e\,(V - V_o)}{\eta kT}\right] \end{aligned} \tag{2}$$

A direct method could be to apply a small voltage to the LED and increasing it till the LED turns ON. This turning ON could be detected by visually observing the light emission. Plotting threshold voltage vs. frequency of peak light output (obtained from LED datasheets) provides the value of $\frac{h}{e}$. The visual observation of the emission onset is quite vague though. Use of photo-multiplier is sometimes suggested for this purpose but working with it raises maintenance problems and it is quite costly. Alternately, a measurement of threshold current ($< 10^{-11}$ A) through the LED may be attempted but it is difficult and not entirely accurate due to inefficiencies of actual LEDs.

Another procedure, sometimes used, is to draw a tangent to the $I - V$ characteristics of the diode and obtain its intercept. This procedure may give reasonably good results if the tangents to the $I-V$ characteristics of the diodes are drawn at the same current. The method then really becomes equivalent to measuring voltage across the LEDs at a single current. The intercepts of the tangent are, except for an additive constant, identical to diode voltages. The additive constant may be eliminated by considering data from different LEDs. However, the bulk of data collected from the original $I - V$ graph becomes irrelevant. A basic drawback of these methods is the assumption that the barrier height V_o is constant and is equal to the energy gap

divided by the electronic charge (i.e., $\frac{E_g}{e}$), which is true only when electric potential V is small or less than $\frac{E_g}{e}$. Further, this method assumes that the material constant, η, is unity which is not correct.
The present method is free from these drawbacks. The height of potential barrier is obtained by directly measuring the dependence of diode current on the temperature keeping the applied voltage and thus, the height of the barrier is fixed. The external voltage is kept fixed at a value lower than the barrier. In our experimental set-up, the variation of current I with temperature is measured over a range of about 30° at a fixed voltage V (= 1.8 V) kept slightly below V_o. The slope of $ln(I)$ vs $1/T$ curve gives $\frac{e(V_o-V)}{\eta k}$. The constant η may be determined separately from $I-V$ characteristics of the diode at room temperature rom the relation

$$\eta = \left(\frac{e}{kT}\right)\left(\frac{\Delta V}{\Delta ln(I)}\right) \tag{3}$$

The Planck's constant is then obtained using the relation

$$h = \frac{eV_o\lambda}{c} \tag{4}$$

The contact resistance of LED is usually around 1 Ω, while overall internal resistance of LED at applied voltage (1.8 V) is few hundred ohms. The factor RI in expression $V = V_m - RI$ may, therefore, be neglected.
The value of Planck's constant obtained from this method is within 5% of accepted value (6.626×10^{-34} Joules.sec).

EXPERIMENTAL SET-UP

The set-up consists of following units:

1. **Variable Voltage Source**
   - ▻ Specifications:
     - Range : 0-2 V DC
     - Resolution : 1 mV
     - Accuracy : ±0.5%
     - Display : $3\frac{1}{2}$ LED DPM
2. **Current Meter**
   - ▻ Specifications:
     - Range : 0-20 mA/2000μA
     - Resolution : 10 μA /1μA
     - Display : $3\frac{1}{2}$ LED DPM
3. **Temperature Controlled Oven**
   - ▻ Specifications:
     - Range : Ambient to 60°C
     - Resolution : 0.1°C
     - Sensor : PT-100
     - Display : $3\frac{1}{2}$ LED DPM

CONNECTION DIAGRAM OF EXPERIMENTAL SET-UP

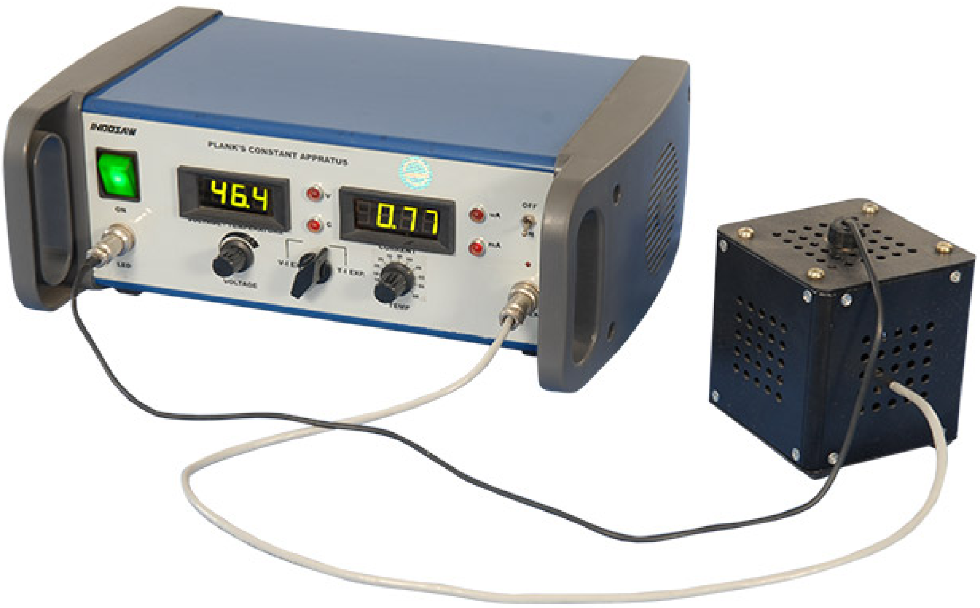


Figure 1: Set-up

EXPERIMENTAL SET-UP PROCEDURE

(a) To draw $I-V$ characteristics of LED

1. Connect the LED in socket on set-up and switch ON the power.
2. Switch the two-way switch to $V-I$ position. In this position, the first DPM would read voltage across LED and the second DPM would read current passing through LED.
3. Increase the voltage gradually and tabulate the $V-I$ readings. Please note that there would be no current till about 1.5 V.
4. Plot the graph between $ln(I)$ (I in μA) vs V.

(b) Dependence of current (I) on temperature (T) at a constant applied voltage

1. Keep the mode switch to $V - I$ side and adjust the voltage across LED slightly below the band-gap of LED, say, 1.8 V for both yellow & red and 1.95 V for green LED.
2. Change the mode of two-way switch to $T - I$ side.
3. Insert LED in the oven and connect the other end of LED in the socket provided on the set-up. Before connecting the oven, check that the oven switch is in OFF position and Set Temperature knob is at minimum position. Now, first DPM would read ambient temperature.
4. Set the different temperatures with the help of Set Temperature knob. Allow about 5-7 minutes on each setting for the temperature to stabilize and take readings of temperature and current.
5. Find the inverse of temperature and draw the graph between $ln(I)$ & $\frac{1}{T}$.

OBSERVATIONS:

(a) **Determination of material constant η**
Sample: (RED/YELLOW) LED
Room Temperature: 300 K

Sr. No.	**Junction Voltage, V** (V)	**Forward Current, I** μA	$ln(I)$

○ Plot the graph between $ln(I)$ and voltage (V).
○ Determine the slope of the graph

$$Slope = \frac{\Delta ln(I)}{\Delta V}$$

○ Using the slope of the graph, η can be determined from

$$n = \frac{e}{kT} \times \frac{1}{slope}$$

(b) Determination of Temperature Coefficient of Current

Sample: (RED/YELLOW) LED

Voltage = 1.803 V (constant for whole set of readings)

Sr. No.	**Temperature** (°C)	**Temperature** (K)	**Current** mA	$1/T \times 10^{-3}$ (K^{-1})	$ln(I)$ (I in mA)

From graph, $\frac{\Delta ln(I)}{\Delta T^{-1}} =$

Therefore,

$V_o = V - \left[\frac{\Delta ln(I)}{\Delta T^{-1}} \times \frac{K}{e} \times \eta\right]$

Now,

$h = \frac{e \times V_o \times \lambda}{c}$

$h =$ ____________ Joules.sec

CHECK POINTS:

1. $V - I$ characteristic of LED should be drawn at very low current (up to $\sim 1000\mu$A only), so that disturbance to V_o is minimum.

2. In $T - I$ mode, make sure that the oven switch is OFF and Set Temperature knob is at minimum position before connecting the oven.

3. On each setting of temperature, please allow sufficient time for the temperature to stabilize (between 6-7 minutes).

SUGGESTED READING:

1. Neamen, Donald A. *Semiconductor physics and devices.* McGraw-Hill Higher Education, 2003.

2. Sze, Simon M., and Kwok K. Ng. *Physics of semiconductor devices.* John wiley & sons, 2006.

13.

Diffraction grating

OBJECT

To determine the wavelengths of light emitted by a mercury vapour lamp by using a diffraction grating.

INTRODUCTION:

Consider a light beam transmitted through an aperture in an opaque screen (see Fig. 13.1). If light were treated as rays traveling in straight lines, then the transmitted light would appear as a 'bright shadow' of the aperture. However, because of the wave nature of light, the transmitted pattern may deviate slightly or substantially from the aperture shadow. depending on the distance between the aperture and the observation plane, the dimensions of the aperture and the wavelength of light. Indeed, the transmitted intensity distribution, which is known as the *diffraction pattern*, may contain intensity maxima and minima even well outside the aperture shadow (see Fig. 13.1). The angles at which the intensity maxima and the minima occur depends on the wavelength of light and the width of the slit. This phenomenon of spreading out of light waves into the geometrical (dark) shadow when light passes through a small aperture (or about an obstacle) is known as *diffraction*.

A *diffraction grating* consists of a periodic array of a large number of equidistant slits of width 'b' which are separated by a distance 'a' as shown in Fig. 13.3. The period ($= a$) is known as the *grating constant*. Thus if N is the number of slits per unit length (say, 1 mm), then $a = I/N$ mm

The diffraction pattern due to a grating is essentially the same as the diffraction pattern due to M slits, where M is a large number ($\sim 10^3$) and is obtained by the superposition of waves emanating from all the slits on the observation plane. The resulting intensity distribution is given by

$$I = I_0 \left(\frac{sin\beta}{\beta} \right)^2 \left(\frac{\sin M\alpha}{sin\alpha} \right)^2 \tag{13.1}$$

where

$$\alpha = \frac{ka\sin\theta}{2} \text{and } \beta = \frac{kb\sin\theta}{2} \tag{13.2}$$

with $k = \frac{2\pi}{\lambda}$, λ being the wavelength of light and θ is the angle at which the diffracted beam propagates relative to the incident beam.

The grating equation

Consider the incidence of plane waves making an angle θ_i with the plane of the grating as shown in Fig. 13.3. The net path difference for waves from successive slits is given by

$$\Delta = \Delta_1 + \Delta_2 = a\sin\theta_i + a\sin\theta \tag{13.3}$$

where θ is the angle corresponding to any arbitrary direction of the diffracted light.

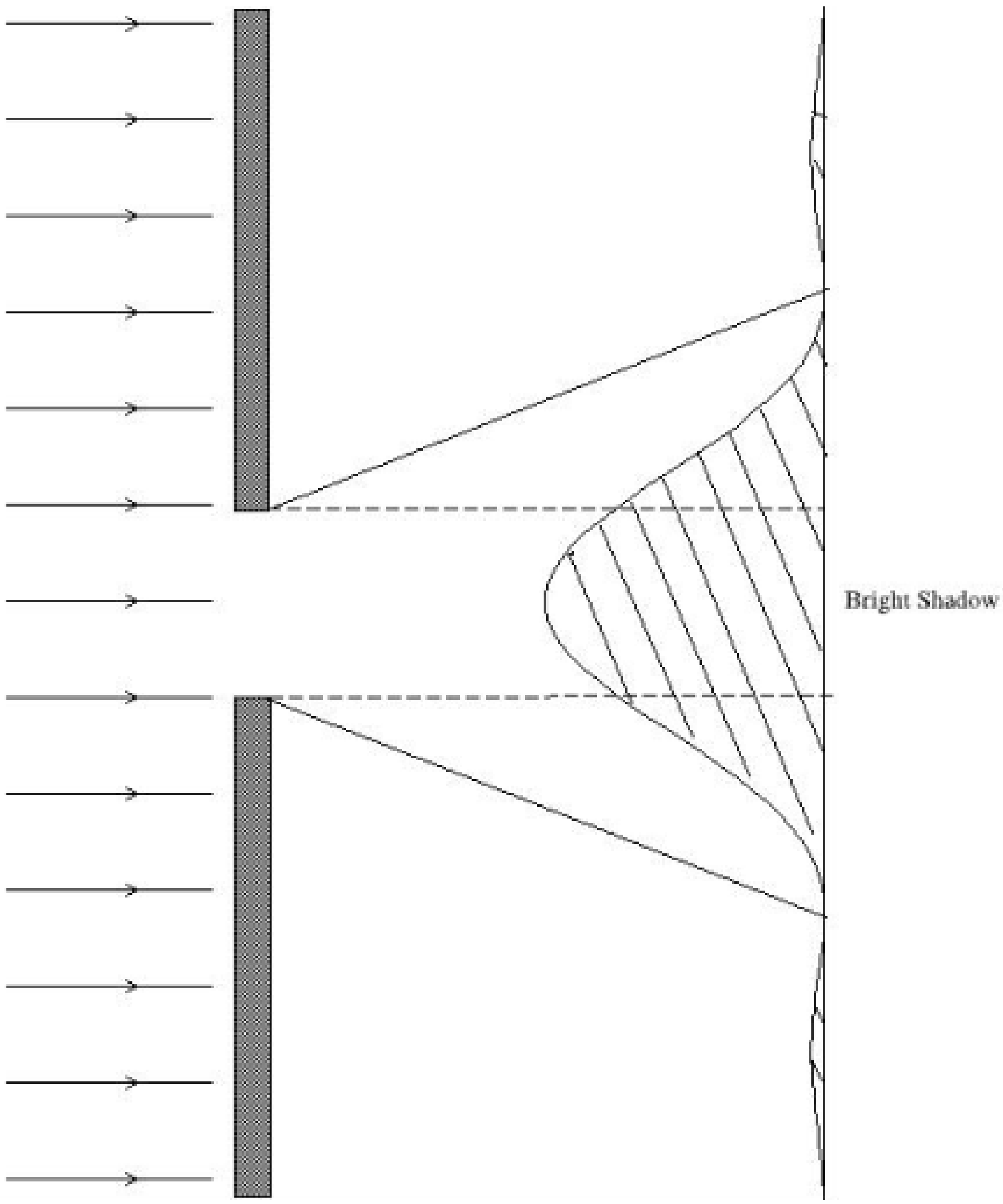


Figure 13.1: Diffraction of light through an aperture

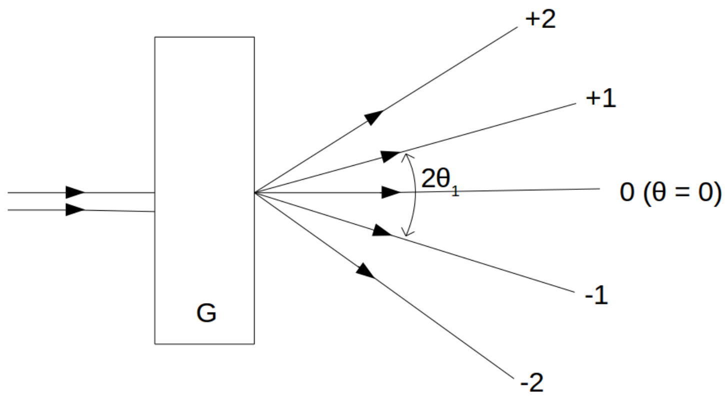


Figure 13.2: Diffracted orders at a particular wavelength

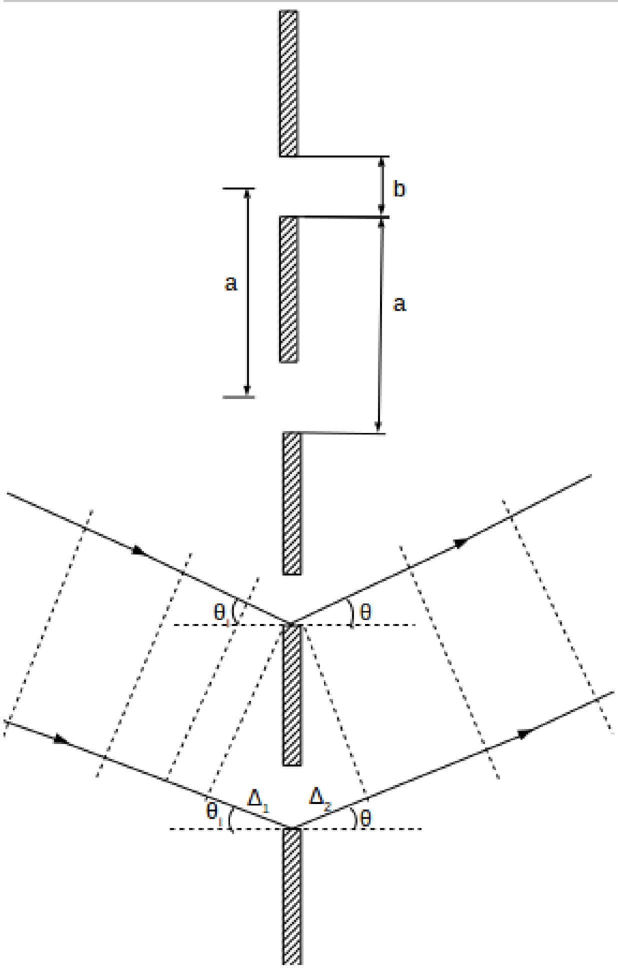


Figure 13.3: Plane waves incident on a diffraction grating at an angle θ_i 'a' is the grating constant

For normal incidence $\theta_i = 0$ and therefore

$$\Delta = a \sin\theta \tag{13.4}$$

When $\Delta = n\lambda$, where n is an integer, all diffracted waves in the corresponding direction θ_n are in phase, and their amplitudes add up to give maximum intensity. Thus, we have the grating equation, which gives the positions of the intensity maxima as

$$a \sin\theta_n = n\lambda \tag{13.5}$$

n = 0, ±1, ±2,... refers to the order of the spectrum.

The zeroth order (n = 0) occurs for $\theta_n = 0$, i.e. along the direction of the incident light, for all λ. Thus, light of all wavelengths appears in the zeroth order peak of the diffraction pattern. For orders $n \neq 0$, the grating leads to angular separation of the wavelengths present in the incident beam (see Eq. (13.5). In other words in each order, different colours would appear at different angles with reference to the direction of the incident beam. This feature of the granting makes it extremely useful in wavelength measurement and spectral analysis. Note that for every θ_n, satisfying the grating equation, the angle $-\theta_n$ also satisfies the grating equation with n replaced by -n. Thus, for normal incidence the +ve and -ve orders appear symmetrically on either side of the zeroth order (see Fig. 13.2).

Source of Light:

Mercury vapour lamp is used as the source of light. This source gives a well defined line spectrum arising from interstate electronic transitions taking place in the excited mercury atoms.

Spectrometer:

The spectrometer consists of a collimator which is mounted on the rigid arm, and a telescope mounted on the rotatable arm which can rotate in a horizontal plane about the axis of the instrument. A prism table of adjustable height is mounted along the axis of rotation of the telescope. A circular scale-and-vernier arrangement is provided to enable measurement of the angle through which the telescope arm or the prism table is rotated.

Experiment

1. Setting the prism table (This part is same as that for Expt. 8)

The prism table is made horizontal first with the help of a spirit-level by adjusting the leveling screws D, E and F (see Fig.4). To start with, the prism-table is rotated about its axis and adjusted in such a way that the parallel straight lines along with the two screws E and F are perpendicular to the axis joining the collimator and the telescope when they are aligned. A three way spirit level is kept on the prism table with its edge along the parallel lines.

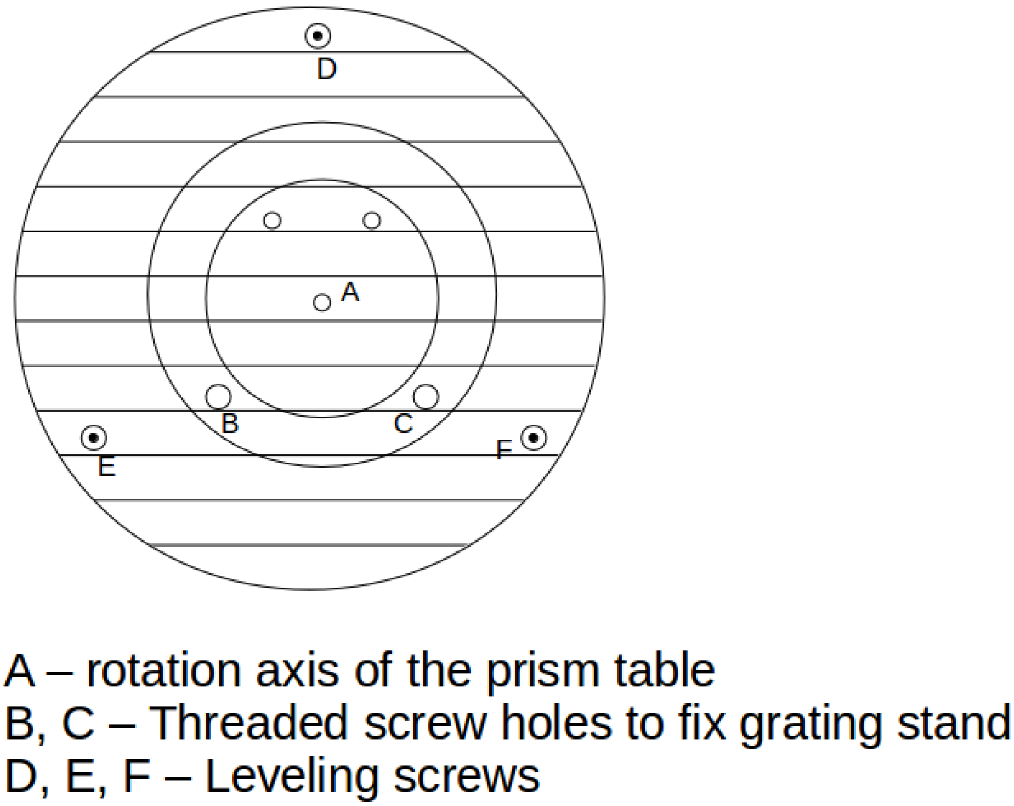


Figure 13.4: Top view of the prism table showing relevant details

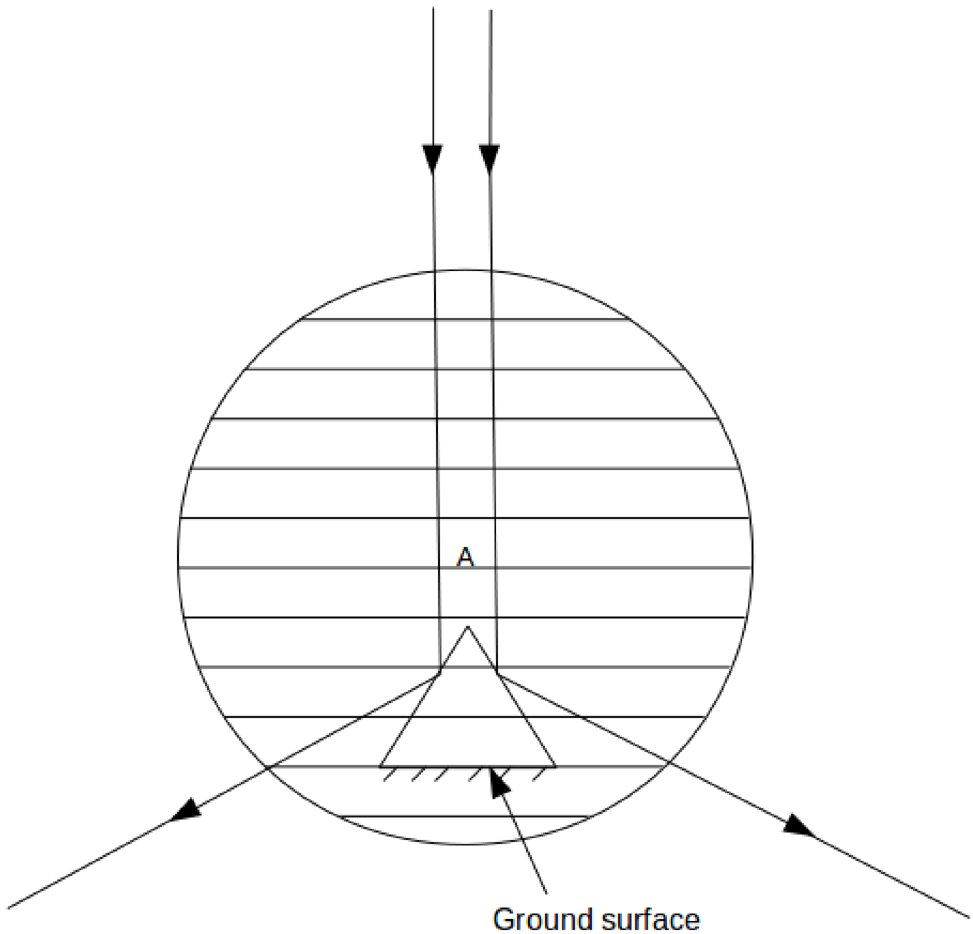


Figure 13.5: Positioning of the prism for optical alignment

Further adjustments of the prism table is done using the method of optical alignment. The given prism is placed such that the ground surface is facing towards the telescope and is perpendicular to the collimator. Adjust the position of the prism such that the edge of the prism opposite to the ground surface lies approximately along the axis of the prism table (see Fig.5). If you know rotate the telescope arm, you would be able to see the reflected images of the slit on both sides of the incident direction. Adjust the screws D, E and F such that the image of the slit appears symmetrically placed about the horizontal cross wire when viewed from both sides. The prism table adjustments are now complete.

2. Schuster's method of focusing a spectrometer for parallel incident light: (This part is same as for Expt. 8)

When a distant object is not available or if the spectrometer is too heavy to be carried outside the dark room where the experiment is being performed, the setting of the spectrometer is done by the so called Schuster's method.

First , the entrance slit of the collimator is kept facing the brightest porting of the mercury lamp and its width adjusted to permit a thin line of light to act as incident light. The given prism is now placed on the vernier table with its ground face along the parallel lines ruled on the prism table. The prism table is rotated so as to obtain mercury light incident from the collimator on one of the polished surfaces of the prism. The telescope arm is moved to a suitable position to see the spectrum through it (see Fig.6). The vernier table is rotated to achieve the position of minimum deviation.)of course, you will have to rotate the telescope arm also, as you rotate the vernier table, to retain the spectrum in the field of view of the telescope.) At this position, the spectrum which appeared to be moving (in the telescope) in one direction (say, left to right) reaches an extreme limit and retraces its path on further movement of the vernier table in the same direction.

Keeping the position of the telescope fixed, the vernier table is rotated slightly away from this position of minimum deviation, bringing the refracting angle towards the telescope and the telescope is now focused (see 1 - 1 in Fig.6) on the image as distinctly as possible. The vernier table is then rotated to the other side of the minimum deviation position towards the collimator and the collimator is focused (see 2 - 2 in Fig.6) to obtain a sharp image of the spectrum. The process is repeated till the motion of the prism does not effect the focus of the spectral lines.

The collimator and the telescope are then set for parallel light ant *these settings are not be disturbed during the course of the experiment.*

3. Setting up the diffraction grating for normal incidence:

The diffraction grating is positioned securely in the grating stand with the help of two clamps, and is fitted on the prism table with the help of two screws into the threaded holes B

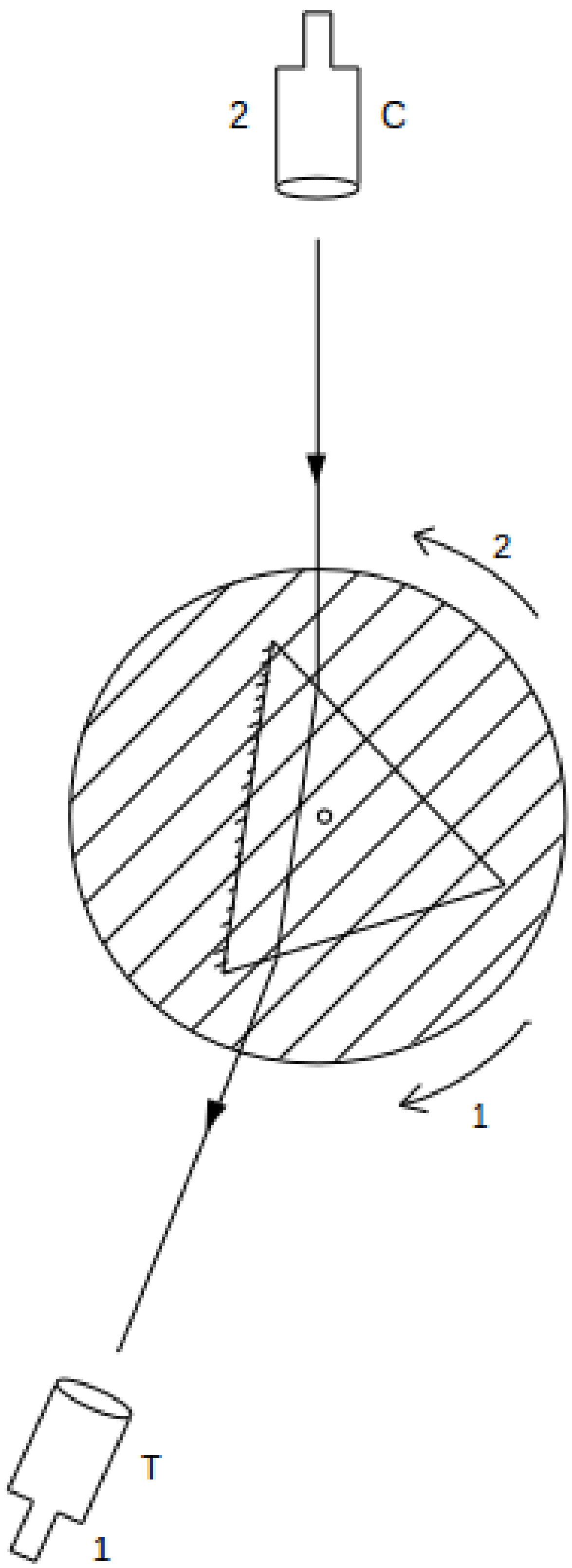


Figure 13.6: Top view of the setup for Schuster's method.

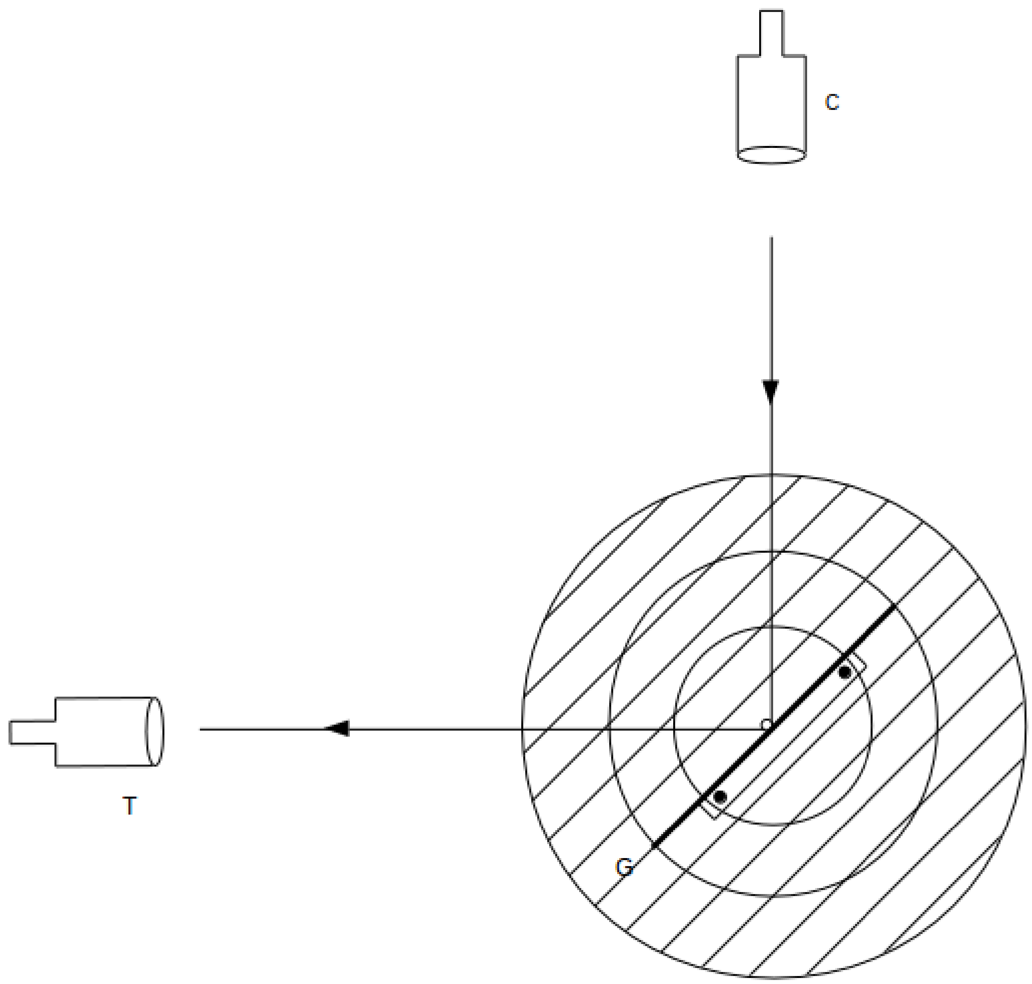


Figure 13.7:

and C, in Fig.4).

The position of the telescope is carefully adjusted such that the direct image of the slit coincides with the vertical crosswire on the telescope. Readings of the two circular scales I & II are recorded. The telescope arm is rotated through 90°, and locked in this new position. The prism table is rotated so as to coincide image of the slit reflected from the grating with the vertical crosswire in the telescope (see Fig.7). Readings of scales I and II are recorded again. The prism table is now rotated away from this position by an angle of 45° so as to make the grating face perpendicular to the incident light coming from the collimator. The prism table is locked in this position. The telescope arm is now released so that it can be moved freely on both sides of the incident light position.

4. Determination of Angle of Diffraction:

Experiment is performed with a grating having 2000 lines/inch or so. The diffraction spectrum contains a white line in the centre (zero order spectrum) with dispersed set of coloured lines (blue, blue green, green, yellow I, yellow II, red I, red II etc.) appearing repetitively on both sides of the zeroth order representing the higher orders of diffraction spectra. Readings of the telescope positions are taken while coinciding its crosswire with the various coloured lines on the left-side spectra. note down the readings of both the verniers for each spectral line in the first order and in the second order. Then take the telescope to the right side of the direct image and repeat the above procedure. Tabulate all the readings systematically as per the given format (see Table 1). Find out the differences in angles corresponding to the same kind of vernier for each spectral line in both the orders. Determine from this the wavelength of the light of a particular colour by using the grating formula

$$asin\theta = n\lambda \tag{13.6}$$

Observations and calculations:

No. of rulings per inch on the grating 'N' = (given)
The grating constant $\alpha = ---$m = (Periodicity of the grating)
Least count of spectrometer =
Reading of telescope position for direct image of the slit =
Reading of telescope position after rotating it through 90° =
Reading on circular scale when the reflected image is obtained on the cross-wire =
Reading after rotating the prism tabel through 45° =

Order of Spectrum	Color of light	LHS reading for telescope position (p)	RHS reading for telescope position (q)	p − q (deg)	$\theta = \frac{\lvert p-q\rvert}{2}$ (deg)
2	Yellow Green Violet	↓	↑		
1	Yellow Green Violet	↓ →	↑		

*The direction of the arrow indicates the sequence of recording the readings.

Precautions:

i Care should be taken to ensure proper setting of the spectrometer and these settings of the telescope and the collimator are not touched during the course of taking the various readings.

ii The position of the grating adjusted to be normal to the incoming light from the collimator, should not be distrubed throughout the experiment. Ensure that the prism table locking screw is tightened properly.

iii It is necessary to point the slit towards the brightest part of the source, in order to obtain reasonable intensity of the lines of different colours especially in the higher order spectra. It is known that the intensity of lines in the higher order spectra reduces sharply with increase tn order.

Sources of error:

Think and find out yourself after doing the experiment!!

14.

Brewster angle measurement

Brewster angle measurement

Objective:

1. Measurement of reflection coefficient of a glass plate for p- and s- polarizations
2. Determination of Brewster angle

Theory:

When a monochromatic plane wave is incident on an interface between two materials, its **E**-field can be decomposed into two transverse components that are in a plane normal to the **k**-vector as shown in Fig. 1. The two transverse components are typically defined with respect to the plane of incidence. The component in the plane of incidence is known as p-polarized wave whereas the component normal to the plane of incidence is known as the s-polarized wave.

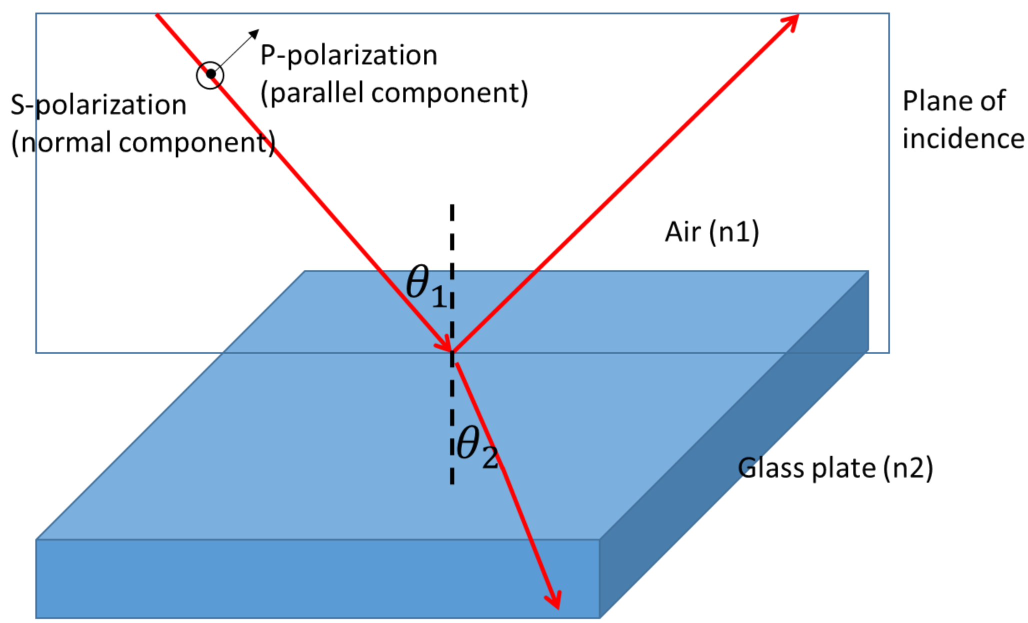


Fig. 1: Illustration of p- and s- polarization components in relation to plane of incidence.

The amplitude or Fresnel reflection coefficients for the p and s polarization components can be obtained using appropriate boundary conditions and are given by:

$$r_p = \frac{n_1 \cos\theta_2 \ - \ n_2 \cos\theta_1}{n_1 \cos\theta_2 \ + \ n_2 \cos\theta_1} \quad \text{and} \quad r_s = \frac{n_1 \cos\theta_1 \ - \ n_2 \cos\theta_2}{n_1 \cos\theta_1 \ + \ n_2 \cos\theta_2}.$$

Here the angle of incidence and angle of refraction are related by the Snell's law:

$$n_1 \sin\theta_1 \ = \ n_2 \sin\theta_2.$$

Using the expressions for reflection coefficients and the Snell's law it is easy to show that when $\theta_1 + \theta_2 = \pi/2$ or equivalently when $\theta_1 = \theta_B = \arctan(n_2/n_1)$, $r_p = 0$. This angle of incidence is known as the Brewster angle (θ_B). The reflected wave is thus purely s-polarized whereas the transmitted wave has both polarizations. The aim of this experiment is to measure the energy reflection coefficients at air-glass interface for both p- and s-polarizations and for various values of incidence angle. The typical plots for energy reflection coefficients $R_p = |r_p|^2$ and $R_s = |r_s|^2$ are shown in Fig. 2.

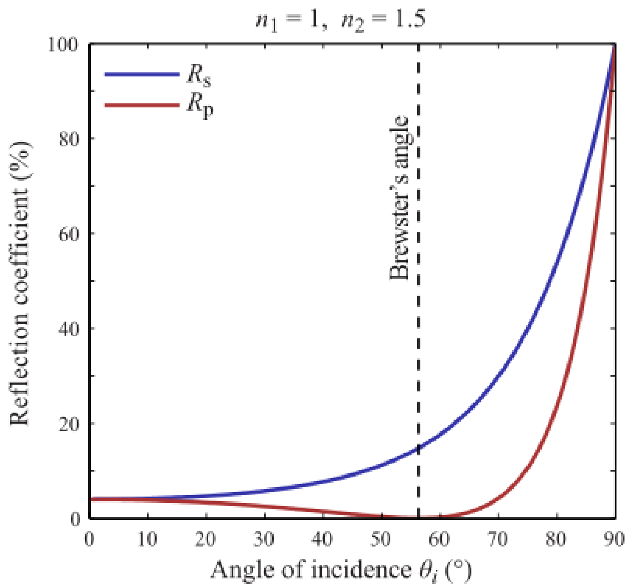


Fig. 2: Plot of energy reflection coefficients as a function of angle of incidence for p- and s-polarized light. The reflection coefficient for p-polarized wave vanishes when angle of incidence is equal to the Brewster angle.

The polarization state of light for incident unpolarised light at Brewster angle can be shown diagrammatically as in Fig. 3.

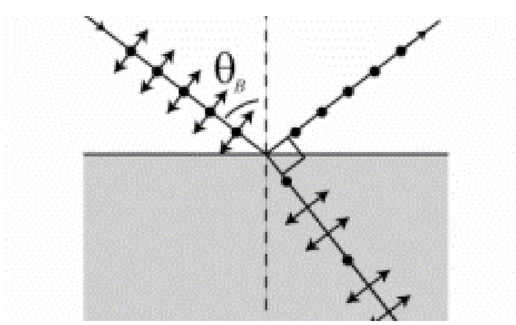


Fig. 3: Polarization state of unpolarised light incident at Brewster angle on reflection and transmission.

Procedure:

The experimental setup is shown in Fig. 4 below.

1. Diode Laser with power supply (3mW 650nm Red)
2. Kinematic Laser mount
3. Polarizer
4. Goniometer Based Detector Mount
5. Glass Slide Specimen
6. Pinhole Photo Detector with power supply
7. Optical Rail (500mm)

Fig. 4: Experimental setup for Brewster angle measurement.

1) Without the glass plate in place, first arrange the laser and the detector such that the laser illumination falls directly on the detector pinhole and you get some photocurrent from the detector.
2) Now insert the polarizer in laser path. Rotate the polarizer at 5-degree intervals and note down the detector signal. Make a plot of detector intensity vs. polarizer angle. What do you conclude about state of polarization of the laser from this plot?
3) Now orient the pass axis of the polarizer (shown by notch on the polarizer mount) in vertical and horizontal directions. Verify that the detector readings for the two cases are approximately equal. This will ensure that the laser is oriented such that its polarization is at 45-degree angle (why?).

4) Insert the glass slide in the central mount and identify the p- and s-polarization components with the horizontal and/or vertically polarized light states respectively.
5) Turn the polarizer such that it passes vertically polarized light. Using the goniometer arrangement find the reflected light power as a function of incidence angle. Make a plot of energy reflection coefficient vs. incidence angle. Use sufficient number of incidence angle values to get a smooth curve.
6) Repeat step (5) for horizontally polarized light.
7) Determine the Brewster angle and the refractive index of glass using your plots.
8) Find log error in estimation of refractive index.

Direct power measurement for p and s polarized light with detector:

Representative data table for p or s polarized light:

Angle of incidence	Detector signal	Reflection coefficient

15.

(A). To determine the surface tension of water by Jeager's method. (B). To measure surface tension of water by capillary rise method.

Experiment 14(S)

15.1 Object: (A). To determine the surface tension of water by Jeager's method

15.1.1 Apparatus:

Jeager's setup, traveling microscope and a table lamp.

15.1.2 Theory:

It is well known that in curved liquid surfaces the surface tension gives rise to excess pressure P which is given by the relation $P = T(\frac{1}{r_1} - \frac{1}{r_2})$ where T is surface tension of the liquid, r_1 and r_2 are the principal radii of curvature. This excess pressure is always directed towards the center of curvature and for an air bubble it is given by $P = 2T/r$. Jeager's method for measurement of T is an application of this relation between surface tension T and radius of curvature.

15.1.3 Procedure:

Apparatus required for Jeager's method consists of a big water reservoir R fitted with air tight cork at its top through which is inserted a glass tube immersed below the water level and a conical vessel connected to bottom outlet of water reservoir through a stop clock S (Fig.15.1). The conical vessel is also connected to a tube T whose other and is joined to a capillary tube which is dipped inside the liquid whose surface tension is to be determined. Open the stop clock S which allows the water to fall in the conical flask C. This increases the pressure of air bubble inside C as also of the air in the tube B and capillary tube A and water level in tube B becomes lower and lower. As more and more water falls in to C, pressure of air in the flask and the capillary tube continues to build up and when the excess pressure which is equal to the pressure difference between two sides of the air bubble formed at the orifice of capillary, becomes equal to 2T/r(r being the radius of the bore of capillary) the air bubble gets released. At the moment when bubble is released the water level in the tube B reaches its lowest level i.e. H cm below the surface of water in the beaker. Now if the position of the orific of the capillary A is 'h' cm below the water level in the beaker, (H-h)gρ gives the pressure difference 'p' at the time of the bubble is released. Thus we have

$$(H - h)\rho g = 2T/r$$

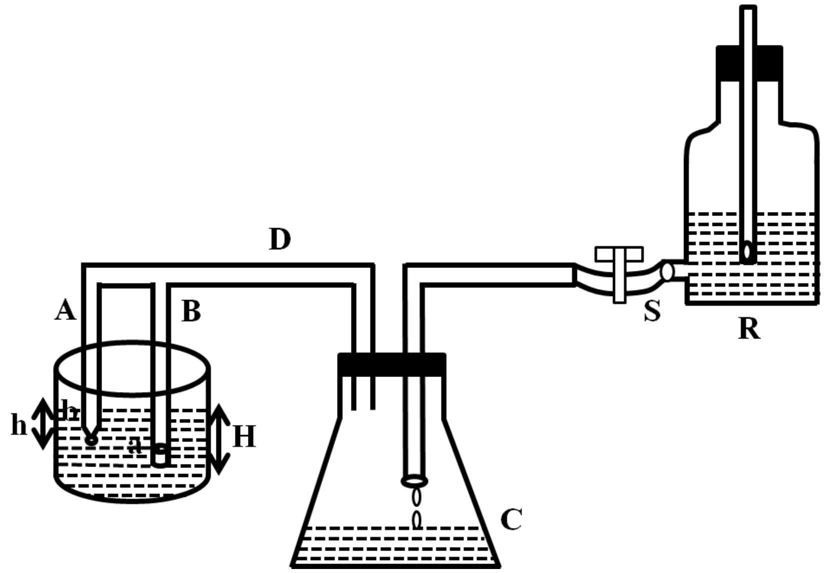


Figure 15.1:

To measure the radius of orifice of capillary A, fix the capillary tube A in the horizontal position and focus the microscope on its orifice to get a clear image. Then adjust the microscope such that its vertical cross-wire coincides with one edge of the bore and note down the readings. Now move the microscope so that the vertical cross wire coincides with the diametrically opposite edge of the bore. The difference between these two readings gives the diameter of the bore (2r). Thus by measuring H,h and r one can easily determine T using the relation

$$T = \rho r(H - h)\frac{g}{2}$$

15.1.4 Observations:

Density of liquid =
Ambient temperature=

Table for measuring H and h

Sr. No.	meniscuswater in A	sur-face A	h	meniscuswater in B	sur-face B	H	(H-h) in cm
1.							
2.							
3.							
. .							

Table for determining radius of capillary , r

Sr. No.	position of one end of capillary	position of dia-metrically opposite end	diameter (cm)	radius (cm)
1.	vertical			
2.	vertical			
3.	horizontal			
4. .	horizontal			

Mean r=

Calculations and Log errors

Result: The surface tension of the liquid at C is =

15.2 Object: (B). To measure surface tension of water by capillary rise method.

15.2.1 Apparatus:

A beaker, a capillary tube, a stand and a traveling microscope.

15.2.2 Theory:

When we dip a capillary tube vertically inside a liquid which wets it, the liquid immediately rises inside the capillary above the general level of the liquid outside. If h is the maximum height to which it rises then the surface tension of the liquid is given by the relation

$$T = r(h + \frac{r}{3})\rho\frac{g}{2}$$

where r is the radius of the bore of capillary, ρ is the density of liquid. In the above given relation, the angle of contact has been taken as zero, a condition which is reasonably justified for light liquids like water. Thus we see from the above equation that by knowing r, ρ, g and h, one can determine surface tension T of liquid.

15.2.3 Procedure:

Take a beaker and fill it with water approximately half of the height. Now dip a capillary inside the water and hold the capillary in the vertical direction by the help of a stand. Wait until water rises inside the capillary to a maximum height. Next focus the microscope on the meniscus of water inside the capillary and

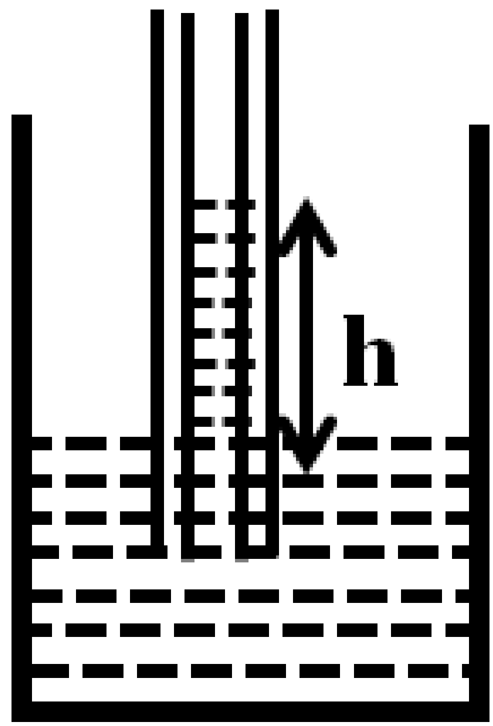


Figure 15.2:

adjust the microscope such that horizontal cross wire just coincides with the meniscus and note the reading on vertical scale. Now move the microscope downwards and note the position of the general level of water in the beaker. The difference between the two readings gives height 'h'. Measure the radius of capillary as described earlier in the previous part of this experiment and calculate T using he equation given above. Repeat the experiment with different capillaries of different radii and find out the average values of T.

15.2.4 Observations:

Density of liquid=
Radius of capillary tube=

Observation table for measurement of h

Sr. No.	position of meniscus in the capillary	position of water level in the beaker	height h (cm)
1.			
2.			
3.			
. .			

Mean h=
Calculation and log errors
Result: The surface tension of the liquid at C is =

16.

To determine the viscosity of water by Meyer's oscillating disk method

Experiment 14(V)

Theory

If a disk undergoes torsional oscillations about its symmetry axis in a fluid medium, it does not push aside any additional fluid while executing this motion. The fluid in contact with the disk then remains at rest with respect to it, while the fluid far away is at rest with respect to the enclosure/container. so a transverse velocity gradient is set up in the fluid, and this in turn causes a viscous force to act and damp out the oscillations. Oscar Meyer suggested measuring the decay of these oscillations to find the viscosity of a liquid.
The equation to a harmonic oscillator undergoing torsional os-

cillations is.

$$I\frac{d^2\theta}{dt^2} + K\frac{d\theta}{dt} + \tau\theta = 0. \tag{16.1}$$

Here I is the moment of inertia of the oscillator, K is the damping coefficient, τ is the restoring torque per unit twist and θ is the oscillations (twist) angle. The solution of this equation is given by,

$$\theta(t) = \theta_0 e^{-\frac{2\lambda t}{T}} sin(\frac{2\pi t}{T} + \phi), \lambda = \frac{KT}{4}, T = 2\pi I\left(\frac{1}{\tau - \frac{K^2}{4}}\right)^{\frac{1}{2}} \tag{16.2}$$

where θ_0 and ϕ are constants of integration. The variation of this function with time is shown in the Fig 16.1. The quantity λ, known as the logarithmic decrement, is the logarithm of the ratio of any two successive amplitudes on opposite sides of the equilibrium position. Thus,

$$e^{\lambda} = \frac{B_1C_1}{B_2C_2} = \frac{B_2C_2}{B_3C_3} = \frac{B_1C_1 + B_2C_2}{B_2C_2 + B_3C_3} = \frac{B_1C_1 + B_2C_2... + B_nC_n}{B_2C_2 + B_3C_3... + B_{n+1}C_{n+1}} \tag{16.3}$$

Here B_j is the amplitude at the i^{th} turning point of the disk, as shown in Fig.1. Thus by measuring the amplitudes on either side of the equilibrium position, we can find out the damping coefficient using Eq.(16.3).

In the case of a disk oscillating inside a liquid, the damping is due to two causes: damping due to the viscous forces of the liquid, and damping due to the friction of the wire suspension at the support. Meyer suggested that the instrument be first used to find the logarithmic decrement λ_0 in air, where the viscous damping is negligible, followed by a measurement of the logarithmic decrement λ in the liquid. As the frictional damping at the support is the same in both cases., this (unknown quantity) can be eliminated by taking the difference $\lambda - \lambda_0$. Using this, he was able to find a formula for the viscosity of the liquid as,

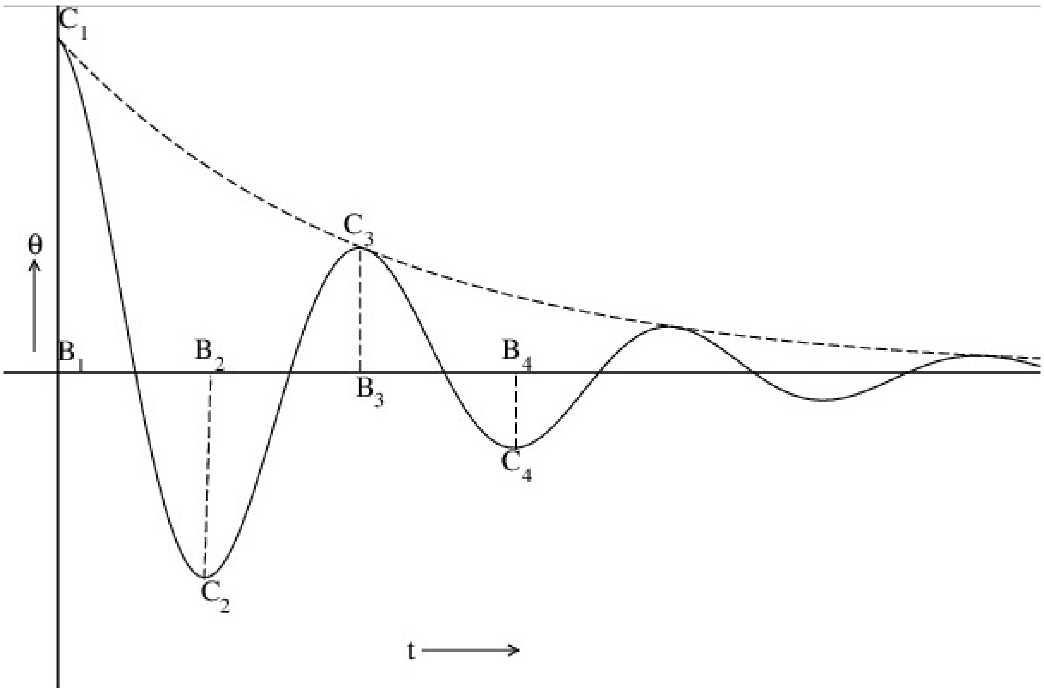
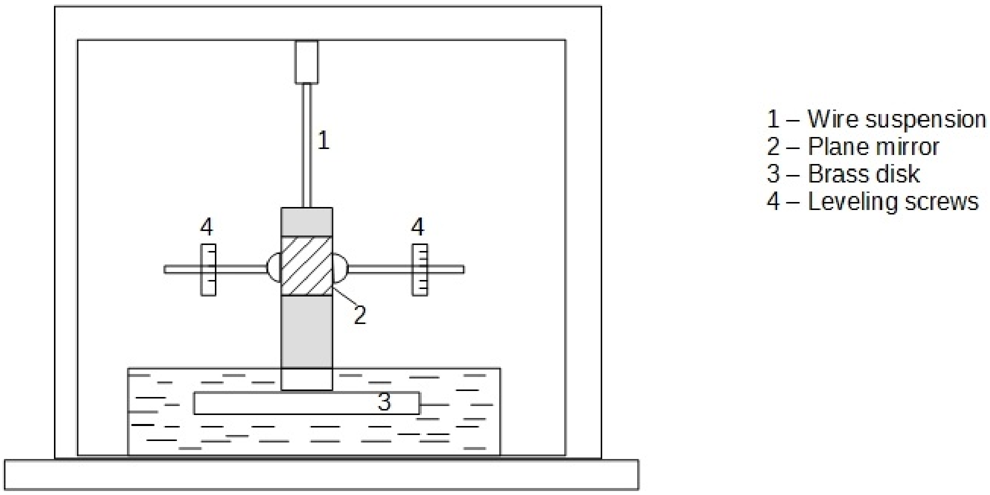


Figure 16.1: Damped Oscillations

$$\eta = \frac{16I^2}{\pi\rho T(r^4 + 2r^3 d)^2}\left[\left[\frac{\lambda - \lambda_0}{\pi}\right] + \left[\frac{\lambda - \lambda_0}{\pi}\right]^2\right]^2 \qquad (16.4)$$

Here,
I - moment of inertia of the torsional pendulum about the suspension axis.
T - time period for one complete oscillation.
r - radius of the disk.
d - thickness of the disk.



H

Figure 16.2: Meyer's Apparatus

ρ - density of the liquid.
λ - logarithmic decrement in the liquid.
ρ_0 - logarithmic decrement in air.

The quantities mentioned above can all be measured directly, except the moment of intertia of the disk which is a complex object. To find the moment of inertia, the time period (T) of the disk in air is found and then a ring with a known moment of inertia I_r is placed on the disk with its center on the suspension axis. The time period of the disk and the ring together in air(T') is again found, when the moment of inertia of the ring-loaded disk is $I + I_t$. Then, we have

$$I_r = ma^2 \qquad \therefore \quad I = ma^2 \frac{T^2}{(T')^2 - T^2} \tag{16.5}$$

$$T = 2\pi \left(\frac{I}{\tau - \frac{\kappa^2}{4}} \right)^{\frac{1}{2}} = \left(\frac{I}{\tau} \right)^{\frac{1}{2}} \qquad and \qquad T' = \left(\frac{I + I_r}{\tau} \right)^{\frac{1}{2}} \tag{16.6}$$

here, m is the mass, a is the average radius of the ring, i.e., $a = (d_1 + d_2)/4$ where d_1 and d_2 are the inner and outer diameters of the ring, respectively. Using equations (4) and.(6) we can find the viscosity of water.

PROCEDURE

1. The apparatus consists of a flat disk attached to a short rod passing through its center which is suspended (with the disk remaining horizontal) by means of a phosphor bronze wire. The central rod has a perpendicular screw with two movable masses on opposite sides for leveling the disk. A small concave mirror with a radius of curvature of about one meter is also mounted on this rod (see Fig.2).

A lamp and scale arrangement is provided which is to be adjusted till a beam from the lamp after reflection from the concave mirror forms a well defined circular patch of light on the scale. The image of the cross wires on the lamp should be clearly visible on the screen. The positions of the scale and the disk are adjusted till the equilibrium position of the spot of light is close to the center of the scale.

2. Taking care to avoid all transverse oscillations (such as lateral swing or wobble), the disk is rotated slightly to give a small torque and left free to undergo torsional oscillations. By measuring the time of 25 oscillations, the time period of the pendulum

T is found. Repeat this step once more and take the mean value of T.

3. The given metallic ring is placed flat on the disk, so that it's center is as close as possible to the axis of suspension. The time period of the pendulum T' is now found by the procedure described above. The mass of the ring, and the outer and inner diameters (d_1 and d_2) of the ring are measured. Make observation tables for these measurements. (The ring may not be exactly circular: therefore measure the diameter along different directions and take the average value). Using these two measurements and Eq.(6) the moment of inertia I of the pendulum can be calculated. The ring can now be removed and is not required in the rest of the experiment.

4. To measure the logarithmic decrement, the disk is again set into torsional oscillation. When the amplitude has fallen to approximately the full scale reading, start the readings by noting down the reading on the scale at one extreme position, B_1C_1. The very next reading at the outer turning point B_2C_2 is then recorded (see Fig.1).

5. After 20 complete oscillations, again record the maximum amplitudes on both sides $B_{41}C_{41}$ & $B_{42}C_{42}$. The logarithmic decrement in air can now be found by using these readings and Eq.(3) for 20 oscillations (i.e., for n=20) as,

$$\lambda_0 = \frac{1}{40} \ln \left(\frac{B_1C_1 + B_2C_2}{B_{41}C_{41} + B_{42}C_{42}} \right) \tag{16.7}$$

In general, if n is the number of oscillations, then the logarithmic decrement is the given by

$$\lambda_0 = \frac{1}{2n} \ln \left(\frac{B_1 C_1 + B_2 C_2}{B_{2n+1} C_{2n+1} + B_{2n+2} C_{2n+2}} \right) \tag{16.8}$$

Repeat the procedure for 30 and 40 oscillations to calculate λ_0. Take the mean value of λ_0 to obtain the logarithmic decrement.

6. A clean glass dish is now placed so as to contain the disk, and water is poured into it so as to cover the disk but not submerge the mirror (see Fig.2). The equilibrium position of the light spot is now adjusted (if necessary) so that it again lies at the center of the scale. The same procedure (as that to find the logarithmic decrement in air) is now repeated to find the logarithmic decrement λ in water. Since the oscillations in this case are very much damped, the experiment has to be performed for smaller number of oscillations.

Tabulate the observation for air and water as shown in Table 1 and Table 2.

7. Using the data measured above, and the dimensions of the disk equation (4) is used to find the viscosity of water. The temperature of the water used must be measured and quoted along with the result.

Observations:

Least count of vernier caliper used =
Least count of stop watch =
Least count of balance used =

Radius of the disk, r =
Thickness of the disk, d =
Outer diameter of the ring, d_1 =
Inner diameter of the ring, d_2 =
Average radius of the ring, a =
Mass of the ring, m =
Temperature of water =
Time required for 25 oscillations in air =
Time period in air, T =
Time required for 25 oscillations in air with ring =
Time period in air with ring, T' =

Table 16.1: Readings for finding logarithmic decrement in Air

Trial number	Serial no. of oscillation		Maximum Amplitude Left(B_iC_i) Right(B_{i+})C_{i+1})	λ_0 {using Eq.(8)}
1	Start	(i= 1)		
	n = 20	(i = 41)		
2	Start	(i= 1)		
	n = 30	(i = 61)		
3	Start	(i= 1)		
	n = 40	(i = 31)		

Calculate the maximum probable error $d\eta$ and write down the precautions and sources of error.

Result:

The viscosity of water was found to be ________ poise, at a temperature of ________degrees centigrade.

Table 16.2: Readings for logarithmic decrement in Water

Trial number	Serial No. of oscillation		Maximum Amplitude Left (B_iC_i) Right ($B_{i+1}C_{i+1}$)	λ {using Eq.(8)}
1	Start	(i= 1)		
	n = 5	(i = 11)		
2	Start	(i= 1)		
	n = 10	(i = 21)		
3	Start	(i= 1)		
	n = 15	(i = 31)		