NATIONAL OPEN UNIVERSITY OF NIGERIA

SCHOOL OF SCIENCE AND TECHNOLOGY

COURSE CODE: PHY141

COURSE TITLE: BASIC EXPERIMENTS IN PHYSICS

Course Code	PHY 141
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BASIC EXPERIMENTS IN PHYSICS

Course Guide

Course Introduction

In the course Basic Apparatus in Physics, you have become acquainted with the basic apparatus found in a school or college physics laboratory. You have learnt about their working and the precautions you need to take while using them. You will now actually work in the lab and perform experiments using this apparatus. Though it will come with experience, an important thing about the laboratory work is your attitude towards it. The time you spend in the laboratory can be rewarding depending on how you approach your work. You can take it as an opportunity to handle different apparatus, learn how to classify them according to their use, identify defects in different equipment, correct the identified defect, and design simpler and easy to manage equipment. Then you will enjoy your work. In lab work, it helps to have an open mind!

To get the maximum benefit from this course, you are advised to read the write-ups carefully and go prepared to your laboratory. You should have an idea of the physical principle involved in the experiment you do on any particular day. For this, you may like to go back to Block 1 and read the relevant sections. This understanding will help you in performing the experiment better.

While in the laboratory, you will work with many instruments, some of which may be expensive and delicate. Handle them carefully – and whenever you are not sure, observe restraint and consult your counsellor. Set up the apparatus as per the directions given in this course material. Take help from your counsellor, if need be.

When you are in the physics laboratory, you should observe good practices. You have learnt about these in earlier laboratory courses. For brevity, we list some simple rules:

- Wear proper footwear in the laboratory.
- Do not smoke or eat while in the laboratory.
- Act in an orderly manner.
- Handle the equipment with proper care. Do not fiddle with the equipment
- not intended for your use. **You are liable for damages** caused **by your** negligence.
- Report breakage to your counsellor/instructor so that repair or replacement may be effected without delay.
- Get all electrical circuits checked by your counsellor before switching on the supply voltage.
- Return/replace apparatus and clean up your table before leaving.

In this course we have given the introduction, aim and procedure in detail for all experiments. But you are expected to become less dependent on the print material as you progress through the course. In some experiments we expect you to gain skills in handling instruments. In others, you will gain hands-on experience of taking observations, making calculations and fabricating simple apparatus.

We would like to make it clear at the outset that you will not necessarily be judged on how well your results agree with the standard value. What is important is that your conclusions are based on your observations and that these are consistent.

You should keep a practical notebook for recording your observations and difficulties faced while doing the experiment. **Record all your measurements in ink directly in your practical notebook; do not use a loose sheet**.

Your practical notebook is a permanent record of your work. If a mistake has been recorded, strike it out and write the correct reading; do not write over your mistake.

We have observed that some students begin to make calculations as soon as they have recorded the first observation and that too in a rough sheet. This is not a good laboratory practice and you will be penalised if you are found doing so. Do calculations only after completing your experiment.

You should present your report in the following format for each experiment:

- Aim of the experiment
- Formula used/Principle involved
- Line diagram of the experimental set up/circuit
- Observations
- Precautions observed
- Results and analysis

You will be required to do a total of 9 experiments in the physics laboratory in 12 sessions spread over 6 days. Each day you will have to work for two sessions of 4 hours each. The final exam for the practicals will be held on the seventh day.

You will be assessed for each experiment even while you are doing it. The marks you so obtain will count towards your final score. The weightage of continuous and term-end evaluation in the final score is 50:50.

Each experiment will, in general, be assessed with regard to:

how skilfully you handle the apparatus, and take care of it,
how well you set up and do the experiment, and
how you answer the questions based on the experiment, if any.

A more specific break-up of marks for each experiment is given in the appendix at the end of the block.

If you are employed in a college laboratory, you can opt to be a Mode-1 student. In that case, you can perform experiments 1,2,3,4,7 and 8 at your work place. You must follow the instructions given below.

Specific instructions for Mode-1 learners

- You must complete these experiments in 3 days, i.e., 6 sessions of 4 hours each. You will be attached to a Resource Person from your work place who will guide you and assess your work.
- You must make your copy of Blocks 1 and 2 of this course available to the Resource Person for reference purposes, if need be.

- You must also bring to the attention of the Resource Person the details of experiments 1,2,3,4,7 and 8 and their assessment criteria.
- For all experiments you must maintain a complete record in your practical notebook. Each of these should be assessed and signed by the Resource Person.
- You will perform the remaining experiments at the Study Centre allotted to you. **You should remember to carry with you the following items to the Study Centre:**

    - Blocks 1,2 and your practical note book containing the complete record of your work which you will have to show to your counsellor, and

    - the duly signed original copy of the marks list for the practicals performed at your work place. **The marks list must be signed by the Resource Person and countersigned by the Head of the Institution**.

Mode 2 learners will perform **all** experiments at the study centre allotted to them. All experiments will be assessed continuously by the counsellor at the study centre.

EXPERIMENT 1
MEASUREMENTS IN PHYSICS

Structure

1.1 INTRODUCTION

You know that in almost every physical situation, there is a need for measurement. Length and time measurements are the primary requirements in physics and various devices have been developed for their precise measurement. When we wish to know the dimensions of a room or a piece of land, we use a measuring tape. And we use a metre scale when we buy some cloth. We hope that you are familiar with such measurements and must have seen and perhaps used a measuring tape or a metre scale.

In the lab, however, you will need to measure small lengths, say that of a wooden block or thickness of a metallic needle. These require accuracy better than that obtained from a metre scale; of the order of 0.01 cm or even less. This means that devices such as a tape or a metre scale, though useful, cannot be relied upon in scientific work. For measuring short lengths, we use devices like vernier callipers and screw gauge, depending on the accuracy required. In this exercise, you will get an opportunity to work with both these devices. Even while working with these devices you will observe that

- no measurement can be more accurate than the precision of the measuring instrument; and
- there is a limitation on the accuracy with which data can be taken.

This means that **a measurement can never be exact** and there will always be deviations from the true value. That is, some uncertainty (error) is always present in every measurement. So before you make measurements with any instrument, you must have a clear idea of the concept of errors. (You will discover that we always quote the result along with the error.) One way of depicting the relationships between various measurable physical quantities in an experiment is through graphs. Graphs also enable us to minimise errors and simplify calculations. For this reason, we discuss errors and graphing in Sec. 1.3. In the next two sections, you will learn to measure the thickness of a wooden block and a sheet using a vernier callipers and a screw gauge, respectively.
In the next experiment, you will learn how stringed instruments produce music and determine the frequency of a tuning fork. This exercise will give you an opportunity to use a physical balance to measure another fundamental quantity - mass.

1.2 AIM

The purpose of this experiment is to make you learn how to measure small lengths correctly and estimate uncertainties in your measurements. In doing this you will learn to use a vernier callipers and a screw gauge. Therefore, in this laboratory session, you have to use both these devices.

After you have completed this experiment, you should be able to:

- appreciate that the accuracy of a measurement is limited by the instrument used;
- calculate percentage error;
- draw a graph between any two measurable physical quantities;

- use a vernier callipers to determine the thickness of an object;
- use a screw gauge to determine the thickness of a wire or sheet; and
- take care of and maintain a vernier callipers and a screw gauge.

The apparatus required for this experiment is listed below.

Apparatus

Vernier-callipers, screw gauge, bob of a pendulum or wooden block and metallic wire/needle.

1.3 ERRORS IN MEASUREMENT

We take measurements with the help of instruments. The accuracy of a measurement depends on the precision of the measuring instrument. For example, if we measure the length of this book using a metre scale which has graduations at 1 mm interval, our reading would be good only up to 1mm. Similarly, if we use a more precise device like vernier callipers to measure its thickness, the measurement may be good up to 0.1 mm.

Two types of errors are involved in data collection:

(i) **Systematic errors**: Systematic errors are mostly due to the instruments used in a measurement. These arise due to factors such as incorrect calibration of the instrument, incorrect use, end error, zero error, etc. If the zero marking of the metre scale used to measure the length of the book is worn out by 2 mm and is used as the "zero" of the scale, the measurement would have a systematic error of 2 mm.

Usually, we can identify the causes of systematic errors and minimise or correct them. The ability to detect and remove systematic error is very important in measurements.

(ii) **Random errors:** Random errors arise from various accidental errors in the measurement process. For example, in measuring the dimensions of a basketball court, you may make a mark slightly to the left or right of the exact length and/or breadth. This will introduce an error in the reading. And if you repeat your measurements, you may not obtain the same value. That is, the readings show a scatter, as shown in Fig. 1.1.

Fig. 1.1 Random errors lead to a scatter of readings

To minimise random errors, you should repeat measurements many times and take their (arithmetic) mean as the best value of the measured quantity.

If the values obtained in N measurements are a_1, a_2, …, a_N, the best value is determined as

$$a_{mean} = \frac{a_1 + a_2 + ... + a_N}{N} \tag{1.1}$$

SAQ 1: Classification of errors

Classify the following measurements according to the type of error involved by putting a tick in the appropriate column:

Measurement	Type of error	
	Systematic	Random
1. You travel from your home to your Study Centre at 9 AM every Sunday. The time you take to cover this distance is measured each time.		
2. The length of a needle is measured by several students in a laboratory.		
3. The needle of a voltmeter is so bent that it does not rest on zero.		

From the above discussion you may conclude that errors can be introduced by:

- the inherent limit on the precision of the measuring instrument; and
- your skill, judgement and perception.

You will agree that if inexact measurements are used in calculations, some error, (uncertainty) in the result is inevitable. That is why the magnitude of the estimated uncertainty determines

- the quality of a measurement; and
- reliability of result obtained.

In scientific work, it is customary to quote a result along with its associated uncertainty (with proper units and up to the same order-of-magnitude). Before proceeding further, go through Example 1 on relative and absolute errors.

Example 1: Relative and absolute errors

Audu measures the period of oscillation of a simple pendulum. The recorded readings in successive measurements are 2.60s, 2.59s, 2.62s, 2.65s, and 2.66s. The mean period of oscillation of the pendulum is therefore

$$T = \frac{(2.60 + 2.59 + 2.62 + 2.65 + 2.66)}{5}$$

$$= \frac{13.12}{5} \text{ s} = 2.624 \text{ s} = 2.62$$

Note that we have dropped the last digit. This is because the periods have been measured only to the second decimal. So it is only logical to report the mean value of the period to the second decimal.

The absolute errors in the measurements are:

$\Delta t_1 = 2.60 - 2.62 = -0.02$ s

$\Delta t_2 = 2.59 - 2.62 = -0.03$ s

$\Delta t_3 = 2.62 - 2.62 = 0.00$ s

$\Delta t_4 = 2.65 - 2.62 = +0.03$ s

$\Delta t_5 = 2.66 - 2.62 = +0.04$ s

Note that the absolute errors have the same units as the quantity to be measured. Since errors are cumulative, the arithmetic mean of all the absolute errors is:

$$\Delta t_{mean} = \frac{0.02 + 0.03 + 0.00 + 0.03 + 0.04}{5}$$

$$= \frac{0.12}{5} \text{ s} = 0.02 \text{ s}$$

That is, the period of oscillation of a simple pendulum is 2.62 ± 0.02s and the actual value lies between 2.64s and 2.60s.

A better index of the accuracy of a measurement as well as the precision of an equipment is the relative error or the percentage error. It i*s equal to the ratio of the absolute error to the mean observed value of the quantity expressed in percent:*

$$\% \text{ error} = \frac{\text{absolute error}}{\text{mean observed value}} \times 100$$

To determine the percentage error, you should first calculate the arithmetic mean of measured values and then calculate the required ratio. It will enable you to determine the uncertainty so that (average ± uncertainty) covers all or most of the readings. For this example, the percentage error is

$$\delta a = \frac{0.02}{2.62} \times 100 = 1\%$$

We know that the laws relating physical quantities can be expressed in words, mathematically or graphically. A graph is a pictorial representation of one quantity with respect to another. You will now learn why and how to draw graphs.

1.3.1 Graphing

Graphs enable us to visualise how two related physical quantities behave under given conditions. Graphs can also be used to minimise errors or locate inaccurate results. A graph is not a game of joining the dots!

A straight-line graph is the easiest (Fig. 1.2). The equation for a straight line is $y = mx + c$, where m is the slope (gradient) and c is the intercept on the y-axis. In Fig. 1.2, the gradient or slope of the straight line is given by

$$m = \tan\theta = \frac{BC}{AC}$$

and OP is its intercept.

If $y = Ax^n$; where A and n are unknown, we take the logarithm of both sides to express the given function as a straight line:

$$\log y = n\log x + \log A$$

If we now draw a graph of log y as a function of log x, we obtain a straight line with gradient n and intercept log A.

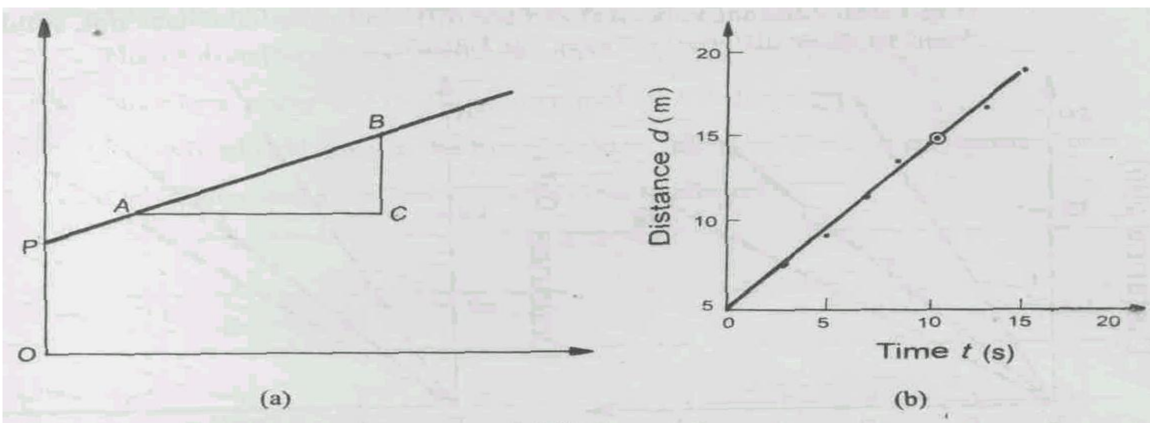


Fig. 1.2 A straight line graph

When drawing graphs, you must observe the following points:

(i) Identify the independent and dependent variables. It is customary to plot the independent variable along the x-axis and the dependent variable along the y-axis.

(ii) You should choose the scales so that the points are suitably spread out on the entire graph paper rather than being cramped into a small portion. Note the minimum and maximum values of the data to be plotted. Then round off these numbers to slightly less than the minimum and slightly more than the maximum. The resulting difference should be divided by the number of divisions on the graph paper. For example, if you are to plot 6.4 cm and 18.7 cm, it would be convenient to allow the scale to run from 5 cm to 20 cm rather than 0 to 19 cm (see Fig. 1.3).

(iii) Draw **axes** clearly and write the **name** of the physical quantity to be plotted, its symbol, unit and the scale used along each axis.

(iv) Use a plotting symbol such as a dot and encircle it to show the measured position of points. In no case should the size of this circle exceed the size of the smallest square on the graph paper.

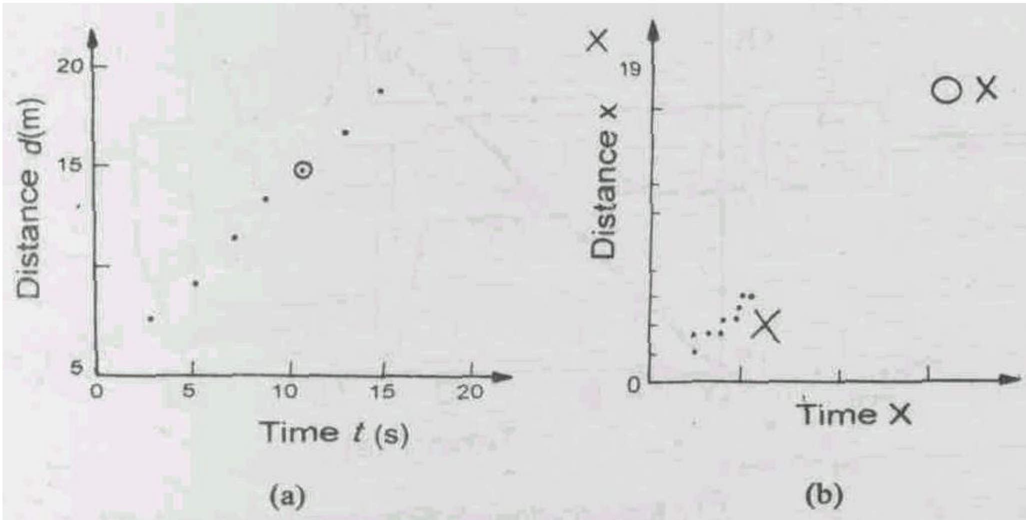


Fig. 1.3 Some (a) Dos and (b) Don'ts to be kept in mind while drawing a graph

(v) You should give the graph a suitable **caption.**

(vi) If there is more than one curve on the graph, label different curves (Fig. 1.4a). Alternatively, you can use different notations (dash dot, solid, dash) to show different curves (Fig. 1.4b).

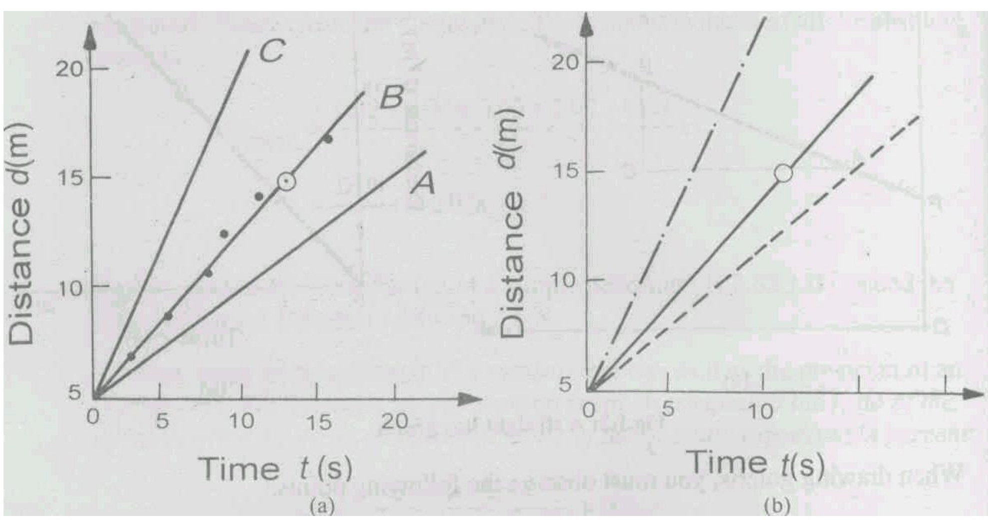


Fig. 1.4 Drawing graphs with more than one curve

(vii) The curve drawn should be the simplest mean curve that fits the data. In the graph shown below (Fig. 1.5), it is easy to see this would be a straight line. Note that the line may not necessarily pass through each observed point. However, it should pass through the region of uncertainty for each point.

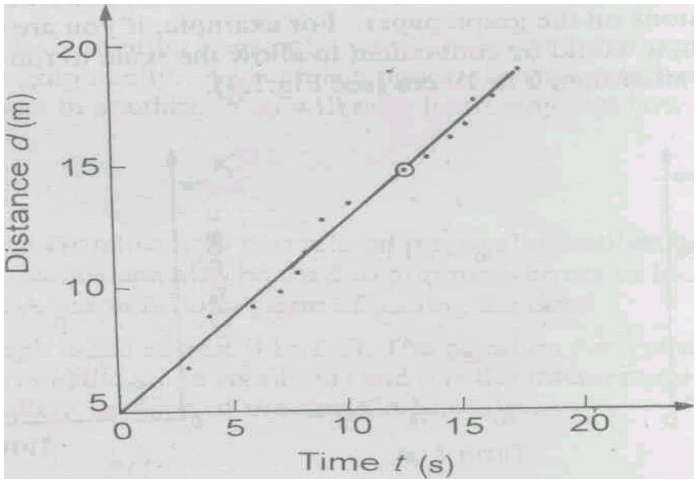


Fig. 1.5 A mean fit curve

1.4 MEASUREMENT OF THE THICKNESS OF A WOODEN BLOCK

Before you perform the actual experiment, it is important for you to be familiar with a vernier callipers (Fig. 1.6). In Unit 4 of the course Basic Apparatus in Physics, you have learnt about it in detail. You should re-read the relevant section of the unit and do the following activity:

- Identify the main scale (MS) and the vernier scale (VS) on the callipers and write the number of divisions on VS:

  No. of divisions in the vernier scale =..

- Note how many of MS divisions equal all VS divisions:

..... No. of divisions in the main scale = ... No. of division on vernier scale

- Calculate the least count of your vernier callipers:

____

____

____

____

You should now follow the steps listed below to measure the thickness of the given block:

1. Bring the jaws of the vernier callipers in contact and note whether or not the zeros of the VS and MS coincide. **In case they do not coincide, do not achieve coincidence forcibly. Doing so may damage the callipers further.** Note the zero error and record it in Observation Table 1.1. You may recall that zero error, whether positive or negative, is always subtracted from each measured value.

2. Record the least count in Observation Table 1.1.

3. Hold the block/bob between the jaws, as shown in Fig. 1.6.

4. Slide the vernier scale so that the jaw of the vernier scale touches the other end of the block.

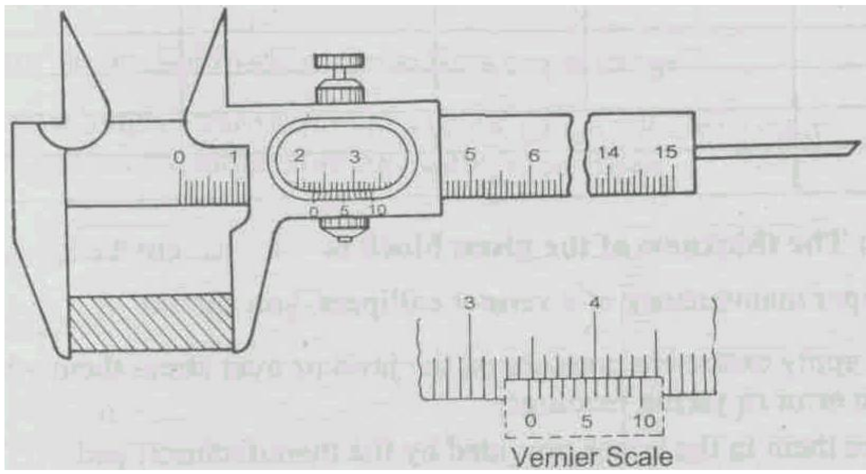


Fig.1.6 Measurement of the thickness of a block with a vernier callipers

5. The position of the zero mark of the vernier scale, as read on the main scale, gives the thickness of the block. If the zero mark of VS corresponds exactly to any particular marking on the MS, read the main scale. This reading gives the thickness of the block. If however the zero mark on the vernier scale is in-between the two markings, say between 3.4 cm and 3.5 cm, then the thickness of the block is more than 3.4 cm (called the main scale reading), but less than 3.5 cm. How much more it is than 3.4 cm can be found by noting the division on the VS that coincides with a MS division. If the sixth division on the VS coincides with a MS division, the thickness of the block would be 3.4 cm + 6 $\times$0.01 cm = 3.46 cm.

   In general, the distance between the two jaws of the vernier callipers is given by:

   (MS reading + vernier reading $\times$ least count)

   Record your reading in Observation Table 1.1. The graduations on the vernier scale are very fine and close together. Therefore, you may find it convenient to use a magnifying glass.

6. Repeat the process at least four times. You may ask as to why we are asking you to take so many readings. The reason for this exercise is to minimise random errors,

7. Subtract the zero error, if any, from each measured value to obtain the correct value.

8. Calculate the mean of corrected values. This will give you the thickness of the given block.

9. Calculate the percentage error using the procedure explained in Sec. 1.3 and quote your result accordingly.

Note that vernier reading is just a number, while MS reading is a measure of length.

Least count of the vernier callipers =
Zero error of the vernier callipers = ± cm

Observation Table 1.1: Measurement of thickness

S.No.	MS reading (cm)	Vernier reading	Thickness(cm)	
			Measured (=MS+LC$\times$VS reading)	Corrected (Measured value -Zero error)
1.				
2.				
3.				
4.				
5.				
:				

Result: The thickness of the given block is .... cm ±.......... cm

For proper maintenance of a vernier callipers, you should

- not apply excessive pressure on the jaws or over stress them while noting zero error or taking readings;
- store them in the boxes provided by the manufacturer; and
- make sure that no part jams or is rusting.

On completing this experiment, you will discover that a vernier callipers can be used to measure lengths in the range 0-15 cm with an accuracy of 0.01 cm. From Unit 3 of Basic Apparatus in Physics, you will recall that when we need accuracy more than that obtained with vernier callipers, we use a screw gauge. In the next part of this experiment, you will work with a screw gauge.

1.5 MEASUREMENT OF THE THICKNESS OF A SHEET

Refer to Fig. 1.7, which shows a screw gauge. You will recall from Unit 3 of Basic Apparatus in Physics, that in a screw gauge, a screw moves in accurately cut grooves. But with constant use, there comes some wear and tear. As a result, it is also possible that there may not be forward linear motion of the screw until a certain rotation is given to the circular head. This lagging behind of linear motion with circular motion is called **back-lash error**. To avoid this, **you should always move the screw gauge in the same direction.** While handling a screw gauge, other important points to take note are:

- keep the spindle and the anvil clean. This will help in avoiding false readings;
- do not overtighten the gauge; and

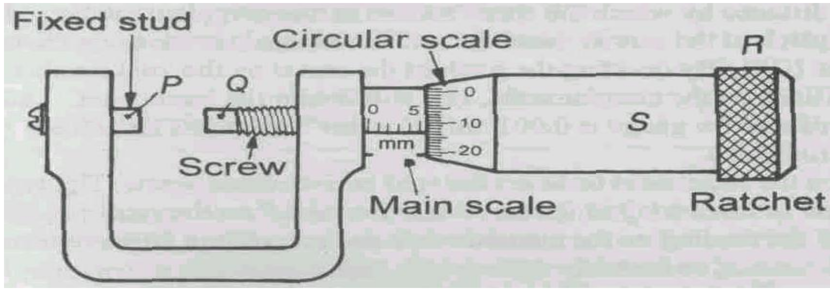
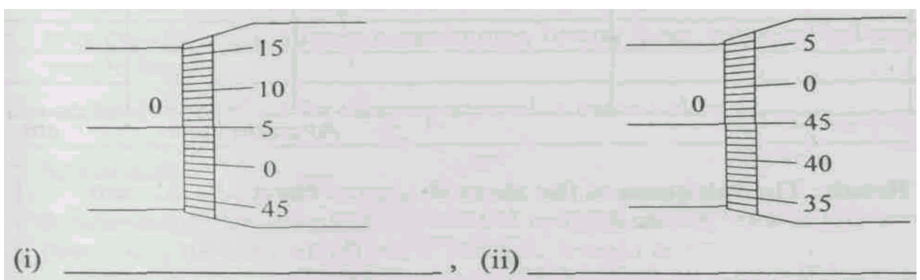


Fig. 1.7 Measurement of thickness with a **screw gauge**

- adjust the screw gauge to the point where it should read zero. In case it reads different, note the error. Like a vernier callipers, a screw gauge can also have positive or negative zero error. You will be required to apply zero correction by subtracting the zero error from each observed value. (For details see Unit 3 of Basic Apparatus in Physics.)

You should now do the following exercise for a screw gauge.

The figures below indicate zero errors in a screw gauge with least count 0.001 cm. Write down the initial readings with proper signs.



We hope you can now confidently work with a screw gauge and take necessary precautions while making measurements. As before, you should follow the steps listed below to measure the thickness of the given sheet:

1. Take a screw gauge and see whether or not its ratchet functions properly. If not, change the screw gauge. In case no other screw gauge is available, check that it is free from back-lash error.

2. Note the length of the smallest division on the linear scale and record it in Observation Table 1.2. Rotate the screw through ten complete rotations and note the distance advanced on the screw. From this, you can calculate the distance by which the screw moves in one complete rotation. This is the **pitch** of the screw. Note the total number of divisions on the circular scale (CS). By dividing the pitch of the screw by the total number of divisions on the circular scale, you will obtain the least count. Usually, the LC of a screw gauge is 0.001 cm. (For this reason it is also called micrometer.)

3. Place the slide/sheet between the stud and movable screw. Tighten the screw so that end *Q* of the screw touches end *P* on the stud.

4. Note the reading on the circular scale and record it in Observation Table 1.2.

5. Repeat the above step at least six times by taking the thickness at different places. In this way, you can account for non-uniformity of the sheet.

   Record all your observations in Observation Table 1.2.

6. Subtract the zero error, if any, from each measured value. Calculate the mean value of the thickness of the given sheet.

7. Calculate percentage error and record your result as before.

Observation Table 1.2: Measurement of thickness

The length of the smallest division on the linear scale = mm
Distance advanced by the screw when it is given ten rotations = mm
Pitch of the screw = mm
Number of divisions on the circular scale (TV) =
Least count of the screw gauge, $\frac{Pitch}{N}$ = mm
Zero error = ± mm

S.No.	Linear scale reading (cm)	Circular scale reading x LC (cm)	Thickness (cm)	
			Measured	Corrected

Average value = cm

Result: The thickness of the sheet is .... cm ± .... cm

EXPERIMENT 2
STATIONARY WAVES IN STRETCHED STRINGS

Structure

2.1 INTRODUCTION

We all know that stringed instruments like guitar, violin, harp or bongo produce pleasing music. Have you ever thought how these instruments produce music? When a string in such an instrument is made to vibrate by bowing or plucking, it produces sound. The quality of sound so produced depends on the frequency of vibration of the string. You may now logically ask: What determines the frequency of vibration of a stretched string? In Unit 3 of Basic Apparatus in Physics, you have learnt that this frequency depends on the tension in the string, its mass per unit length and its vibrating length. In this experiment you will determine the frequency of a tuning fork. For this, you will first set up stationary waves in a sonometer wire and then determine that length of the wire which vibrates with the frequency of the given tuning fork. In this experiment, you will also be required to use a physical balance to measure mass.

In the next experiment you will learn to determine thermal properties of materials. This will involve measurement of yet another fundamental physical quantity – temperature

2.2 AIM

The aim of this experiment is to give you practice in measurement of mass and resonating length for determination of the frequency of vibration of a tuning fork.

After you have completed this experiment, you should be able to:

- set up stationary waves in a sonometer wire;
- obtain unison between the given tuning fork and sonometer wire;
- measure mass using a physical balance;
- determine the frequency of a given tuning fork; and
- take care of and maintain a sonometer, tuning forks, physical balance and weight box.

The apparatus required for this experiment is listed below.

Apparatus

Sonometer, ½ kg hanger, ½ kg slotted weights, tuning fork of unknown frequency, rubber pad, physical balance, weight box.

2.3 SETTING UP STATIONARY WAVES IN A SONOMETER WIRE

The experimental arrangement to set up stationary waves in a sonometer wire is shown in Fig.2.1. You have learnt about a sonometer in Unit 3 of Basic Apparatus in Physics.

A kink free wire, pegged at one end passes over two wedge-shaped wooden bridges, BI and B*2*. The other end of the wire passes over a smooth pulley and carries a hanger. At this stage, the tension in the wire is equal to the weight of the hanger. (If the pulley is not frictionless, you may oil it.) The distance between the bridges can be changed on adjusting their positions by sliding them on the sounding board of the sonometer.

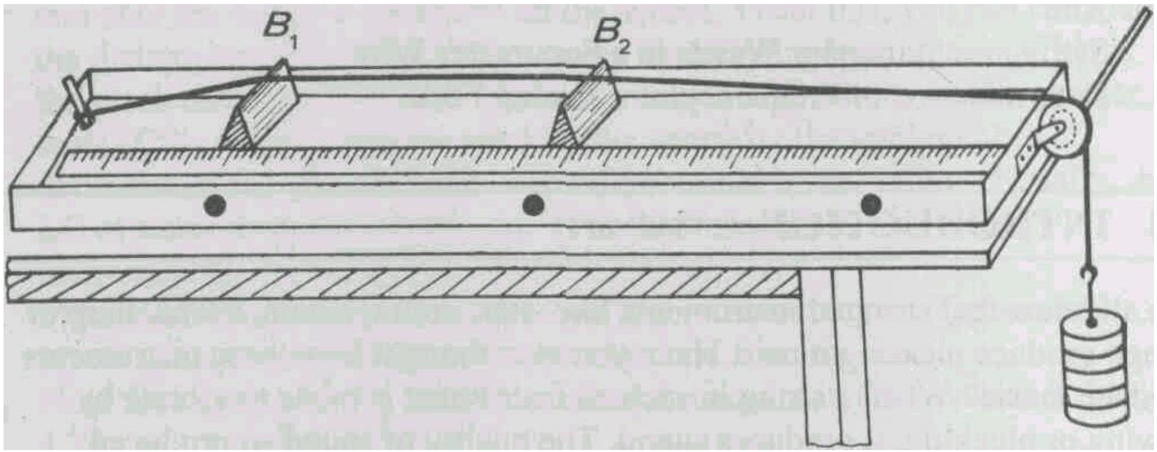


Fig. 2.1 Experimental arrangement for setting up stationary waves in a sonometer wire

Now follow the steps listed below:

1. Note the least count of the metre scale and record it in Observation Table 2.1.

2. Stretch the wire by putting a 0.5 kg mass in the hanger. The tension in the string will be increased by 0.5g newton, where g is acceleration due to gravity.

3. Keep the bridges of the sonometer at a distance of about 20 cm. Now make a V-shaped light paper rider and place it on the string mid-way between the bridges.

4. Strike one of the prongs of the given tuning fork against a rubber pad. The tuning fork will begin to vibrate. Place its lower end on the sounding board of the sonometer. What happens to the length of the sonometer wire between the bridges? Does it begin to vibrate? If so, you have produced stationary waves in it. The positions of the bridges are the nodes. If the wire does not vibrate, adjust the position of bridges and again put a vibrating tuning fork on the sounding board of the sonometer. Go on doing so till the wire begins to vibrate. You can increase the amplitude of vibrations proceeding in this way.

We will now use this arrangement to determine the frequency of the tuning fork.

2.4 DETERMINATION OF FREQUENCY OF A TUNING FORK

1. Place a V-shaped paper rider in the middle of the bridges and repeat step 4 of Sec. 2.3. What happens to the paper rider when the wire vibrates? You may note that it jumps up and down but does not fall. It means that the wire is not vibrating with maximum amplitude.

2. Keeping one of the bridges, say B_1 fixed, move the other bridge towards it by a small distance and again place a vibrating tuning fork on the sounding board. Does the amplitude of vibration of the wire/rider increase or decrease? If it increases, does the paper rider fall? If not, further bring the bridge B_2 closer to B_1. On the other hand, if the vibrations decrease, move B_2 away from B_1. Again place the vibrating tuning fork on the sonometer board and continue to do so till you see the paper rider fall.

In this state, the amplitude of vibration is maximum and the wire segment between the bridges has the same frequency of vibration as the tuning fork. The wire segment is said to be in **unison** with the tuning fork and the length of the wire segment is termed the **resonating length.** Measure the distance between the bridges accurately and record it in Observation Table 2.1. The smallest length for which the rider falls corresponds to the fundamental mode of vibration of the string segment. The frequency corresponding to this mode is given by

$$f_0 = \frac{1}{2l}\sqrt{\frac{T}{m}} \tag{2.1}$$

where T is the tension in the string, m is mass per unit length, and l is the length of the wire between the bridges corresponding to the fundamental mode.

Note the mass put on the hanger and enter the reading in the Observation Table 2.1.

Observation Table 2.1: Frequency of a tuning fork

Least count of the metre scale = cm

S. No.	Mass on the hanger (kg)	$T=mg$ (N)	Length (l) of the wire between the bridges in unison with tuning fork when (cm)				Mean l (cm)	l^2 (cm^2)
			increasing mass		decreasing mass			
			bridges are initially far apart	bridges are initially closer	bridges are initially far apart	bridges are initially closer		
1.								
2.								
3.								
4.								
5.								

3. Next, you obtain the condition of unison by initially keeping the bridges closer, separated by say 10 cm, and moving them apart. Again enter your reading in Observation Table 2.1.

4. Change the tension in the wire by adding another 0.5 kg mass on the hanger and determine the resonating lengths of the wire keeping the bridges initially far apart as in Step 2 above. Record your data, as before.

5. Repeat Step 3 for this tension.

6. Repeat Steps 4 and 5 at least five times by adding masses in steps of 0.5 kg. However, you should not exceed the elastic limit of the wire.

7. To check that you are working within the permissible elastic range, you should repeat the above said procedure by decreasing tension in the wire. For this you should remove masses in equal steps and each time obtain the resonating length. Tabulate your readings in each case.

   Do these lengths differ from those measured while loading the wire? We expect these to-be almost the same. If the difference is significant, discuss the possible reasons with your counsellor.

8. Calculate the mean resonating length for each tension.

9. Plot T along the x-axis and l^2 along y-axis. You should obtain a straight line graph. Using the procedure described in Sec. 1.3.1, calculate the slope of the straight line.

To determine the frequency of the tuning fork, we must also know mass per unit length of the sonometer wire. You can do so using a physical balance.

A. Determination of mass per unit length of sonometer wire

Take a wire of one metre length; it must be of the same material and thickness as the one used in the sonometer. It has to be weighed in a physical balance. For correct weighing, follow the steps listed below:

1. Clean the pans of the balance and make sure that they are dry.

2. Adjust the levelling screws so that the plumb line is in proper position.

3. Close the shutter and turn the knob. The index pointer should oscillate equally about the equilibrium position of the graduated scale. Otherwise, adjust the screw nuts at the ends of the beam till this is achieved.

Now the physical balance is ready for use.

4. Put the wire in the left pan and add weights in the right pan with the help of forceps.

5. Raise the beam slowly and observe the swing of the index pointer. If it goes towards the left, then you have to add more weights. So lower the beam to its resting position using the knob. Add more weight and raise the beam again. Repeat this exercise till the pointer remains in the equilibrium position on raising the beam. If initially the pointer goes to the right, you will have to decrease weight and attain the equilibrium position by putting appropriate weights. When the equilibrium position is attained, the value of the weights put on the right pan gives the mass of the wire.
6. Take out the weights one by one and count them. Make your Observation Table 2.2 and record this reading in it. Repeat the measurement 5 times and record it each time in Observation Table 2.2. Calculate the average value. You can now determine the mass per unit length of the wire, by dividing this mean value by the length of the wire, which is 1m.

You should take care of the following:

- When the tuning fork is vibrating, you should not touch its prongs.
- Always use forceps to add or remove weights from the pan.

- Always lower the beam to its resting position before adding or removing weights.
- The shutter of the balance should be kept closed while raising the beam.
- When you have completed the experiment, lower the knob of the physical balance, and return the tuning forks and the weights to their respective boxes.

B. Calculation of the frequency

From Eq. (2.1), we can write

The inverse of the slope of the graph l^2 vs. T gives the value of $\frac{T}{l^2}$. Using the maximum possible intercept on the graph, calculate the slope. The frequency of the tuning fork can be determined using the relation

$$f_0 = \frac{1}{2\sqrt{\mathrm{m} \times \text{slope of the graph}}}$$

Observation Table 2.2: Measurement of mass per unit length

Calculate the % error using the procedure outlined in Experiment 1.

Result: The frequency of the given tuning fork is .... Hz ± .... Hz

EXPERIMENT 3
MEASUREMENT OF THERMAL PROPERTIES

Structure

3.1 INTRODUCTION

It is common experience that a hotter body loses its thermal energy to another body or its surroundings and becomes cold. A cold body needs energy to become warmer. Do you know the factors on which the amount of thermal energy required to heat a body depends? Experiments show that the thermal energy required to raise the temperature of a substance depends on its mass, nature and rise in temperature. Mathematically, we express this statement as $\Delta Q = mc\Delta T$. It means that for the same increase in temperature, a unit mass of different substances requires different amounts of thermal energy. That is, the value of *c* depends on the nature of a substance. This property characterising any substance is expressed in terms of its **specific heat capacity.** From your school physics, you may know that the specific heat capacity of a substance is defined as the quantity of thermal energy (in joule) required to raise the temperature of 1kg of a substance through 1°C. It is measured in units of $\mathrm{Jkg^{-1}K^{-1}}$.

You also know that most substances expand on heating and contract when cooled. The extent of expansion (contraction) depends on the nature, shape and size of the substance. It is quantitatively expressed in terms of the coefficient of cubical, superficial or linear expansion. For a solid in the form of a rod or a wire, the change in its length with temperature is easier to observe. Though small, particularly for solids, we can measure this change accurately using a spherometer, a microscope or a telescope and an optical lever arrangement. Here we have used the third option. Depending on the apparatus available, your counsellor will advise you how to work with other equipment.

This experiment consists of two parts; in the first part you determine the specific heat capacity of water and in the second part, you determine the coefficient of linear expansion of a metallic rod. However, you are required to perform only one of these, depending on the availability of the apparatus in the laboratory. You will realise that determination of these two physical quantities involves accurate measurement of temperature and length - two of the seven fundamental physical quantities.

In the next experiment you will make some investigations with a concave mirror and a convex lens and determine their focal lengths.

3.2 AIM

The purpose of this experiment is to enable you to measure thermal properties of materials. In doing so, you will get an opportunity to handle thermometers, a calorimeter, linear expansion apparatus, and an optical lever.

After doing this experiment, you should be able to:

- use a thermometer to measure temperature;
- determine the value of specific heat capacity of water; and
- use the telescope and optical lever arrangement to measure very small lengths.

The apparatus required for this experiment is listed below.

Apparatus

Calorimeter with heating coil, a sensitive thermometer, stirring rod, DC power supply, stop watch, ammeter (0-5A), voltmeter (0-5V), rheostat, graph paper, capacitor, coefficient of linear expansion apparatus, metre scale, steam boiler, tripod stand, rubber tubing for steam delivery, burner, beaker, a metallic rod, telescope, optical lever, lamp and scale arrangement.

Before you perform the experiment you should know the basic principles involved. Here we discuss them in brief.

3.3 BASIC PRINCIPLES

You now know that the amount of heat required to raise the temperature of a body of mass *m* through ΔT, say from T to $T + \Delta T$, is given by

$$\Delta Q = mc\Delta T \tag{3.1}$$

where *c* is the specific heat capacity of the body. For some typical materials, the values of specific heat capacity are given in Table 3.1. Note that specific heat capacity of water is maximum. That is why temperature in coastal areas does not show much variation.

Table 3.1: Specific heat capacities of some common materials

Material	c ($\text{Jkg}^{-1}\text{K}^{-1}$)
Water	4186
Copper	389
Silver	234
Aluminium	207
Mercury	138
Lead	130

In order to measure the specific heat capacity of water, we use the principle of conservation of energy:

Heat lost by hotter body = Heat gained by colder body

If water in a calorimeter is heated for time Δt by passing current I through a heating coil of resistance *R* placed in it, the heat produced is given by

$$\Delta Q = I^2 R\Delta t \tag{3.2}$$

This heat is gained by water and the calorimeter. Thus

$$I^2 R\Delta t = (mc\Delta T)_w + (mc\Delta T)_c \tag{3.3}$$

where ΔT signifies the rise in temperature of water and calorimeter. The subscripts w and c denote water and calorimeter, respectively.

On rearranging terms, Eq. (3.3) takes the form:

$$c_w = \frac{I^2 R\Delta t - (mc\Delta T)_c}{(m\Delta T)_w}$$

$$= \frac{I^2 R\Delta t}{(m\Delta T)_w} - \frac{m_c c_c}{m_w}$$

$$= \left(\frac{I^2 R}{m_w (\Delta T / \Delta t)_w} - \frac{m_c c_c}{m_w} \right) \tag{3.4}$$

Table 3.2: Values of α_L for some typical materials

Material	$\alpha_L (K^{-1})$
Platinum	8.9×10^{-6}
Steel	1.2×10^{-5}
Nickel	1.3×10^{-5}
Copper	1.7×10^{-5}
Silver	1.9×10^{-5}
Aluminium	2.3×10^{-5}
Lead	2.9×10^{-5}
Zinc	3.1×10^{-5}

From Eq. (3.4) it is clear that once you measure I, R, m_w, m_c and $(\Delta T / \Delta t)_w$ it is possible to determine the value of specific heat capacity of water. Note that this experiment provides you an opportunity to measure three fundamental quantities – mass, temperature and current.

We now discuss the principle for determination of the coefficient of linear expansion.

Suppose that the length of a rod is l_1 at temperature T_1 and it becomes l_2 at a higher temperature T_2. You will recall that the increase in length is proportional to the rise in temperature. That is, $(l_2 - l_1) \propto (T_2 - T_1)$. It means that the proportional change in length is given by

$$\frac{l_2 - l_1}{l_1} \propto (T_2 - T_1) \tag{3.5}$$

This can be rewritten as

$$l_2 - l_1 = \alpha_L l_1 (T_2 - T_1) \tag{3.6}$$

where α_L is the coefficient of linear expansion and is expressed as fractional change in length per degree rise in temperature. It depends on the nature of the material (Table 3.2). You will note that in general, α_L has a value in the range of 10^{-6} to $10^{-5}\,\mathrm{K}^{-1}$.

We can now write the expression for the change in length of a rod as

$$\Delta l = l_1 \alpha_L \Delta T \tag{3.7}$$

where ΔT is the change in temperature.

Now that you have learnt the basic principles involved in the measurement of specific heat capacity and coefficient of linear expansion, you are ready to perform the experiments.

3.4 DETERMINATION OF SPECIFIC HEAT CAPACITY OF WATER

The procedure for the determination of specific heat capacity of water is given below.

1. Weigh the inner cup of the empty calorimeter.

2. Fill two-thirds of it with cold water and weigh it again. Subtract the mass of the calorimeter cup to obtain the mass of water. Record these measurements in Observation Table 3.1.

3. Place the calorimeter cup (with water), stirrer and a sensitive thermometer inside the empty can. Complete the circuit as shown in Fig.3.1. You should not switch the power on yet.

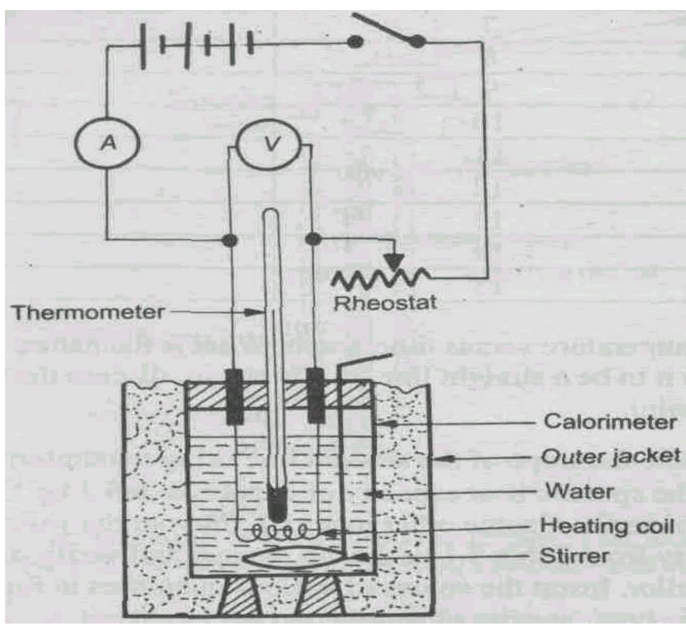


Fig.3.1 Experimental arrangement for specific heat capacity of water

4. Note the initial temperature of water as shown by the thermometer and record it in Observation Table 3.1.

5. Switch on the power supply and start the stop clock simultaneously. Adjust the power supply and rheostat until the ammeter reads 3.0A. Record the corresponding voltmeter reading.

6. Stir water regularly to ensure uniform temperature rise. Note the temperature of water every minute for 15 minutes. Make sure that current and voltage as indicated in ammeter and voltmeter, respectively, remain constant.

7. Switch off the power supply after taking the last reading.

Observation Table 3.1: Specific heat capacity of water

Mass of calorimeter cup, m_c	= …… g
Mass of calorimeter + water, $m_c + m_w$	= …… g
Mass of water, m_w	= ……. g
Initial temperature of water	= …... °C
Current passing through the circuit	= …... A
Resistance in the circuit	= …... Q

Time (min)	**Temperature (°C)**
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	

8. Plot temperature versus time graph. What is the nature of the plot? We expect it to be a straight line. If it is not so, discuss the reasons with your counsellor.

9. Calculate the slope of the straight line using maximum possible intercept. Take the specific heat capacity of copper as 389 $\text{Jkg}^{-1}\text{K}^{-1}$. In case the calorimeter is of some other material, find out the value of its specific heat capacity from Table 3.1 or the lab manual and verify it with your counsellor. Insert the values of various quantities in Eq. (3.4) to obtain the specific heat capacity of water.

Calculate the mean error and quote it along with the result.

Result: The specific heat capacity of water =........... ± .... $Jkg^{-1}K^{-1}$

List the precautions you have taken while doing this experiment.

If you have completed the experiment and have time, you can repeat it by taking some liquid other than water and convince yourself that specific heat capacity depends on the nature of the substance.

3.5 VARIATION OF LENGTH WITH TEMPERATURE

In this part of the experiment, you have to measure a small change in length for a fixed rise in temperature. In Experiment 1 you have learnt to measure small lengths using a vernier callipers and a screw gauge. Can you use them here? No, these devices will not work here. Instead, you can use a spherometer, a microscope or a telescope and optical lever arrangement to measure the small change of length in this experiment. Here we describe optical lever and lamp and scale arrangement. You must understand its working principle before performing the experiment.

A. Telescope and optical lever arrangement

To measure a small change in length, a telescope and optical lever are used along with a lamp and scale arrangement. In an optical lever, a plane mirror is mounted on a tripod stand. The optical lever is placed so that the two legs supporting the mirror '*M*' rest on a support and the third leg *L* rests on the rod at its centre C, as shown in Fig.3.2a. It is important to adjust the mirror so that it is vertical and parallel to the length of the rod.

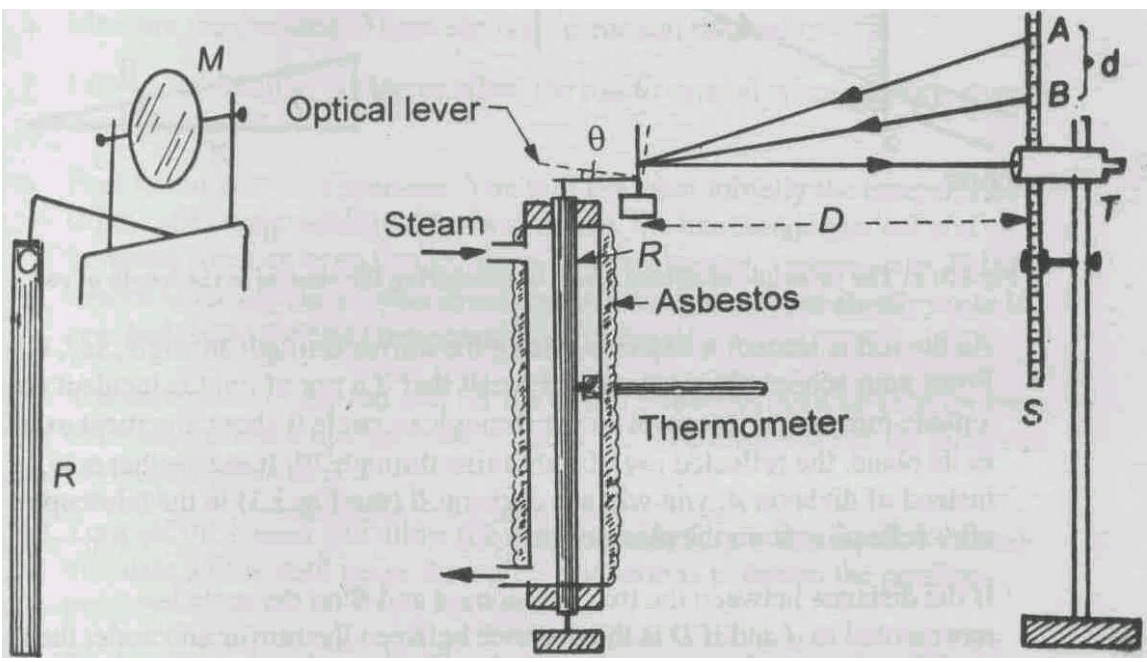


Fig.3.2: (a) Optical level arrangement; (b) experimental arrangement for measuring the change in length of a rod with temperature using a telescope and optical lever

When the rod expands, the leg of the optical lever touching the centre of the rod goes up. This tilts the mirror. To determine the increase in length, you have to measure the angle through which the mirror tilts. Let us understand how to do so using a telescope and lamp and scale arrangement.

1. On a rigid stand, fix a vertical scale *S* in front of the mirror at a distance of about one metre (see Fig.3.2b).

2. Place a telescope *T* close to the scale at the same height as the mirror. Focus the eyepiece of the telescope so that the horizontal cross-wire of the telescope is distinctly visible. Now focus the telescope on the image of the scale in the mirror. For this focussing you may have to turn the mirror slightly about its horizontal axis. If you are not able to focus the image of the scale clearly, you should not waste time. You should consult your counsellor.
3. Note the position of the horizontal cross-wire on the image of the scale and record it in Observation Table 3.2.

What does the position of the horizontal cross-wire signify? See Fig.3.3a. Here M_1 is the initial position of the plane mirror. Division *A* of the scale is seen in the telescope after reflection from the plane mirror. This means that what you have recorded initially is division *A* of the scale.

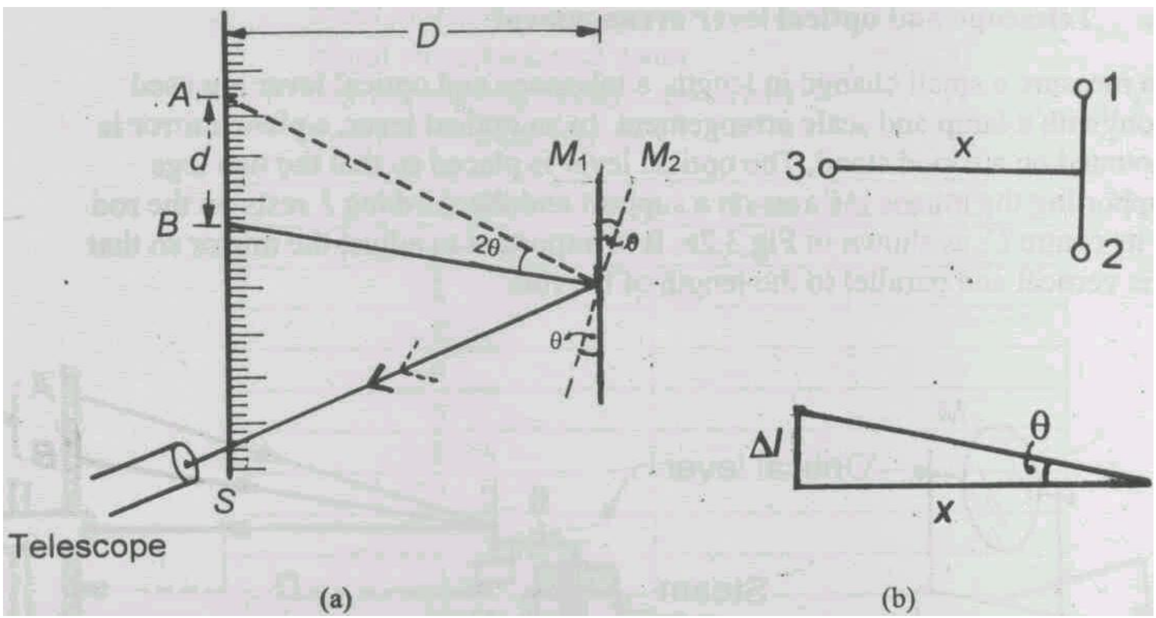


Fig. 3. 3 (a) The principle of optical lever; b) measuring the change in the length of rod

As the rod is heated, it expands, tilting the mirror through an angle, say, θ. From your school physics you will recall that if a ray of light is incident on a plane mirror and it (mirror) turns through an angle θ about a vertical axis in its plane, the reflected ray of light turns through 2θ. It means that now, instead of division *A*, you will see division *B* (see Fig.3.3) in the telescope after reflection from the plane mirror.

If the distance between the two divisions *A* and *B* on the scale is represented as *d* and if *D* is the distance between the mirror and scale, then

$$2\theta = \frac{d}{D} \tag{3.8}$$

If the third leg of the optical lever is at a distance of x from the hind legs (Fig.3.3b), then the change in length, Δl of the rod is given by

$$\Delta l = x\theta$$

$$= \frac{xd}{2D} \tag{3.9}$$

From this relation we find that once x, d and D are known, Δl can be readily obtained.

You now follow the procedure given below to measure α_L .

B. Determination of α_L

1. Note the room temperature using a sensitive thermometer. Record it in Observation Table 3.2.

2. Measure the length of the rod at room temperature using a metre scale and record the value in Observation Table 3.2.

3. Refer to Fig. 3.2. Connect steam inlet opening of the linear expansion apparatus to the steam boiler using rubber tubing. Take rubber tubing and connect its one end with steam outlet opening. Place the other end of the rubber tubing in a beaker. Steam will flow to it after having circulated through the jacket of the apparatus.

4. Insert the thermometer through the hole provided in the linear expansion apparatus.

5. Insert the metal rod inside the apparatus. Adjust the optical lever, telescope and lamp and scale arrangement in place, as explained above. Note the position of *A* on the scale. Record the value in Observation Table 3.2.

6. Measure the distance *D* between the mirror and the scale.

7. Loosen the knob at the top to allow the rod to expand when steam is passed through it. '

8. Pass steam into the apparatus. You will note that initially the temperature (of the rod) rises quickly. After some time, the increase is gradual and becomes constant even though steam is being passed continuously. This is known as steady state**—you must wait till such** time **that** steady **state is** reached. Note the final temperature and tabulate it.

9. The expansion of the rod will tilt the mirror. Note the position of *B* on the scale and record it in Observation Table 3.2. The difference in the positions of *A* and *B* gives us *d.*

10. Turn off the burner and allow the rod to cool before removing it. You may circulate a little cold water through the apparatus to hasten the cooling process.

11. To determine the change in length of the rod, you must measure *x.* For this, place the optical lever on a sheet of paper and press it lightly. You should obtain impressions of its feet on the paper. From these impressions determine the perpendicular distance of the

front foot of the optical lever from the line joining the two hind legs. Record it in Observation Table 3.2.

Observation Table 3.2: Measurement of change in length of a rod using a telescope and an optical lever

Room temperature	= ………………. ^{O}C
Length of the rod at room temperature	= ………………. cm
Distance *D* of the scale from mirror	= ………………. cm
Initial position of the horizontal cross-wire of the telescope	= ………………. cm
Final temperature of the rod	= ....….. ^{O}C
Final position of the horizontal cross-wire	= ………………. cm
Distance *x* of the front foot of the optical lever from the line joining the other two	= ………………. cm
legs	= ………………. cm

12. Calculate *M* from Eq. (3.9) and a/, from Eq. (3.7) for the material of the rod. You must include an estimate of errors.

Result: The coefficient of linear expansion of the rod = ... K $^{-1}$

List the precautions you have taken while doing this experiment.

In case you have time, you can repeat the experiment with a rod of another material.

EXPERIMENT 4
INVESTIGATIONS WITH MIRRORS AND LENSES

Structure

4.1 INTRODUCTION

Light is central to our existence. Visible light allows us to see the world around us in all its colours, brightness and vivid imagery. As you have studied in Unit 4, through various optical apparatus we extend the reach of our vision from the microscopic world to the universe at large. Mirrors, lenses and/or prisms are the basic components of almost all image forming optical instruments. That is why there are always a few experiments on optics in a physics lab involving these devices. In this experiment you will investigate the formation of images by mirrors and lenses.

You may recall that an optical phenomenon like formation of images can be understood if we regard light as travelling in straight lines. For studying image formation we should know the relationship between the object and the image distances from the pole (optical centre) of the mirror (lens). As the position of the object is invariably known to us, the basic exercise in such experiments is to locate the position of the image. This is done by the method of **parallax**. You will learn about it in Sec. 4.3. In Sec. 4.4 you will learn to locate the position of an image formed by a mirror and a lens. You will also be familiarised with the necessary apparatus. In Sec 4.5 you will learn to make observations with real images and determine the focal length of the given mirror/lens.

In the next experiment, you will analyse the spectrum of light from a sodium or mercury lamp using a prism and a spectrometer.

4.2 AIM

Through this experiment, we wish to provide you the experience of handling mirrors and lenses. In particular, you will learn to use them to form images of objects situated at different distances from them and understand their nature.

After doing this experiment, you should be able to:

- remove parallax;
- use parallax method to locate the position of the real image of an object with the help of a mirror and a lens; and
- determine the focal lengths of a concave mirror and a convex lens.

The apparatus required for this purpose is listed below.

Apparatus
Optical bench, concave mirror of focal length 15-20 cm, convex lens of focal length 15-20 cm, pins, index needle and metre scale.

4.3 WHAT IS PARALLAX?

Parallax is the apparent motion between an object and its image (situated along the line of sight) relative to each other. To appreciate it, do the following exercise.

Hold one pencil in each hand at some distance, say about 15 cm, from your eyes. Close one of your eyes and bring the other eye in the line of sight of the two pencils. Now, move your head sideways. What do you observe? Does the farther pencil show an apparent relative shift with respect to the nearer pencil along the direction of motion of the eye? The nearer pencil will then show an apparent shift in the opposite direction. In such a situation we say that a parallax exists between the two pencils.

What happens when you bring the pencils closer? You can see that the relative shift between the pencils decreases. We then say that the parallax is reduced. If you bring the two pencils close together so that the top of one is resting on the top of the other, you will not observe any relative shift on moving your eye sideways. We then say that there is no parallax between them.

By observing parallax, we can easily find as to which object is nearer to the eye. No parallax means that the two objects arc coincident. We use this to locate the position of an image formed by a mirror or a lens. You may do the following activity to familiarise yourself with this method.

Activity

Hold a plane mirror to a wooden block by rubber bands. Place the mirror vertically on a table and put a pencil held by a clothes pin at a distance of about 10 cm from the mirror. Observe the parallax between the pencil and its image. Is the image nearer to the eye or the pencil?

Place another pencil behind the mirror and move it around until there is no parallax between it as seen over the top of the mirror and the image seen in the mirror. This gives you the location of the image. Repeat for several positions of the object pencil. Draw your conclusions about the relationship between the object distance and the image distance from the reflecting surface and record them below.

____

____

____

____

____

Now that you have understood how to remove parallax, you can perform the actual experiment.

4.4 LOCATING IMAGES

In an experiment on mirrors and lenses, we first set up an axis along which we place the **optical elements - pole of the mirror/optical centre of the lens and tip of the pin**. To facilitate this task, we use an **optical bench**. You know that it consists essentially of a long horizontal metallic beam which carries **uprights** for holding lenses/mirrors and object/image pins, etc. A scale is also attached to the bench. We use it to know the position of the object and the image by recording the location of the corresponding pins mounted on uprights.

Sometimes we observe that the distance between two uprights, as read on the scale, is not equal to the distance between the object and the image along the principal axis. For example, in Fig.4.1, the readings of two uprights do not give the actual distance between the tip of the pin and the pole of the mirror. In such a situation, we say that there is an index error and apply what is known as the **index correction.**

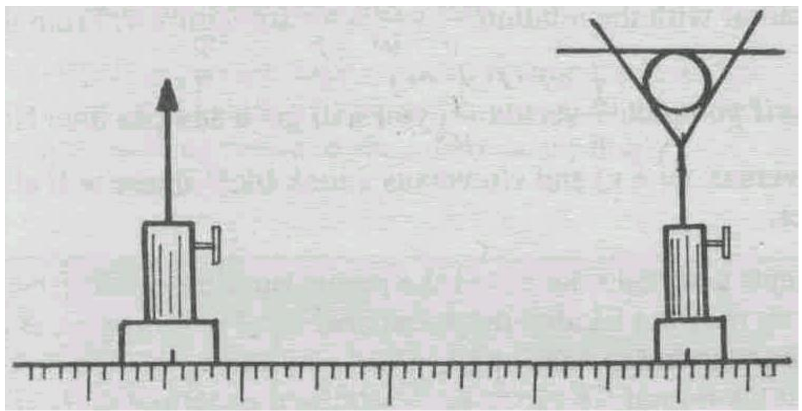


Fig. 4.1 Observing index error

To know index error, take a thin straight needle of about 15-20cm length. Place it so that its one end touches the tip of the pin and the other end touches the centre of the mirror/lens. Read the positions of uprights on the scale and measure the length of the needle with a metre scale. The difference in these two values, if any, is a measure of the index correction.

A. Points to remember

1. In all optical bench experiments it is absolutely essential to **ensure that the optical axis is parallel to the bench.** The mirror/lens and pins should all be in planes at right angles to the axis. The heights of uprights should be so adjusted that the **tips of pins and the pole of mirror/ optical centre of the lens lie along the same line. This line must always remain parallel to the edges of the bench irrespective of the positions of the pins and mirror/lens.**

2. While doing an experiment with a converging mirror or lens, it is **always useful to know a rough estimate of its focal length.** You can do so by obtaining a sharp image of a distant object on a sheet of paper and measuring the distance between the mirror/lens and the paper with a metre scale. A distant tree or window of a building can serve this purpose well.

3. **Use a brightly polished pin as object.** If necessary, illuminate it from the side to get a reasonably bright image. Sometimes it is convenient to put a white screen as background.

4. While performing an experiment, you might confuse between the object and image pins. To distinguish these, it is useful to **put a small piece of white paper on the object pin.**

5. **When magnification is large and the image is thick,** you should use a thin pin as object and a thick pin for locating the image position. But when the **magnification is small and the image is thin,** it is better to use a thick pin as object and a thin pin as image pin.

6. Object and image distances should be measured from the pole of the mirror or the optical centre of the lens. For greater accuracy, make allowance for the thickness of the glass in case of a mirror and add half the thickness of lens to the measurements from its surface.

7. Use sign conventions as given in Unit 4.

> The **pole** of a mirror is the point where the principal axis intersects the reflecting surface. It is usually at the back of the mirror. The **optical centre** of a lens is a point within the lens. A ray of light passing through the optical centre is assumed to suffer no deviation.

B. **Plot of 1/v versus *l/u***

You are familiar with the relation $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ for a mirror. From this it is obvious that if you plot $\frac{1}{v}$ versus $\frac{1}{u}$, you will get a straight line. How will the plots of *uv* versus (*u* + v) and *v/u* versus *v* look like? These will also be straight lines.

For real objects and real images, all the points should lie along the line *EEC* (Fig.4.2). You may not be able to get experimental points in the dotted region since these correspond to very large values of *u* and *v*. Of the points on *BC*, only those in the region *CE* are to be determined experimentally. The points in the region *EB* can be obtained by interchanging *u* and *v*.

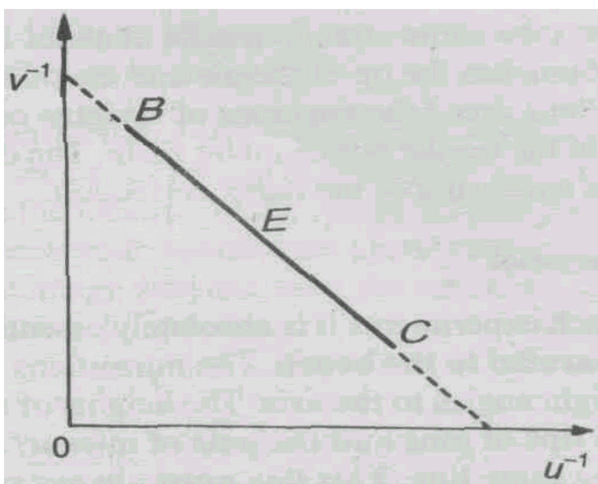


Fig. 4.2 Expected plot of 1/v versus l/u

4.5 INVESTIGATIONS WITH REAL IMAGES

From Unit 4, Block 1 of this course, you may recall that real images are formed by a concave mirror and a convex lens for objects situated between the focus (*F*) and infinity. For object positions between *F* and *2F*, the images lie between infinity and 2*F*. The points between *F* and *2F* are said to be *conjugate* to those between infinity and *2F*. In this experiment, it is sufficient for you to investigate the positions of images for objects situated between *F* and *2F*.

It is convenient to start with the *2F* position of the object because the image is also formed at *2F*. Then, as you move the object towards F, the image shifts beyond *2F* towards infinity. Since the length of the optical bench is finite, it is not possible to explore the image positions for all object positions between *2F* and *F*. For points closer to *F*, the image will go out of the bench. As far as possible, you should try to make the maximum use of the length of the available bench.

Let us now learn to locate the position of an image formed by a concave mirror. You can use this information to determine its focal length.

4.5.1 Focal Length of a Concave Mirror

To determine the focal length of a concave mirror, follow the steps listed below:

1. Estimate the approximate focal length of the mirror using the procedure outlined in Sec. 4.4. It should not be more than 25 cm. You should change it if your estimated value exceeds this value.

2. Refer to Fig.4.3. It shows the experimental arrangement for the determination of focal length of a concave mirror. You have to mount various uprights holding pins and the mirror accordingly.

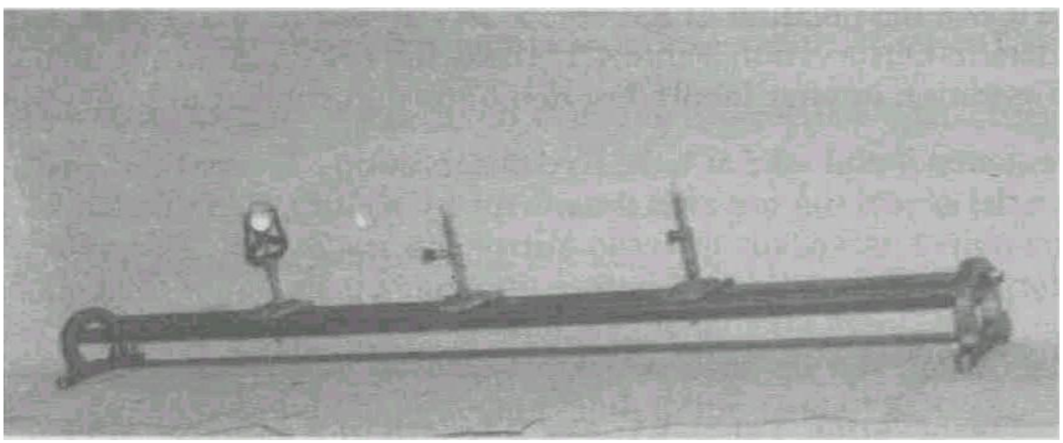


Fig.4.3 Experimental arrangement for determination of focal length of a concave mirror

3. Note the least count of the metre scale and measure the length of index needle. Mount the mirror on an upright and set it near the right end of the bench. Read its position on the scale and enter the reading in Observation Table 4.1.

4. Now, set a pin some distance away. It will act as the object pin. Read the position of the object needle on the scale when the distance between the pole of the mirror and top of the needle is equal to the length of the index needle. The difference between the distance of the two uprights and the length of the needle, if any, gives the index error.

5. Move the upright with object pin to a distance of about twice the estimated focal length from the mirror. This gives you *u*. Record it in Observation Table 4.1.

6. You should now look for an inverted image. Once you observe it, remove the parallax between the object pin and its image by moving the object pin backward or forward, Note the position of the pin in no-parallax condition. This gives you *v*. Record it also in the Observation Table. We expect that the value of v will be equal to the value of *u*. The ray diagram for this configuration is shown in Fig.4.4.

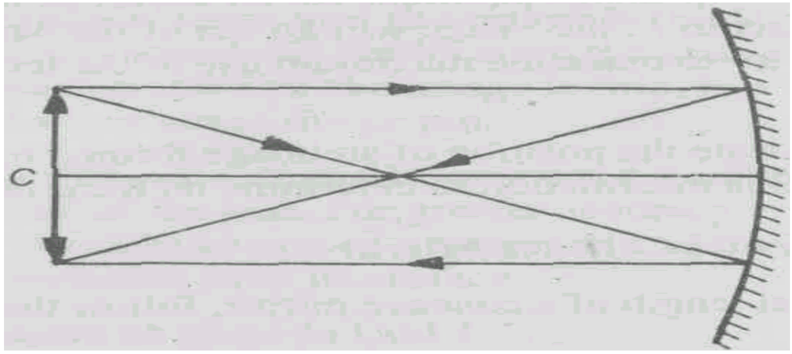


Fig.4.4 Ray diagram for image formed by a concave mirror when the object is at *C*

7. Move the object pin towards the mirror by a few cm (say by about $f/6$). Locate the approximate position of the image by holding a pencil in your hand. Place another pin I, which may be called the image pin, at that position on the optical bench. Locate the exact position of the image by moving the pin / back and forth till it shows no parallax with the image.

8. Note down the position of the object as well as the image pins and tabulate the data in Observation Table 4.1. Draw the ray diagram for this configuration in your laboratory notebook and show it to your counsellor.

9. Repeat step 4 and take at least five observations. Every time you should move the object pin towards the mirror by about $f/6$. You should note that as the object moves towards the mirror, its image moves away from the mirror. You must stop well before the image goes out of the bench.

10. Apply the index corrections for each value of *u* and *v*.

Observation Table 4.1: Focal length of a concave mirror

Least count of metre scale = ……….. cm

Actual length of index needle = ……….. cm

Distance between object pin and the mirror read on the scale = ……….. cm

Distance between image pin and the mirror read on the scale = ……….. cm

Index correction for *u* = ……….. cm

Index correction for *v* = ……….. cm

S. No.	Mirror position	Object position	Image position	Observed		Corrected		$\frac{1}{u}$ (cm^{-1})	$\frac{1}{v}$ (cm^{-1})
				u (cm)	*v* (cm)	*u* (cm)	*v* (cm)		
1.									
2.									
3.									
4.									
5.									

11. Plot 1/*v* along *y*-axis and 1/*u* along x-axis. Draw the best-fit smooth curve through these points. What is the shape of the curve? We expect it to be a straight line. Extrapolate your curve on both sides. Are intercepts on *x* and *y*-axes equal? Note their values. The value of intercept along *y* axis gives you the value of f. You should also calculate the value of f with at least one set of values of *u* and v using the mirror formula. Compare this value of f with that obtained from the graph.

12. Calculate the mean error and quote it with your result.

Result: The focal length of the given concave mirror is = ... cm ± .... cm

4.5.2 Focal Length of a Convex Lens

To determine the focal length of a convex lens, follow the steps listed below.

1. Estimate the approximate focal length of the lens by focussing a parallel beam of light or a distant object, as discussed in Sec. 4.4. As in case of the mirror, your lens should have focal length in the range 15-20 cm.

2. Refer to Fig.4.5 which shows how you should mount the lens, the object and the image pins in the uprights on an optical bench.

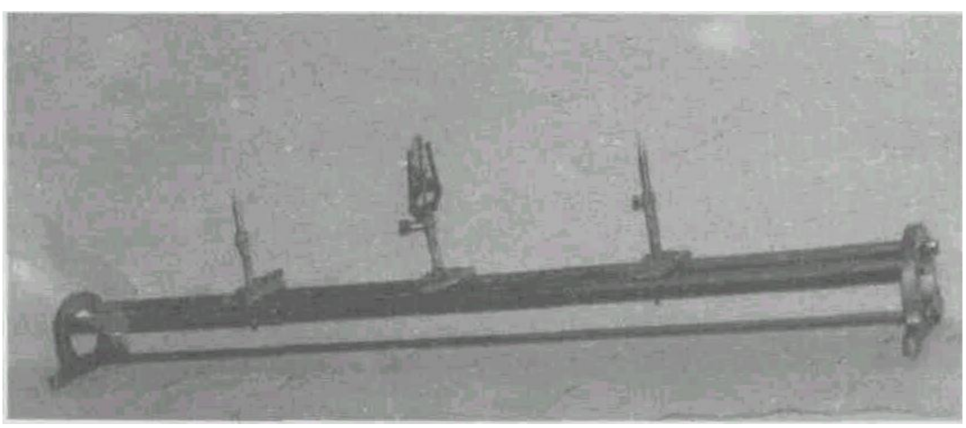


Fig.4.5 Experimental arrangement for determination of focal length of a convex lens

3. The object pin should be closer to the left end of the optical bench. Record its position. Mount the lens on an upright some distance away from the object pin and determine the index correction, as discussed in Sec. 4.5.1.

4. Move the lens upright so that it is at a distance of about twice the estimated value of focal length. Now look from the right end of the bench and locate the approximate position of the inverted image.

5. Mount another pin on the optical bench so that it is on the right hand side of the lens. Place it at the estimated position of the image. Adjust it at the position of no parallax. The ray diagram for this case is shown in Fig.4.6. Make your own Observation Table by drawing columns similar to Observation Table 4.1. Record the positions of the object pin, the lens and the image pin.

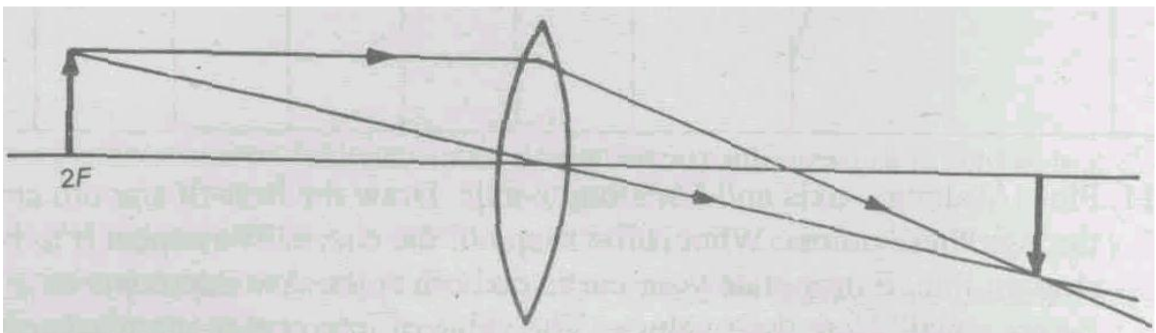


Fig.4.6 Ray diagram for a convex lens when object is placed at *2F*

6. Move the lens towards the object pin by a few cm (say by about $f/6$). Again locate the position of the image with the help of the image pin. Record the positions of the lens and the image pin.

7. Repeat step 5 at least five times. Every time you should displace the lens towards the object pin so that the value of *u* changes by about $f/6$.

8. Apply the index corrections, if present, to each value of *u* and *v*.

Observation Table 4.2: Focal length of a convex lens

From Unit 4 of Basic Apparatus in Physics, you will recall that the lens formula is

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

Therefore, as in the case of concave mirror, you can calculate the value of/ either by drawing a graph between 1/*v* and 1/*u* or using the lens formula. We will advise you to draw a graph.

9. Calculate the mean error and quote it with your result.

Result: The focal length of the given **convex lens is = ... cm** $\pm$ **........ cm**

List the precautions you have taken in this experiment.

EXPERIMENT 5
WORKING WITH A SPECTROMETER

Structure

5.1 INTRODUCTION

As a child you must have been fascinated by rainbows in the sky. You must also have observed the rainbow colours in soap bubbles and thin films of oil on water. Do you know that you can obtain these colours in a physics laboratory? This can readily be done with the help of a spectrometer, a prism and a light source. In Unit 4 of Basic Apparatus in Physics, you have studied about a spectrometer, and how spectral lines are obtained by using a prism when a mercury or sodium lamp is used as a source. In this experiment, you will use a spectrometer to observe the spectrum, determine the angle of the prism, the angle of minimum deviation for a particular wavelength and use this information to identify the material of the prism from its refractive index.

In the next experiment, you will learn to make electrical measurements using ammeters and voltmeters.

5.2 AIM

In this experiment, you will gain practice in setting up a spectrometer for observing spectrum.
After doing this experiment, you should be able to:

- adjust the telescope, prism table and collimator to set up the spectrometer;
- observe spectral lines produced by a light source;
- measure the angle of prism and the angle of minimum deviation for a given wavelength; and
- predict the material of the prism by determining its refractive index.

The apparatus required for this experiment is listed below.

Apparatus
Spectrometer, prism, light source such as sodium or mercury lamp, spirit level, reading lens and a reading lamp.

5.3 ADJUSTMENT OF THE SPECTROMETER

For setting up the spectrometer, you have to adjust its various components, viz. the collimator, prism table and telescope. You should do it in the order given below.

A. Adjustment of the telescope

Look through the eyepiece of the telescope. Do you observe cross wires? Adjust the eyepiece by sliding it in and out till cross wires are distinctly visible. **Do not move the eyepiece after adjusting it.** Now turn the telescope towards a distant object like a building or a tree. It should be more than 20 m away. Using the focussing screw, adjust the distance between the objective and the eye-piece so that the details of the distant object say, the leaves of the tree, are seen clearly.

You know that a telescope focuses a parallel beam of light coming from a distant object in its focal plane. If the cross-wires have no parallax with the image (of the distant object), the telescope is adjusted for parallel rays. **Do not disturb this adjustment throughout the experiment.**

B. Adjustment of the collimator

Having adjusted the telescope, you have to adjust the collimator. An adjustable slit is mounted at its end closer to the source. Illuminate the slit by adjusting the opening of the box enclosing the light source and adjust the width of the slit so that you obtain good visibility with minimum width. Look through the telescope and move the slit in and out using the focussing screw till there is no parallax between the slit image and the cross-wires. This ensures that the slit is at the focus of the collimator lens and a parallel beam of light will emerge from the collimator. The objective of the telescope, which is already set to receive a parallel beam of light, will converge the light in its back focal plane forming an image of the slit. **Do not alter the collimator adjustment now onwards**.

C. Levelling the spectrometer

It is quite possible that the work table on which the spectrometer is placed is not horizontal. You should adjust your spectrometer using the three levelling screws provided at its base with the help of a spirit level. Next you should use the spirit level to adjust the prism table so that it is horizontal. There are three screws on which the prism table rests. Keep the spirit level on the line joining any two screws and turn those screws suitably to bring the bubble to the centre. Then keep the spirit level perpendicular to the original position and turn the third screw so that the bubble is again at the centre. Repeat this alternatively till the bubble of the spirit level is at the centre for any position on the prism table. Now you can be sure that the prism table is horizontal.

You have now adjusted the spectrometer and can proceed to observe the spectrum.

5.4 OBSERVING SPECTRUM

Follow the procedure given below to observe spectrum produced by the given source of light using a prism and the spectrometer.

1. Place the spectrometer in front of the sodium lamp so that the collimator slit is illuminated.
2. Mount the prism on the prism table such that its centre coincides with the main axis of the spectrometer and its side *AB* is normal to the collimator, as shown in Fig.5.1.

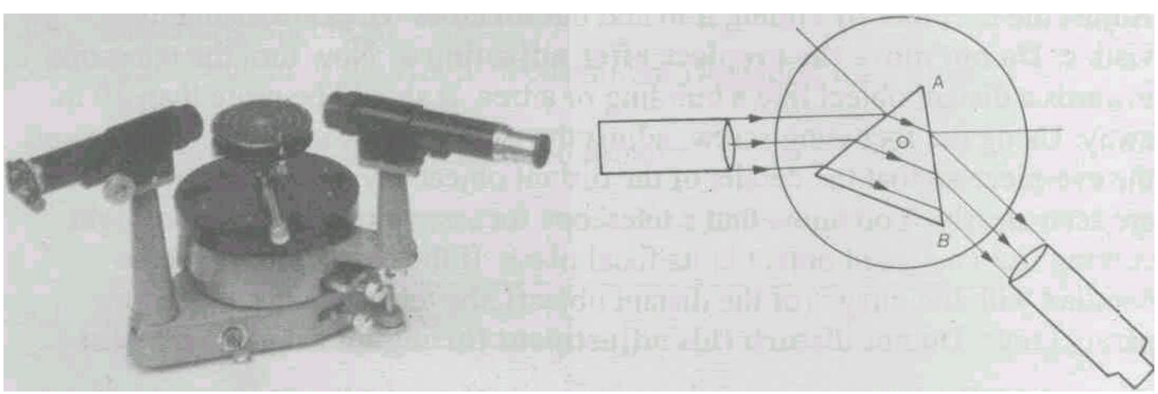


Fig. 5.1 Observing spectrum

3. From Unit 4, Basic Apparatus in Physics, you may recall that after refraction through the prism, the emergent ray deviates towards the base of the prism. To locate the position of image, turn the telescope to your left and look through it. What do you observe? For a sodium lamp, you should observe a pair of sharp yellow lines corresponding to wavelengths 5890 Å and 5896 Å. This pair is usually referred to as sodium doublet. With a mercury lamp you will observe sharp spectral lines of different colours of wavelengths:

R_1 = 6908 Å R_2 = 6234 Å Y_1 = 5790 Å, G = 5461 Å BG = 4961 Å

B = 4358 Å, V_1 = 4078 Å V_2 = 4047 Å

You can now determine the variation of angle of deviation with the angle of incidence.

5.5 MEASUREMENT OF THE ANGLE OF MINIMUM DEVIATION FOR A GIVEN WAVELENGTH

1. Note the value of one vernier division on the main scale and calculate the least count. Record it in the Observation Table 5.1.

2. Make one of these lines to coincide with the **vertical line** of the crosswire and record the reading of both the verniers in Observation Table 5.1. Here after, you should always focus the same spectral line.

3. Rotate the prism table through a small angle say, 5°. As a result of this, the angle of incidence changes. What do you expect to happen to the emergent ray? Are you still able to see it through the telescope? If not, move the telescope further towards the left. To locate the exact position, focus the cross-wires on the spectral line. Record the reading corresponding to both the verniers in Observation Table 5.1.

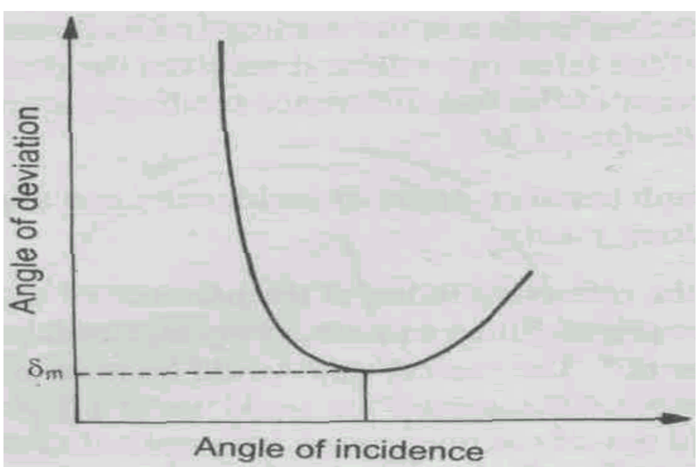


Fig.5.2 Variation of angle of deviation with angle of incidence

4. Again rotate the prism table and follow its motion through the telescope. Note the corresponding positions of the incident and deviated rays. If you continue to rotate the prism table in the same direction, the spectral line will also move in the same direction. At one position of the prism table, you will note that the spectral line begins to move in the opposite direction. Fix the prism table where the spectral line just stops momentarily

before changing direction. This defines the position of minimum deviation for the given wavelength. Record your reading in Observation Table 5.1.

5. Around the position of mean deviation, take readings at intervals of 2°.

6. Take at least four readings beyond the position of minimum deviation.

Observation Table 5.1: Measurement of the **angle of minimum** deviation

Value of one division on the main scale $= \frac{1^0}{2}$ or $30'$

Least count = 1 m.s.d – 1. v.s.d

$= \frac{1}{\text{no. of divisions on the m.s}} \times \text{value of 1 m.s.d}$

Position of direct ray		Position of emergent ray		Angle of deviation		Mean angle of deviation $\left(\frac{\theta_1+\theta_2}{2}\right)$
Vernier V_1	Vernier V_2	vernier V_1	vernier V_2	corresponding to vernier $V_1 \approx \theta_1$	corresponding to vernier $V_2 \approx \theta_2$	

7. Now remove the prism, release the telescope, turn it in line with the axis of the collimator and take the direct ray reading on both verniers. Tabulate these readings in Observation Table 5.1.

8. Calculate the difference in the readings of the same vernier for the positions of the telescope where it receives the deviated and the direct rays. Take the mean of the two difference readings. It gives the angle of minimum deviation, *D*.

9. Plot the graph between angle of incidence i and angle of deviation *D* by taking *D* along the *y-axis.*

To determine the refractive index of the material of the prism, you must know the angle of the prism. Since a prism forms an equilateral triangle each of its angle should be 60°. The easiest way would be to take the outline of the prism on a piece of paper and measure the angle using a protractor. However, its accuracy would not be commensurate with optical measurements. Therefore, it is usually preferred to measure the angle of the prism using the spectrometer.

5.6 MEASUREMENT OF THE ANGLE OF THE PRISM

To measure the angle of the prism, follow the steps listed below.

1. Mount the prism on the prism table in such a way that its refracting edge *A* lies over the centre of the prism table and the face *AB* is normal to the line joining levelling screws *Q* and *R,* as shown in Fig.5.3.

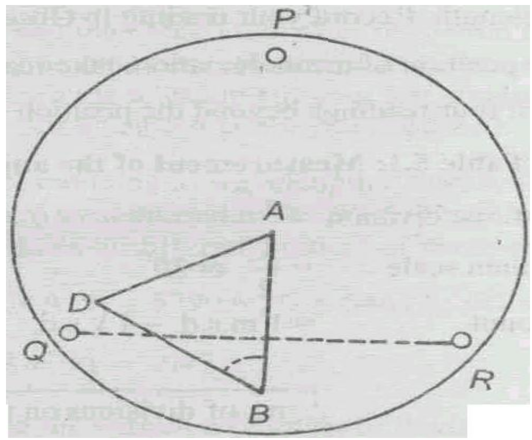


Fig.5.3 Mounting the prism for measurement of its angle

Now rotate the prism table so that edge *A* is placed symmetrically with respect to the collimator. In this setting, both the faces *AB* and *AD* will receive parallel rays from the collimator. Turn the telescope to locate the reflected image of the slit from the face *AB* of the prism (Fig.5.4).

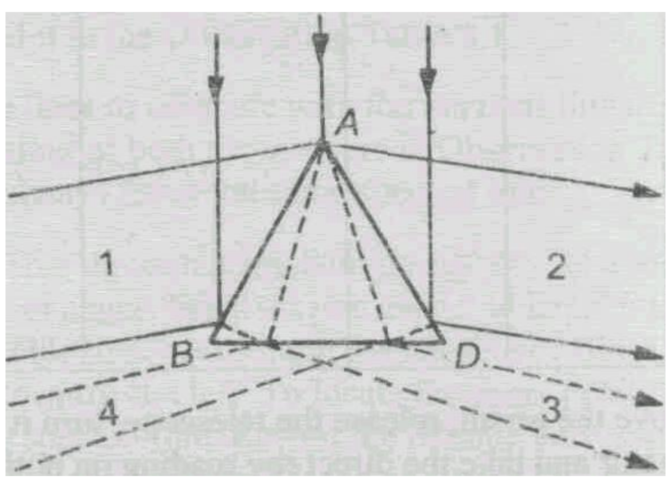


Fig.5.4 Determination of the angle of the prism

3. Fix the main screw and using the tangent screw make the vertical wire of the crosswire to coincide with the image of the slit exactly, as shown in Fig.5.5.

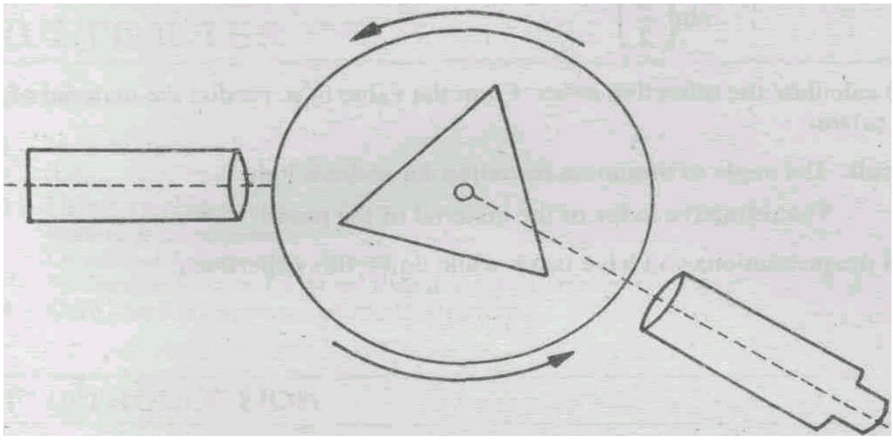


Fig.5.5 Locating the reflected image

4. Using a reading lens and a lamp, note the readings on both the verniers V_1 and V_2 and enter the data in Observation Table 5.2. We expect the difference between these two readings to be nearly equal to 180°.
5. Release the telescope and rotate it to receive light from the face *AD*. Again make the vertical wire to coincide with the image and note the readings on both the verniers. Tabulate the readings.
6. The difference in the two readings of the same vernier gives the angle through which the telescope is rotated. This is twice the angle of the prism *(2A)*. From this you can determine *A*. Calculate the mean value.
7. Repeat the experiment at least five times and tabulate your readings in Observation Table 5.2.

Observation Table 5.2: Measurement of the angle of the prism

Vernier	Location of spectral line after reflection from face *AB*			Location of spectral line after reflection from face *AD*			$2A = \alpha - \beta$
	Main scale reading	Vernier scale reading	Total reading (α)	Main scale reading	Vernier scale reading	Total reading (β)	
V_1	1.						
	2.						
	3.						
	4						
	5.						
V_2	1.						
	2.						
	3.						
	4.						
	5.						

Mean value (*2A*) = ………………

Result: Angle of the prism = …………………..

Now substitute the values of *A* and *D* in the relation

$$n = \frac{\sin \frac{(A+D}{2}}{\sin\left(\frac{A}{2}\right)}$$

and calculate the refractive index. From the value of n, predict the material of the prism.

Result: The angle of minimum deviation for sodium light is = ...

The refractive index of the material of the prism =...............

List the precautions you have taken while doing this experiment.

EXPERIMENT 6
HANDLING AND MAINTAINING A MULTIMETER

Structure

6.1 INTRODUCTION

You have studied in Unit 6 (Basic Apparatus in Physics) that a **multimeter** is a multipurpose instrument used for measuring resistances, *AC* and *DC* voltages and currents. It is a must in every physics laboratory as it is useful for fault finding in electrical circuits and testing of components. For example, suppose you discover that a given circuit is not working even though all connections are correct and all devices and components in it are working. Then the fault could lie in one of the connecting wires. You can use the multimeter to test the continuity of the connecting wires by measuring their resistance, find out which one of these is faulty and replace it.

As another example, suppose we have a *pn* junction diode which has no markings on it. How can we find out which of its ends is *p*-type and which one is *n*-type? We can do so with the help of the multimeter. You can also use the multimeter to identify the emitter, base and collector terminals of a bipolar junction transistor. So you can see how useful an instrument a multimeter is. Therefore, you must learn how to handle it and take care of it. We have designed this experiment to provide you the experience of using a multimeter and maintaining it.

6.2 AIM

In this experiment, you will learn how to use a multimeter for measuring resistance, ac and dc currents and voltages, and testing electronic devices. You will also learn how to take care of it. After doing this experiment, you should be able to:

- use a multimeter to measure resistances, *AC* and *DC* currents and voltages;
- test the continuity of a wire with the help of a multimeter;
- test an electrolytic capacitor;
- check whether a/w junction diode is working and identify its p and n ends;
- identify the emitter, base and collector terminals of an *npn* and *pnp* transistor;
- test whether a given transistor is working;
- maintain the multimeter in good working condition.

The following apparatus is required for this experiment.

> **Apparatus**
>
> Multimeter, resistors, electrolytic capacitors, connecting wires, simple electrical circuits, *pn* junction diode, *pnp* and *npn* transistors, signal generator and power supply.

6.3 USING A MULTIMETER

We will explain how to use an analogue multimeter. The digital multimeter also works in the same way. The only difference is that readings are displayed on it in the form of numbers. Before you actually start using the multimeter, you should get familiar with its front panel. For this, do the following activity.

Activity

(a) Take the multimeter available in your lab. List all the controls on the panel and write their functions. You may refer to Unit 6 or read the manual accompanying the multimeter.

(b) Find out the relevant specifications of the multimeter such as its operating temperature, storage temperature, battery voltage and battery life from its manual, if available.

(c) Write down the ranges of the resistance, *AC/DC* voltages and currents that can be measured with this multimeter.

Once you are familiar with the multimeter, you can use it for many purposes as explained above. For each measurement, practise till you feel confident about your ability to handle the multimeter. While using the multimeter, you should always keep in mind the following precautions:

- If you do not know the source of voltage (ac or dc), then keep the meter in the ac voltage range.
- While taking any measurement, start from the maximum range corresponding to the physical quantity being measured.
- While measuring current, the multimeter should be connected in series.
- While measuring high voltages, do not touch any part of the multimeter.
- When the multimeter is not in use, do not leave it in the resistance range.
- While using the multimeter in resistance range, first make the zero adjustment.
- For measuring *DC* voltage, connect the +ve lead of the multimeter to the +ve terminal of the source and -ve lead to the -ve terminal of the source.

6.3.1 Resistance Measurement

Follow the steps given below to measure an unknown resistance.

1. Set the range selector switch on the Q scale in the highest range;

2. Insert black lead in 'COM' input terminal and red lead in $V\Omega$ input terminal.

Always connect red lead to the +ve terminal of the multimeter and black lead to the -ve terminal.

3. Make the zero adjustment as follows: Short circuit the two leads, i.e., make them touch each other and rotate the knob marked 'zero adj' or 'ohms zero' to adjust zero on the scale.

4. Turn power on.

5. Now connect the unknown resistance to the leads, and note the value of the resistance on the meter. If the value falls in a lower range then select that range for greater accuracy.

While measuring the resistance of a component connected in a circuit, you should make sure that the power supply to the circuit is off and the capacitors in the circuit are discharged. Otherwise, the multimeter fuse will blow up due to excessive current.

Take several resistors of known and unknown resistance in different ranges, measure their values and tabulate your results in an observation table.

You can use the multimeter in its resistance measurement mode to check the continuity of a wire.

You can also check whether a circuit is open or short-circuited and test a capacitor.

A. Checking the continuity of a wire

You know that a connecting wire is a good conductor and has low resistance. However, if there is a break in the wire, no current will pass through it because there will be infinite resistance between the two ends of the wire. This basic principle gives us the method for checking the continuity of the wire using a multimeter:

1. Take a continuous wire and connect its ends to the black and red leads of the multimeter. You should get a small finite reading.

2. Now join two pieces of wire using an electric tape in such a way that their ends do not touch. Connect the ends of the joined wire to the red and black leads of the multimeter. What do you observe? We expect the value to be very high. Why? Discuss your findings with your counsellor.

3. Repeat this process to check the continuity of several other wires.

In this way you can also test whether a resistor is in working order or broken internally; or whether a circuit is open ($R = \infty$) or short ($R = 0$).

B. Testing a capacitor

You can also use a multimeter in the resistance measurement mode to test whether an electrolytic capacitor is in working order or not:

1. Connect the -ve end of the capacitor to COM and the +ve end to VΩ. If the connections are done properly, the battery inside the multimeter charges the capacitor.

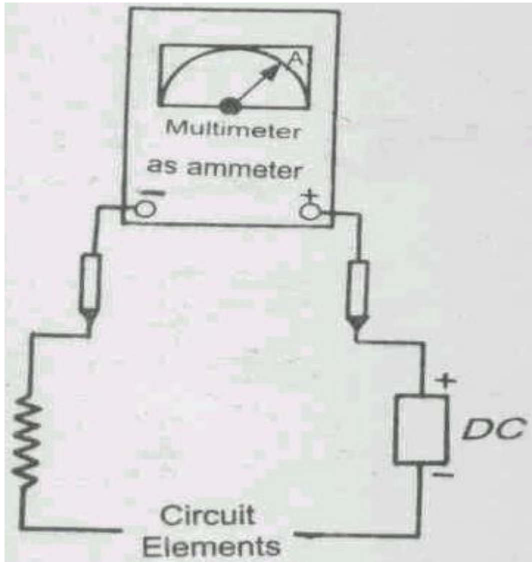


Fig.6.1 Direct current measurement in a circuit

2. The pointer on the scale comes to a point close to zero. Once the capacitor is fully charged, it starts discharging through the multimeter and the resistance increases. The pointer slowly moves towards the end of the scale marked ∞. If this happens, the capacitor is working properly.

3. For discharging the capacitor after testing it, disconnect it from the multimeter and short circuit its positive and negative ends.

4. If the capacitor is broken internally, it acts as an open circuit and the pointer registers ∞ on the scale.

5. If the capacitor is short circuited, the value of resistance remains zero at all times.

6. If the capacitor is leaking, the pointer does not go to ∞, and it cannot be used again.

6.3.2 Current and Voltage Measurements

Since a multimeter can be used to measure both ac and dc signals, we will discuss all cases here. You will be provided appropriate circuits for taking these measurements. Follow the steps listed for each measurement.

A. Direct current measurement

1. Connect red test lead to A input terminal and black test lead to COM input terminal.
2. Set range selector knob to the highest current range for dc, If the value of the current lies in a lower range, then go to that range. **Remember that the expected current should not exceed the maximum permissible current in the multimeter**.
3. Turn off power supply to the device or the circuit being tested and discharge all capacitors.
4. Open the circuit in which the current is to be measured and connect test leads in series with the load through which current is to be measured (Fig.6.1). Keep the polarities as shown in the figure. In this case the multimeter functions like an ammeter.
5. Turn on power to the circuit being used.

6. Read current value on the meter.
7. After taking the current measurement, turn off all power to the circuit being used and discharge capacitors.
8. Disconnect test leads from circuit and reconnect the circuit in which current was being measured.

B. Alternating current measurement

1. Connect red test lead to the A input and the black test lead to COM input.
2. Set range selector knob to highest range for *AC*. If the value of the current falls in a lower range, go to that range.
3. Follow the Steps 3 to 8 above.

C. Direct voltage measurement

1. Connect red test lead to $V\Omega$ input terminal and the black test lead to COM input terminal.
2. Set range selector knob to desired *DC* V position. If the voltage to be measured is not known, set range selector at the highest *DC* V range and reduce range, if necessary, for a satisfactory reading.
3. Follow steps 3 to 8 listed for measuring direct current except step 4.

In step 4 **remember to connect the multimeter in parallel with the load across which the voltage is to be measured with appropriate polarity**. In this case, the multimeter functions as a voltmeter.

D. Alternating voltage measurement

Follow the steps given for direct voltage measurement with the only difference that the range selector switch should be set in *AC* V position.

Make an appropriate Observation table and enter your measurements in it.

6.3.3 Testing a *pn* Junction Diode and Bipolar Junction Transistor

For the measurements you take in the following activities, make your observation tables and record all your readings in them. You will be assessed for these.

Recall from Sec. 6.3.1 of Unit 6 that a *pn* junction diode has a low resistance when it is forward biased and a high resistance when it is reverse biased. We can use this property to test the diode and also find out which of its ends is *p*-type and which one *n*-type.

A. Testing a*pn* junction diode

1. Set the function/range switch to the resistance measurement position in the range of 10 $k\Omega$

Handling and Maintaining a Multimeter

The range of 10 $k\Omega$ is chosen so that the current through the diode is low.

2. Make zero adjustment.

Note: In some multimeters, the terminal marked negative (-) on the meter is actually connected to the positive terminal of the battery inside. We advise you to always find out the polarity of the multimeter, i.e., its positive and negative leads, with the help of a voltmeter before identifying the ends of a *pn* junction diode.

If there are markings for *p*-type and *n*-type on the *pn* junction diode then proceed as follows:

3. Connect the red lead to the *p*-side and black lead to the *n*-side. If the diode is in working condition, you should get a low resistance reading (Fig.6.2a).

4. Reverse the connection, i.e., connect black lead top-end and red lead to n-end. You should get a very high resistance reading (Fig.6.2b).

If the multimeter shows zero or low resistance reading for forward bias and does not change even on reversing the connection then the diode is defective. It is short (Fig.6.3a).

If the diode shows a high resistance under both forward and reverse biased conditions, it is defective. It is open (Fig.6.3b).

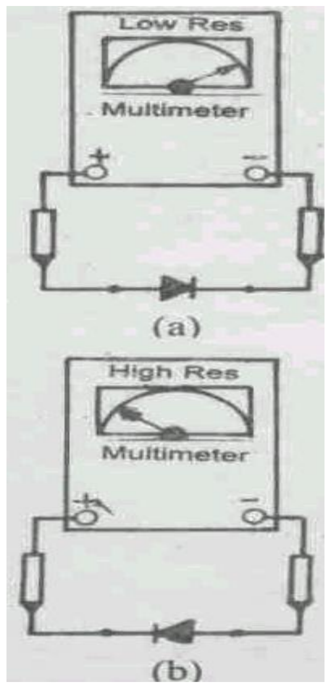


Fig.6.2 Testing of *pn* Junction diode

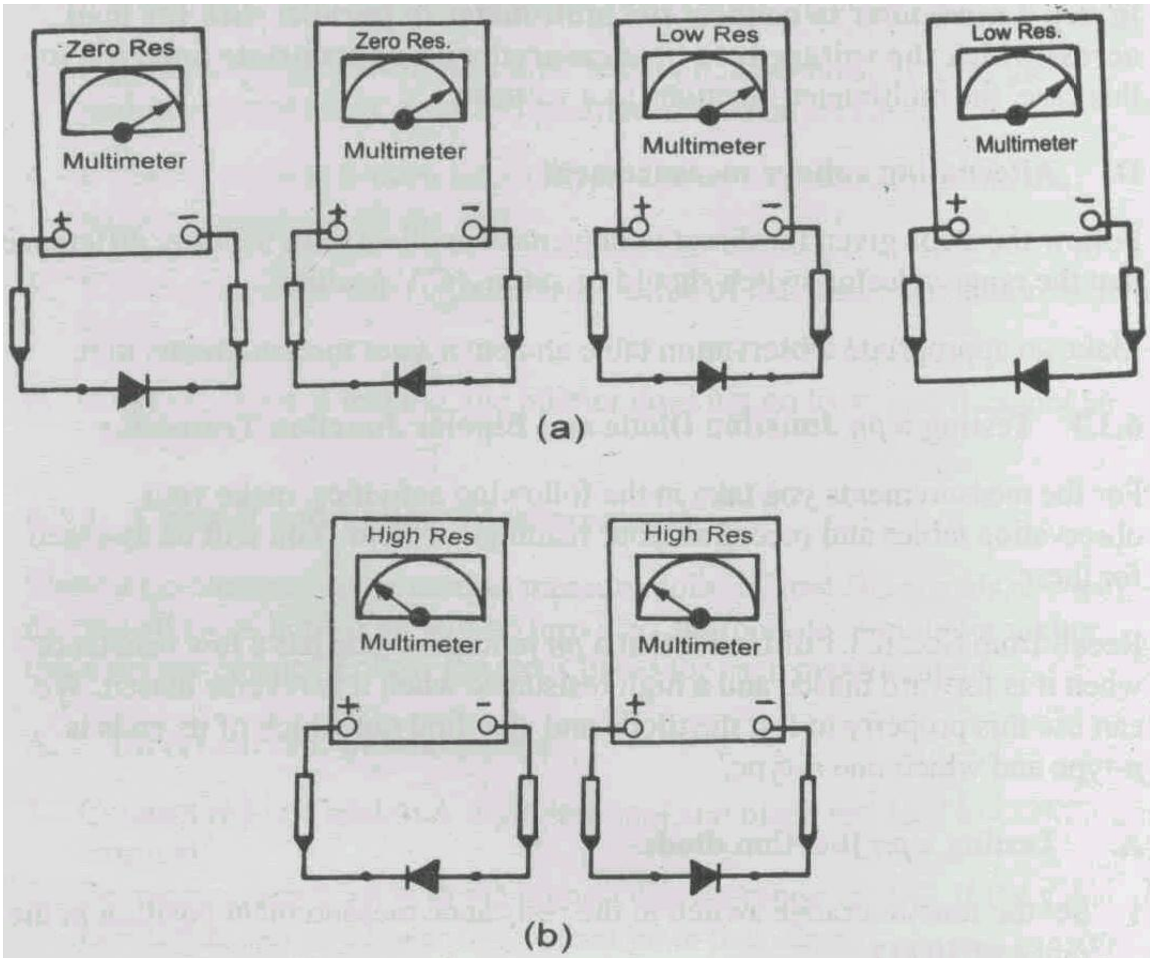


Fig.6.3 Behaviour of a defective *pn* junction

Now suppose the diode is unmarked and you have to identify its *p*-and *n*-ends. **The end of the diode that shows low resistance when connected to the negative lead of the multimeter is its *n*-end**. Now refer to Fig.6.4

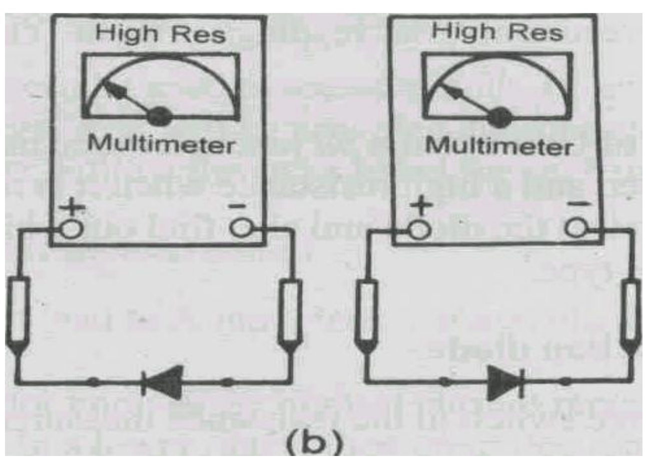


Fig.6.4 Identification of *p*-end and *n*-end in a *pn* junction diode

1. Set the function/range switch to the resistance measurement mode in the range of 10 kΩ.
2. Make zero adjustment.
3. Now connect the two multimeter leads to the two ends of the diode. Note the reading.
4. Is the reading high as in Fig.6.4a? Then the *end A* is *p*-type.
5. Is it low as in Fig.6.4b? Which is the *n* end? Obviously, end *A* is *n*-type.

B. Testing of bipolar junction transistors

You know that in a bipolar junction transistor, the emitter base junction is forward biased and the collector base junction is reverse biased. Sometimes the emitter, base and collector terminals are not identifiable on the transistor. To identify these terminals, proceed as follows:

Turn the transistor upside down. The three terminals lie within a semi-circle (Fig. 6.5). The emitter (*E*) and collector (C) terminals are diametrically opposite. The collector is near the notch (*N*). The third junction is obviously the base (*B*).

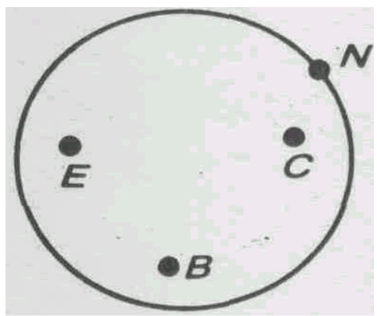


Fig.6.5: Identifying emitter, collector and base terminals of a transistor

Now that you know the emitter, base and collector leads *of a pnp* or *npn* transistor, proceed as follows to test whether they are in working order.

1. Set the function/range switch to the resistance measurement mode in the range of 10 kΩ.

2. Make zero adjustment.

***pnp* transistor**

3. Forward bias emitter the base junction. What connections does this imply for a *pnp* transistor? Connect red lead of the multimeter to emitter terminal and black lead to base terminal. Note the reading. The reading should be low. Reverse the connections. You should get a high reading. Then the *E-B* junction is working.

4. If the multimeter shows low reading in both cases, the *E-B* junction is short. If it shows high reading in both cases, the *E-B* junction is open.

5. Reverse bias collector-base (*CB*) junction, i.e., connect red lead to base and black lead to collector terminal. You should get high resistance. Reverse the connections and if you get a low resistance then the junction is working.

6. If the multimeter shows low reading in both cases, the *C-B* junction is short. If it shows high reading in both cases, the *C-B* junction is open.

What will the situation be for an *npn* transistor? Obviously, you will have to bias the *npn* transistor exactly in reverse *of pnp* transistor. Write down the necessary steps for testing an *npn* transistor in your practical notebook.

The emitter-base and collector-base are two *pn* junctions. Therefore you can determine their types (*p* or *n*) by measuring the resistances exactly as for the *pn* junction diode.

6.4 CARE AND MAINTENANCE OF THE MULTIMETER

You have to take the usual precautions for handling electronic instruments that we have discussed in Sec. 6.2.2 of Unit 6. In addition, **maintenance of a multimeter requires changing its battery from time to time. You may also need to replace its fuse at times.** In both cases, **turn off the multimeter and disconnect test leads before removing battery cover or back cover to prevent electrical shock.**

A. Battery replacement

- The battery is located in the battery compartment at the bottom rear of the multimeter.
- After disconnecting test leads and turning off multimeter, press battery cover and push in the direction of the arrow to open.
- Take out the battery from the instrument and replace with a standard 9V battery. Replace battery cover. Wind the excess lead length once around the battery clip.

Failure to turn off the instrument before installing the battery could result in damage to the instrument. Connect the battery terminal correctly or else the battery and the multimeter will get damaged.

B. Fuse replacement

- After disconnecting test leads and turning off multimeter, press battery cover and push in the direction of the arrow to open.
- Remove old fuse and replace with spare fuse. Replace battery cover.

Note: Use only 0.8A/250 V fuse or as specified in the multimeter manual.

EXPERIMENT 7
FABRICATION OF AN EXTENSION BOARD

Structure

7.1 Introduction
7.2 Aim
7.3 Laboratory Wiring
Earthing
7.4 Assembling an Extension Board
7.5 Safety Measures

7.1 INTRODUCTION

You must have seen electrical sockets fixed on the walls of your home. If you wish to use an electrical appliance such as a table lamp or an iron at some distance from the wall, you need an (electrical) extension board. Similarly, in a physics laboratory, you may be required to use an extension board particularly when many students are working on a table or when many electrical instruments are to be used. An extension board provides for more than one electrical socket. These sockets are connected to a plug through a long three-core electrical wire. When this plug is inserted in the socket on a wall of the laboratory, electricity becomes available at the sockets of the extension board. And that is why an extension board is such a useful laboratory tool. In this experiment, you will learn how to fabricate an extension board.

7.2 AIM

The main purpose of this experiment is to enable you to learn how to fabricate an electrical extension board. Moreover, as you do this experiment, you will also learn to identify the live, neutral and earth wires and corresponding terminals of electrical sockets and plugs.

After doing this experiment, you should be able to:

- identify the live, neutral and earth terminals of a socket and corresponding wires in a three-core electrical wire;
- select appropriate wires, plugs, switches and sockets for fabricating an extension board; and
- fabricate an extension board.

The apparatus required for this experiment is listed below.

Apparatus

Wooden or plastic box (30cm $\times$ 15cm $\times$ 4cm), good quality 5m three-core electric wire of 20 gauge, 2 two-in-one (5 A and 15 A) sockets, 1 three-pin plug (15 A); 2 switches (15 A), half meter single core electric wire of gauge 22.

7.3 LABORATORY WIRING

In Unit 5, you have learnt that household electricity connection is provided through a heavy cable which has two wires. These two wires are insulated from each other. One of these wires is called the **live** (L) wire and another is called the **neutral** (*N*) wire. The electric supply is AC (alternating current) and the live wire is alternately at positive and negative potential of 220V with respect to the neutral wire. The potential of the neutral wire is zero because it is earthed at the local electric sub-station. Therefore, when an electrical appliance is plugged to AC mains, charge flows from the live wire, through the appliance to the neutral wire when the live wire is at positive potential and vice-versa when the live wire is at negative potential.

The electrical connection to the mains of the physics laboratory is also provided through a two-core heavy cable. The electricity supplied is used for lighting, running electrical and electronic equipment etc. You will note that the laboratory electrical wiring has many sockets (in addition to light and fan points) at various points on the walls.

From Unit 5, you will recall that household electrical wiring comprises a number of parallel circuits. It means that all live wires should be connected at one point. Separate electrical circuits are used for lighting and power.

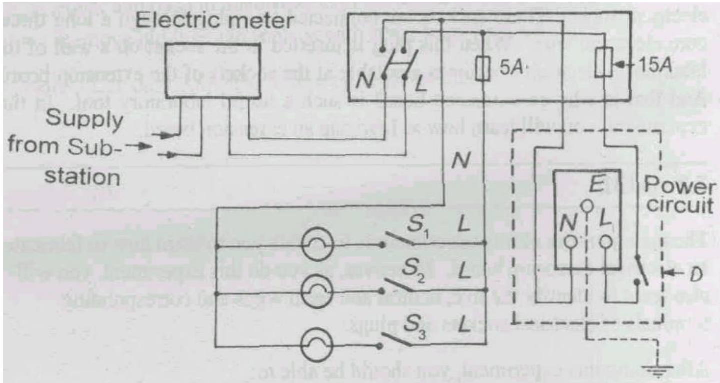


Fig.7.1 A typical laboratory wiring system

Fig.7.1 shows a typical laboratory wiring. Some of its salient features are:

(a) The switch such as *S* is always connected in the **live** *(L)* wire of the circuit so that when it is **off,** the socket (or the bulb holder) is not live. However, if the switch is connected in the neutral wire, the socket is live even when the switch is in off position (see the next box). In such a condition, anyone touching the socket or the bulb holder would get a shock. For this reason, you should fix switches in the extension board along the live wire.

(b) The fuse is connected along the live side of the circuit so that when it (fuse) blows, the appliances are also dead. The fuse will indeed blow even if it is on the neutral side. But, in this case, the appliance may be damaged.

(c) Although neutral wire of the circuit is earthed at the electric substation, for extra safety, the power circuit (Fig.7.1) contains an additional earth wire *E*.

To understand the rationale for putting switches along the live wire, refer to Fig.7.2 which shows a portion of the laboratory wiring.

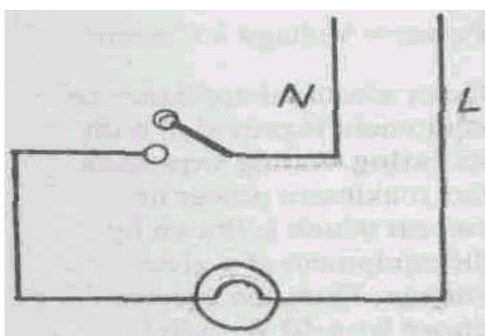


Fig.7.2: Portion of laboratory wiring

The switch for the light point has been placed along the neutral (TV) wire. Let the switch be in off position. In this condition, if you touch the holder of the bulb, your body provides the earth (the conducting path) and hence completes the circuit for the current to flow. As a result, you would feel an electric shock. Thus, even if the switch along the *N* wire is off, the electrical point (such as bulb holder, **socket** etc.) is live and may cause harm to anyone touching it accidentally.

You will learn the rationale for the additional earth wire in power circuit of the laboratory wiring in the next sub-section.

The above features of laboratory wiring pertaining to the placement of switches, earth wire etc. are of vital importance for assembling an extension board. Further, earthing is the most important aspect of any wiring from safety point of view. Therefore, we now briefly discuss earthing.

7.3.1 Earthing

The neutral wire of the electric cable supplying electricity is grounded at the electric power station. Therefore, you may like to know: Why do we need a separate earth wire for power circuits in the laboratory? To appreciate the need of an additional earth wire, refer to Fig.7.3a which shows an electric supply cable connected to a socket. You will note that a person standing on the floor is at the same potential as the neutral wire. If s/he happens to touch the live wire by mistake, her/his body provides a low resistance path for electric current. Thus, the individual is at a risk of receiving electric shock, particularly, if the floor is wet and the person is bare-foot. The possibility of getting in contact with the live wire increases while handling electrical appliances or equipment with metal casing. It is because the live wire may become loose and touch the. metal casing.

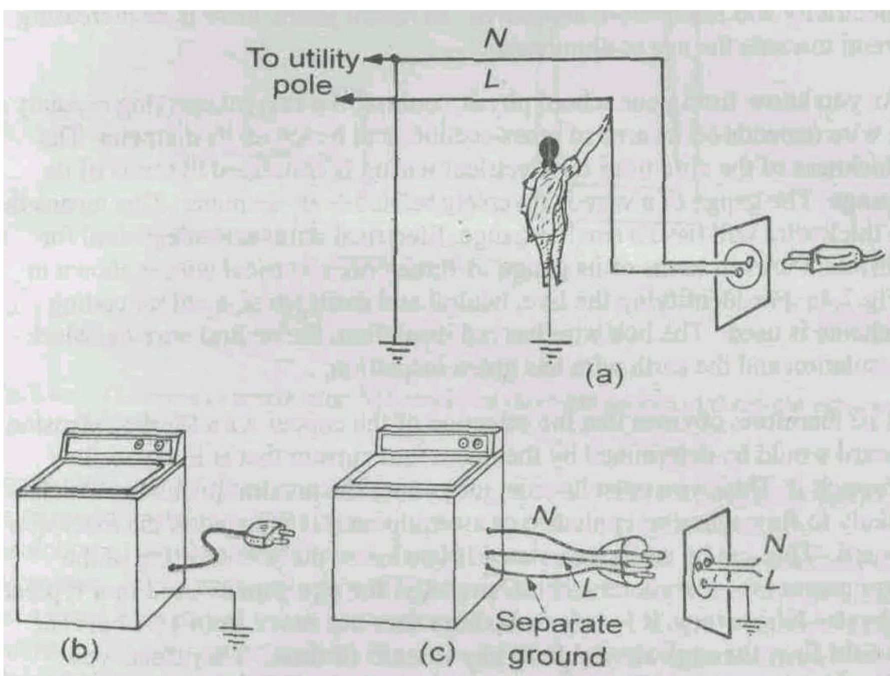


Fig.7.3 (a) Human body provides low resistance path for electric current; (b) and (c) the two ways of earthing an electrical appliance

We can avoid electric shock due to the absence of earthing in two ways (See Fig.7.3b and c): By grounding the metal casing of the electrical appliance or equipment and by using a **three-pin socket**.

When electrical equipment is provided with a separate earthing, the risk of electric shock is minimised. Generally, instead of separately earthing each equipment or appliance (Fig.7.3b), a common earth wire is provided in the power circuit of the laboratory. The earth terminal of the socket is connected to this common earth wire of the power circuit (Fig.7.3c).

For calculating the current required by an electrical appliance, you can use the formula

Power = Voltage × Current

Every electrical appliance or equipment is provided with its rating. Rating expresses the maximum power or current which is drawn by the equipment at a given voltage. Thus, the current drawn by a 40 W bulb is given as

$$\text{Current} = \frac{40W}{220V} = 0.18 \text{ A}$$

and by a 3 kW electric heater as

$$\text{Current} = \frac{40W}{220V} = 13.6 \text{ A}$$

The power rating of an electrical appliance is marked on its body in one of the two ways:

(i) **220 V, 2kW**: This power rating implies that when operated at 220 V, the appliance will consume 2kW power, that is, it will draw

$$\frac{2000W}{220V} = 8.7 \text{ A current from the mains supply}$$

(ii) 5A, 220 V: This power rating straightaway gives the value of the maximum current (5A) the appliance/equipment will draw from the mains supply at 220 V.

So far you have studied about the laboratory wiring and its salient features. You now know why parallel circuits are used in wiring, how to obtain the value of current drawn by an electric equipment of given wattage (see box above), what is the importance of the earth wire in the power circuit etc. With this, you are ready to undertake the fabrication of an extension board. However, you need to understand the circuit diagram of the extension board before you wire its various components. Therefore, now we discuss various electrical components of an extension board and how they are connected.

7.4 ASSEMBLING AN EXTENSION BOARD

The basic activities involved in assembling the extension board are to wire switches, sockets and plugs in accordance with a circuit diagram. Therefore, let us first know about these components and the proper method of connecting them in a circuit.

A. Electrical wires

Electrical wires are made of copper because copper is a good conductor of electricity and relatively inexpensive. In recent years, there is an increasing trend towards the use of aluminium. As you know from your school physics course, the current carrying capacity of a wire depends on its area of cross-section, and hence on its diameter. The thickness of the wire used for electrical wiring is expressed in terms of its **gauge.** The gauge of a wire is inversely related to its diameter. This means that a thick wire will have a smaller gauge. Electrical wires are categorised for different uses in terms of its gauge. A three-core electrical wire is shown in Fig.7.4a. For identifying the live, neutral and earth wires, a colour coding scheme is used. The live wire has red insulation, the neutral wire has black insulation and the earth wire has green insulation.

It is, therefore, obvious that the selection of the copper wire for the extension board would be determined by the maximum current that is likely to flow through it. Thus, you must have an idea about the maximum current which is likely to flow when an appliance or an equipment is plugged in the extension board. This can be easily calculated if you know the power rating of the equipment (see margin remark). **Generally, for equipment used in a typical physics laboratory, it is safe to assume that not more than ISA current would flow through the cable at any instant of time. Therefore, you should take copper wire gauge of 20 gauge for making an extension board.** In India, the terminology usually used for wires by electricians is 7/20, 3/20, 1/18, 3/22 where the first digit signifies the number of strands of wire and the second digit signifies the gauge. For power, 7/20 wire is used. For light, 5/20 and/or 3/22 may be used. For earthing 1/18 is used.

B. Socket and plug

Now refer to Figs.7.4b and 7.4c which show a 15A three-pin socket, and a 15A three-pin plug, respectively. Nowadays, sockets are available in which both 5A and 15A loads can be plugged in one at a time. Such sockets are called two-in-one sockets (see Fig.7.4b). Both the three-pin socket and the three-pin plug have three terminals, namely, live (*L*) neutral (*N*) and earth (*E*). These terminals have to be connected to the corresponding wires of three-core electrical wire. It is, therefore, important to identify live, neutral and earth wires.

C. Switch

The electric switch (Fig.7.4d) has only two terminals. It is always connected along the live wire

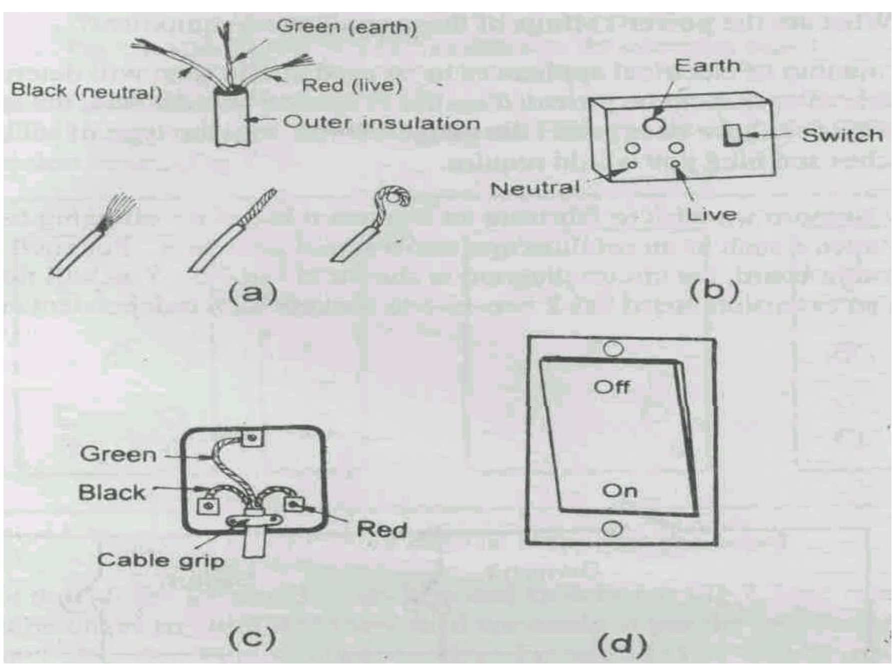


Fig.7.4 (a) Three-core electric wire; (b) two-in-one three-pin socket; (c) three-pin plug; and (d) 15A switch

For connecting the three-core wire in a plug, or a switch or a socket, you will be required to strip its outer insulation for about 3 cm length. Then, the insulation of the three inner wires should be stripped as per the requirement of the socket. Afterwards, you should tightly twist the strands so that the live and the neutral wire do not touch each other (if this happens, it will cause sparking and spoil the plug or the socket). You should **wrap each wire clockwise around the terminals of the socket so that the screws tighten in the same direction.** The same method should be used for connecting wires in a plug or a switch.

We would now like you to answer the' following S AQ.

SAQ1

(a) How will you identify live, neutral and earth wires of the three-core electric wire?

(b) State the precautions in wiring a three-pin socket.

You should proceed ahead only if you are confident about your answers. You may also discuss them with your counsellor.

D. Circuit diagram

For drawing a circuit diagram for an extension board, the following questions have to be considered:

(a) How many electrical appliances/equipment are to be plugged in the extension board?

(b) What are the **power ratings** of these appliances/equipment?

The number of electrical appliances to be used at one time will determine the number of sockets to be provided on the extension board. And, the answer to question (b) above determines the gauge of wire, and the type of sockets, switches and plug you would require.

Now suppose we wish to fabricate an extension board for plugging two instruments such as an oscilloscope and a signal generator. For such an extension board, the circuit diagram is shown in Fig.7.5. You will note that such an extension board has 2 two-in-one sockets with mdependent switches.

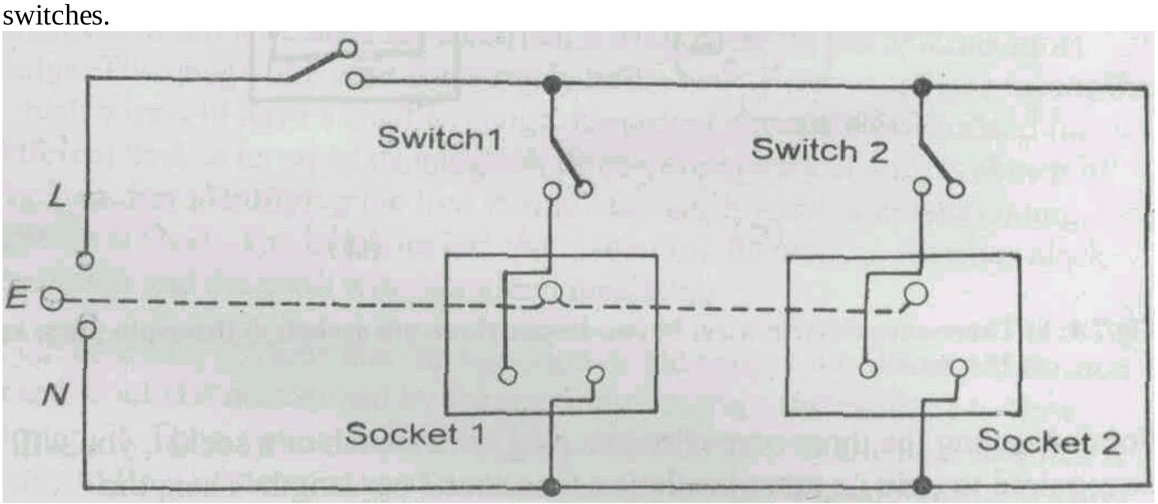


Fig.7.5 Circuit diagram of an extension board

We hope that now you understand the basic principle that determines the choice of various components of an extension board. Now you will learn to assemble an extension board.

E. Procedure

1. Take out the top of the wooden/plastic box for drilling holes in it to fix the sockets and switches (Fig.7.6). With a pencil, mark the points shown in Fig.7.6 for holes. Use a hand drill to drill holes of appropriate size at these points. Fix the sockets and switches in their appropriate positions on the top of the box with screws. Take help of your counsellor for this activity, if need be.

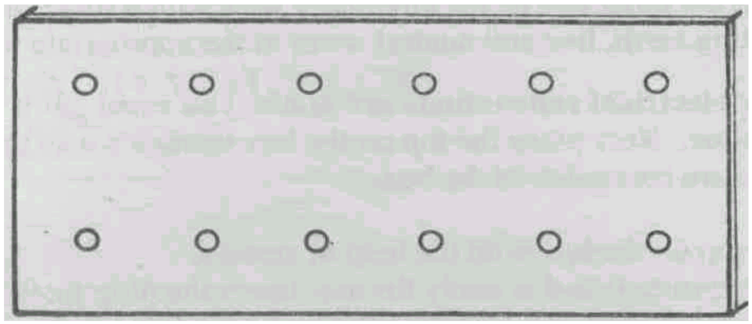


Fig.7.6 Fixing of sockets and switches on the extension board

2. Keep the labelled circuit diagram (Fig.7.7) of the extension board before you. This diagram is the labelled version of the circuit diagram of the extension board (Fig.7.5).

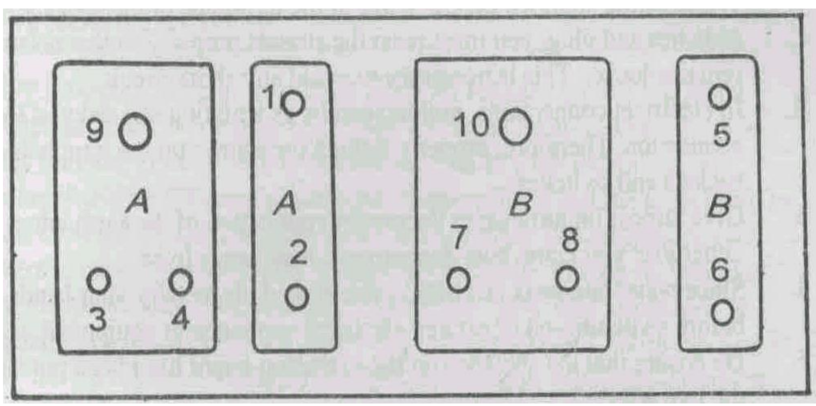


Fig.7.7 Labelled circuit diagram of the extension board

Note that all the terminals of sockets and switches in Fig.7.7 are numbered. You just have to join these numbered terminals as per the instructions given below using the single core wire of gauge 22. You will have to cut this wire into pieces of appropriate length:

(a) Connect points 2 (the lower end of the switch *A)* and 3 (the live terminal of socket *A*).
(b) Connect points 1 and 5 (the upper ends of switches *A* and *B*).
(c) Connect point 6 (the lower end of switch *B)* with point 7 (the live terminal of socket *B*).
(d) Connect points 4 and 8 (the neutral terminals of sockets *A* and *B*).
(e) Connect points 9 and 10 (the earth terminals of sockets *A* and *B*).

Now all the internal electrical connections of the extension board are complete. Let us now join the 5m long three-core wire with the extension board so that it can be plugged into the wall socket.

3. Remove the outer insulation at both ends of the 5m long three-core wire. You will obtain three wires of different colours. Remove the insulation from about 1 cm length of each of these wires.

4. Connect the live wire (red in colour) to point 1 (the upper end of switch *A)* of the extension board.

5. Connect the neutral wire (black in colour) of the three-core wire with point 4 (the neutral terminal of socket *A*).

6. Connect the earth wire (green in colour) of the three-core wire with point 9 (the earth terminal of the socket *A*).

7. Connect the other end of the three-core wire with a three-pin 15A plug connecting earth, live and neutral wires at the appropriate terminals.

After these electrical connections are made, you must get it checked by your counsellor. Now place the top on the box in such a way that all electrical connections are concealed in the box.

8. Fix the top on the box with the help of screws.
9. Your extension board is ready for use. Insert the plug fixed at one end of the three-core wire into a wall socket and switch it on. To check that electricity is available at your extension board, you should use an **electrical tester.**

7.5 SAFETY MEASURES

1. While fixing stranded copper wires at the terminals of the sockets, switches and plug, you must twist the strands properly so that no strand remains loose. This is necessary to avoid any short circuit.

2. In electrical connections, nothing can be as irritating and risky as loose connection. Therefore, properly tighten the screws on the terminals of the sockets and switches.

3. Give utmost importance to the proper connection of the earth wire. Otherwise you know how dangerous it may prove to be.

4. Since water conducts electricity, you should always dry your hands before switching-on or off any electrical appliance or equipment.

5. Do ensure that the switches on the extension board have been put along the live wire.

EXPERIMENT 8
CURRENT AND VOLTAGE MEASUREMENTS

Structure

8.1 Introduction
8.2 Aim
8.3 Getting to Know Ammeters and Voltmeters
8.4 Ammeters and Voltmeters in *DC* Circuits
IV Characteristics of a Resistor
IV Characteristics of a *pn* Junction Diode

8.1 INTRODUCTION

Electricity is now an integral part of our life. Our reliance on it is too much. From Unit 6 of Basic Apparatus in Physics, you may recall why electrical measurements form an important component of physics experiments. And as a lab technician you must be familiar with the principle of such measurements and the tools used. In almost all experiments on electricity and electronics, we use **ammeters** and voltmeters to measure current and voltage, respectively. Therefore, you must learn how to handle these instruments. In particular, you must know how to connect them in a circuit and use them to make measurements. With this aim in mind, we have designed some activities and experiments involving ammeters and voltmeters. Recall that you have studied about these meters in Unit 6 of this course.

In the activities and experiments you do now, you will use ammeters and voltmeters in *DC* circuits only. In particular, you will study the variation of current with applied voltage in a resistor and a *pn* junction diode. This exercise will also help you to understand the behaviour of these devices. You should take about 4 hours to do this experiment.

In the next experiment, you will learn to use the cathode ray oscilloscope to measure *AC* voltages.

8.2 AIM

In this experiment you will learn to select and use appropriate meters for various current and voltage measurements. You will also learn how to take care of these instruments.

After doing this experiment, you should be able to:

- identify the ammeters and voltmeters and state their ranges;
- select the appropriate meters required for various current and voltage measurements;
- measure direct currents and voltages in circuits containing resistors and *pn* junction diodes;
- plot the *IV* characteristics of a resistor and *apn* junction diode; and
- maintain the ammeters and voltmeters in good working condition.

The apparatus required for this experiment is listed below.

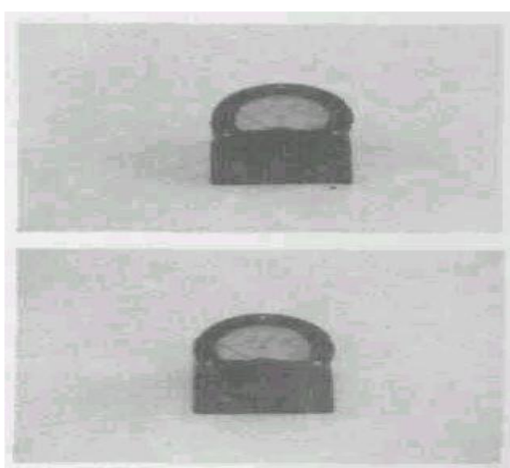


Fig. 8.l Analogue ammeters and voltmeters in a physics laboratory

Apparatus

Ammeters and voltmeters of different ranges, rheostat, *DC* power supply, resistors, resistance boxes, one way key, *pn* junction diode and connecting wires.

8.3 GETTING TO KNOW AMMETERS AND VOLTMETERS

In the laboratory you will find ammeters and voltmeters in different ranges. There would be two types of devices, digital and analogue. You may recall from Unit 6 that in digital devices, measurements appear as numbers on a display panel. In the analogue type, the deflection of the pointer is read on a scale to obtain the reading (Fig. 8.l). In Unit 6, you have also learnt that ammeters can be used to measure currents in different ranges—from microamperes to a few amperes. Similarly, voltage measurements may range from millivolts to a few volts.

An important point to remember when doing an electrical experiment is that **we should always connect the meter of appropriate range in the circuit.** Otherwise, the measurement will not be as accurate as needed. We have explained this point in detail in Sec. 6.2.1 of Unit 6 and we advise you to read that section again.

For brevity, let us consider an example. Suppose we connect an ammeter of the range 0 to 1A and least count 0.1 A in an experiment involving a *pn* junction diode. Since the current in a *pn* junction diode is of the order of a few mA, the deflection of the pointer on the meter would be too small. You may not even be able to take a reading. And if you are, it may not be of the desired accuracy. Therefore, **it is important that you get familiar with the ammeters and voltmeters in different ranges and learn which of them to use for what measurement.**

For this purpose, we would like you to do the following activity before you start doing the experiment.

Activity

(a) Identify at least ten ammeters and voltmeters in 5 different ranges. Write their ranges and least counts in the first two columns of Observation Tables 8.1 and 8.2. In Experiment 1 you have learnt that **the least count of an instrument is the minimum value that it can measure. In ammeters and voltmeters it is the value of the smallest division on the scale.** For example, if 10 divisions on the ammeter scale equal 1A, its least count is 0.1A.

(b) Find out from your counsellor the experiments in which each of these meters is used and complete the tables.

(c) Do any of these meters have zero error? Discuss with your counsellor what is to be done in such cases.

Observation Table 8.1: Ammeters in a physics laboratory

Current and Voltage Measurements

S.No.	**Range**	**Least count**	**Name of the experiment**
1.			
2.			
3.			
4.			
5.			
6.			

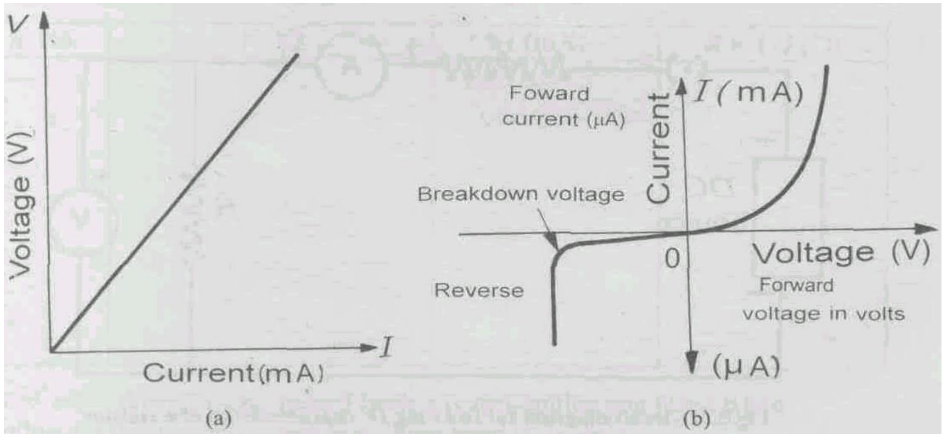
Observation Table 8.2: Voltmeters in a physics laboratory

S.No.	Range	Least count	Name of the experiment
1.			
2.			
3.			
4.			
5.			

With these activities, you will be able to select a meter of appropriate range for any given experiment. You can now use these meters to make current and voltage measurements in *DC* circuits.

8.4 AMMETERS AND VOLTMETERS IN *DC* CIRCUITS

In order to familiarise you with the use of ammeters and voltmeters, we have devised two simple experiments involving *DC* circuits: obtaining the *IV* characteristics of a resistor, and a *pn* junction diode. You have studied about these characteristics in Units 5 and 6. You may recall that these curves are important because they characterise a device and reveal its properties. For example, if you are given a device and you want to find out whether it is a resistor or a *pn* junction diode, all you require to do is to plot its *IV* characteristics. If it is a straight line, the device is a resistor (Fig.8.2a); if it is a curve like Fig.8.2b, it is a *pn* junction diode. These characteristics suggest the many ways in which *pn* junction diodes and transistors can be used and how.



(b) Fig.8.2: *IV* characteristics of (a) a resistor; and (b) a *pn* junction diode

8.4.1 *IV* Characteristics of a Resistor

In this experiment, you will plot the *IV* characteristics of the given resistor. In doing so, you will learn how to select an ammeter and a voltmeter of the correct range and connect them properly in the given circuit. You will also learn how to handle them properly and take care of them. Before you actually perform the experiment we briefly recall the basic concepts to refresh your memory. You have learnt in Sec. 5.2 of Unit 5 that for a resistor

$$V = IR$$

where V is the voltage across it and I, the current through it.

When we plot the measured values of current I along the x-axis and voltage V along the y-axis, we get a straight line whose slope gives the value of resistance in the circuit. This plot, as you know, is called the *IV* characteristic of a resistor.

> Normally, we should plot V along the x-axis as it is the independent variable. However, in plotting *IV* characteristics for a resistor, we plot V along the y-axis because the slope of the straight line directly gives the value of R.

When doing experiments involving electrical circuits, you must always keep in mind the following factors:

- All connections in the circuit should be tight. Loose connections can cause trouble.
- If by mistake you make a wrong connection, heavy current may pass through devices and damage them. Therefore, after making circuit connections and before allowing current to pass, ask your counsellor to check the circuit. Switch on current only when you know that all connections are right. Allow the current for only as long as needed for taking the necessary readings. Never let current flow unnecessarily in a circuit.
- Always take care to connect the positive and negative terminals in a proper manner while using ammeters, voltmeters, electrolytic capacitors, etc.
- While using a cell – especially a storage cell – always use a resistance in series with it. Do not allow the cell to be short-circuited.

- Do not connect sensitive apparatus like the galvanometer, ammeter etc. directly with a cell.

Setting up the apparatus

Connect a *DC* power source to a key, ammeter, rheostat, resistor and voltmeter as shown in the circuit diagram given below (Fig.8.3).

Notice here that you are using a rheostat as a variable resistance.

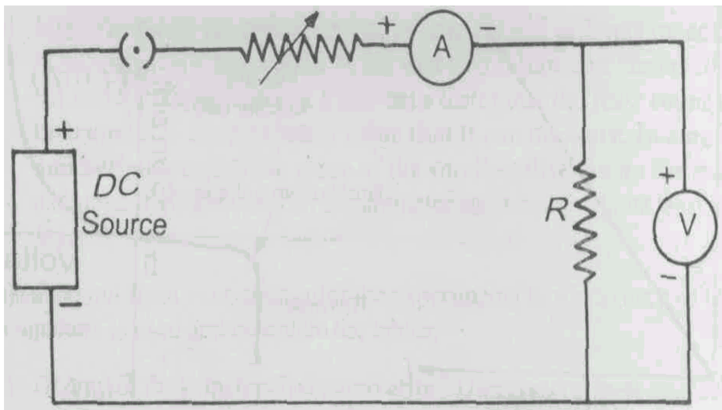


Fig.8.3: Circuit diagram for drawing *IV* characteristics of a resistor

The choice of the ammeter and voltmeter will depend on the value of the total resistance in the circuit. In the first instance, select a resistance of known value. Decide on the range of the *DC* source. Depending on the range of V and the total resistance, including that of the rheostat, you will know the range of the current. For example, if the *DC* source provides voltage ranging from

0 to 5V and $R = 1000\ \Omega$, current will range from 0 to $\dfrac{5V}{1000\Omega}$ = 0.005A = 5mA.

Thus your voltmeter should be in the range 0 to 10V and ammeter in the range 0 to 10mA. After selecting the meters for a given *R*, connect them in the circuit, as shown in Fig.8.3. To begin with, set the rheostat slider to include the maximum resistance in the circuit.

Ask your counsellor to check the circuit connection. Plug in the key, only when they are told to be correct.

When you plug in the key, the circuit is complete and some current should flow for a finite voltage. Note whether you get a deflection in the meters. If you don't, check once again whether you have made the connections properly. If the problem remains, seek the help of your counsellor.

Once the circuit is satisfactorily connected, follow the steps given below.

1. Vary the voltage in the circuit by moving the slider across the rheostat.
2. Start from the value 0V across the resistor *R*. The corresponding current in the ammeter should be OA. Do you observe anything to the contrary? If so, discuss with your counsellor. Otherwise record your reading in Observation Table 8.3.

3. Increase the voltage across R in small steps by moving the slider of the rheostat. Note the corresponding current in the circuit for each voltage.
4. Record at least 8 to 10 values of currents and voltages and tabulate them in the Observation Table 8.3 by repeating the above steps.

You should not pass current through the resistor continuously for a long time as it would get heated up and the value of its resistance may change.

Connect the positive and negative terminals of the ammeter and the voltmeter as shown in the circuit. The positive terminals of the ammeter and voltmeter should always be connected to the positive terminal of the *DC* power source. If by mistake you reverse the connections, the meters will get damaged.

Observation Table 8.3: Measurements of current and voltage across a given resistor

S.NO.	V(V)	I (mA)	$R = V/I(\Omega)$
1.			
2.			
3.			
4.			
5.			
6.			
7.			
9.			

Now write down in your record book any difficulties you faced when following this procedure and how these were overcome.

Draw a graph by plotting V along the *y-axis* and I along the x-axis. Paste it in your record book. The slope of the straight line gives the value of the resistance R. Calculate the slope by using the maximum possible intercept on the straight line:

R = Slope of the *VI* graph

$$= \frac{V_2 - V_1}{I_2 - I_1} = \ldots\ldots\ \Omega$$

In your record book, note down the precautions you observed while doing this experiment.

Now write answers to the following questions and submit them to your counsellor as you will be assessed for them.

1. Suppose the current in your circuit were of the order of 50 mA and you had connected an ammeter of the range 0-10 mA. What would have happened? What precautions would you observe to avoid this?
2. Why do you keep the rheostat slider at maximum in the beginning?
3. Do you get a straight line graph? If not, explain why?
4. What possible errors can damage an ammeter and a voltmeter? What should you avoid doing to prevent this damage?

8.4.2 *IV* Characteristics of a *pn* Junction Diode

This experiment is similar to that performed with a resistor. However, the *pn* junction diode is a very sensitive device and can get easily damaged if not handled with extra care. Moreover, the ammeter and voltmeter used will be of different ranges.

As you have learnt in Sec. 6.3 . 1 of Unit 6, the *pn* junction diode is a semiconducting device and allows flow of current, which is of the order of a few mA, in only one direction. Its *IV* characteristics are shown in Fig.8.2b. In order to avoid damage to the diode, you should first find out its ratings from your counsellor and note them down.

Ratings of the diode:

Maximum voltage V = ...
Maximum reverse voltage V_R = ...
Maximum power P = ...

Since $P = VI$, you can easily determine the maximum current that can flow in the circuit without damaging the diode. Write it here.

Maximum allowed current / = ...

You must take care never to exceed these ratings in your experiment.

This information will also help you select the ranges of the *DC* power source and the meters, and prevent damaging the diodes you use.

You can now do the experiment using the following steps.

1. Connect the circuit as shown in Fig.8.4a. Notice that the/j-end of the diode is biased positively. Therefore, this is the **forward bias.** For making this connection note whether or not the *p*-and *n*-ends are marked on the diode. If not, use a multimeter to identify these ends using the method you have learnt in Experiment 6. Seek your counsellor's help if you are not sure.

2. After making the connections, ask your counsellor to check the circuit. You should begin only when the circuit connections are found to be correct.

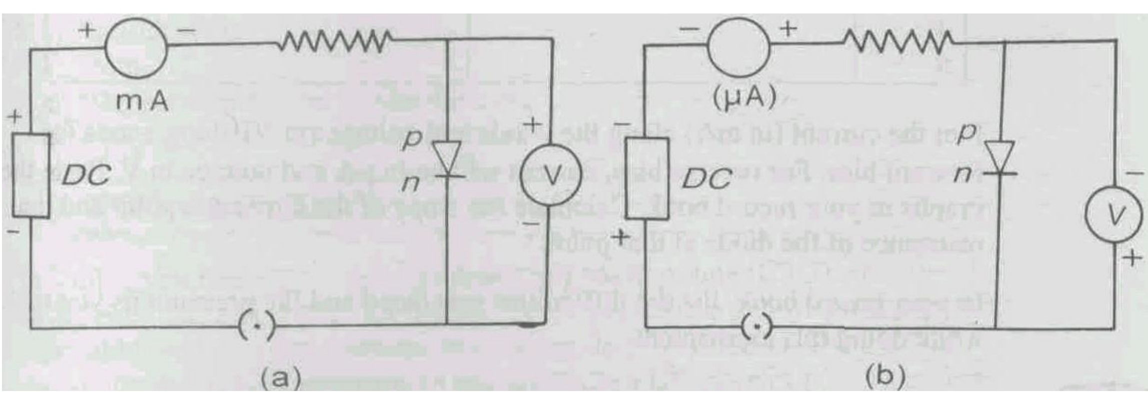


Fig.8.4 Circuit diagram for the *IV* characteristics of a *pn* junction diode in (a) forward bias; and (b) reverse bias.

3. Set the value of the resistance in the circuit at about 1000 Ω by taking out appropriate plugs from the resistance box.

4. Set the voltage from the *DC* power supply at 2V and plug in the key. If the connections are proper, you would note a deflection in the meters. Check your circuit if there is no deflection. Ask for your counsellor's help if you cannot solve the problem.

5. Reduce the value of the resistance in steps of 100Q by inserting appropriate plugs in the resistance box. Record the readings of voltmeter and ammeter in Observation Table 8.4.

   Do not reduce *R* to such a low value that the current exceeds the rating specified for the diode. Excess current will destroy it.

Now connect the circuit as shown in Fig.8.4b with the voltage from *DC* power supply at 0V. This is the **reverse bias** since the *p*-end of the diode is biased negatively. Increase the voltage in steps of 0.5V and measure the current. Stop much before reaching the maximum **reverse voltage** for the diode. Record your readings in Observation Table 8.5.

Observation Table 8.4: Currents and voltages across a *pn* junction diode in forward bias

Least count of voltmeter = ... V

Least count of ammeter =...................... A

S.No.	Voltage (V)	Current (mA)
1.		
2.		
3.		
4.		
5.		

There is a certain maximum reverse voltage beyond which the diode gets destroyed. This is also termed the **breakdown voltage** of the diode. This is usually in the range of 20V to 40V.

Observation Table 8.5: Currents and voltages across a reverse biased junction diode

S.No.	Voltage (V)	Current (μ A)
1.		
2.		
3.		
4.		
5.		

Plot the current (in mA) along the *y*-axis and voltage (in V) along the x-axis for forward bias, For reverse bias, current will be in μ A and voltage in V. Paste the graphs in your record book. Calculate the slope of the curve at a point and the resistance of the diode at that point.

In your record book, list the difficulties you faced and the precautions you took while doing this experiment.

Care and maintenance

While doing the experiment, keep all components on a dust free surface. Once you have completed an experiment, you should dismantle the circuit and put the components and devices in their respective places in the laboratory. Keep a dust free environment. This is a very important part of maintenance of these instruments. While doing the experiments, you would have noticed that their maintenance involves

- preventing damage to them due to excess flow of current through them;
- connecting them properly in the circuits; and
- handling and storing them with care.

EXPERIMENT 9
USING AN OSCILLOSCOPE

Structure

9.1 Introduction
9.2 Aim
9.3 Measurements with an Oscilloscope

9.1 INTRODUCTION

In Unit 6, you have learnt that a **cathode ray oscilloscope** (CRO), simply called oscilloscope, is used for measuring the peak value and frequency of alternating voltages and currents, and tracing their waveforms. The CRO is used in quite a few experiments in electronics in a UG physics lab. Therefore, you should learn how to operate and maintain it.

A school or college physics laboratory has simple oscilloscopes with fewer numbers of control knobs on their front panel. You have studied about such an oscilloscope in Unit 6. In this experiment, we will familiarise you with the control knobs of a simple oscilloscope. You will learn how to use the CRO to measure the peak value (amplitude) and frequency of *AC* voltages and currents. You will also get an opportunity to read the manual accompanying a CRO and use it to operate the CRO. You should ask for the manual from your counsellor.

9.2 AIM

The purpose of this experiment is to give you hands-on experience in using and maintaining a simple oscilloscope. You will also make measurements with the help of an oscilloscope.

After doing this experiment, you should be able to:

- identify and state the functions of various control knobs on the front panel of an oscilloscope;
- measure the peak value of *AC* voltage;
- measure the frequency of *AC* voltage; and
- take care of and maintain an oscilloscope.

The following apparatus is required for this experiment:

Apparatus Oscilloscope, signal generator and tracing paper.

9.3 MEASUREMENTS WITH AN OSCILLOSCOPE

Fig.9.1 shows the front panel of a simple CRO. Before you use an oscilloscope for measuring *AC* voltages and currents, you should be familiar with the functions of various controls in a CRO. For this purpose, you should do the following activity.

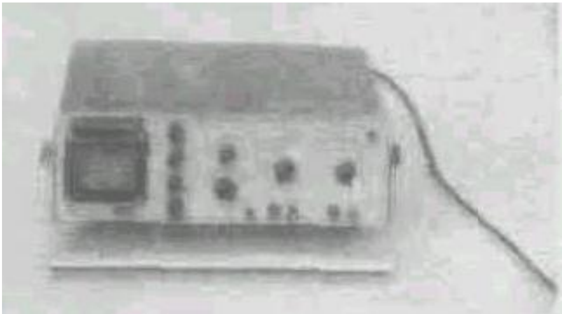


Fig.9.1 A simple cathode ray oscilloscope

Activity

(a) List the control knobs on your CRO. Read the manual accompanying it or read Sec. 6.4 of Unit 6 and write down the functions of the various control knobs.

(b) Using a metre scale, measure and note down the smallest separation that can be measured along the horizontal and vertical axes on the oscilloscope screen.

Discuss the outcome of this activity with your counsellor and if s/he is satisfied, you may proceed further.

The basic features of *AC* voltage are its amplitude, frequency and waveform. In this experiment, you will measure the (i) peak value (amplitude) and (ii) frequency of an applied *AC* voltage, and trace its waveform. *AC* voltage can be applied to the CRO using a **signal generator or oscillator.** A signal generator usually has the following control knobs on its front panel (Fig.9.2):

- **Output terminals:** The *AC* signal is drawn from these terminals.
- **Output amplitude selector:** By adjusting this knob, you can vary the amplitude of the voltage generated by it.
- **Frequency selector:** By adjusting this knob, you can vary the frequency of the output voltage.

There is also an ON-OFF switch to turn the signal generator on. You should familiarise yourself with these controls before proceeding further.

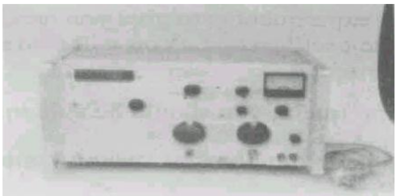


Fig. 9.2 Signal generator

You will now set up the CRO for measuring the peak value and frequency of the *AC* voltage. **However, before you operate the oscilloscope you must carefully go through Sec. 6.4 of Unit 6 taking note of the precautions listed there.**

A. Setting up the CRO

1. Set the CRO in *AC* mode.
2. Set the time base control in off position.
3. Switch the oscilloscope on. Adjust the **focus and brightness** knobs to obtain a spot at the centre of the screen.

As you know, the bright spot at a fixed point on the screen for a long time may damage it. Therefore, after focussing the spot, keep the brightness control switched off until you are ready for measurement.

4. Set the gain control knob to say, 2V c/m. This means that 1 cm on the *y*-axis of the oscilloscope is equal to 2V. Now your oscilloscope is ready for receiving the *AC* input voltage.

5. Set the controls of the signal generator as follows:
   Amplitude: 4V
   Frequency: 100Hz

6. Connect the output of the signal generator to the input (y-terminals) of the oscilloscope as shown in Fig.9.3.

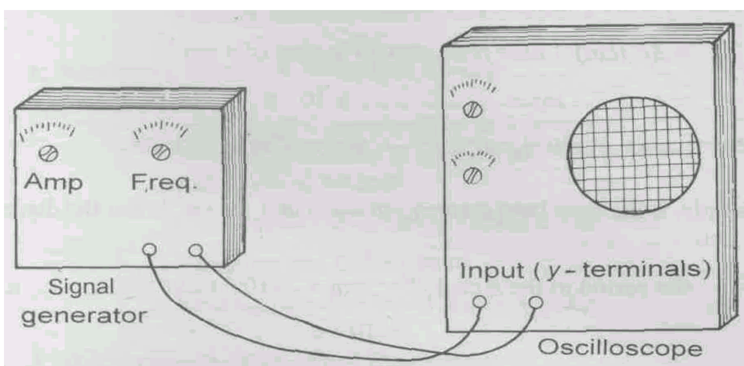


Fig. 9.3 Circuit diagram for connecting an oscilloscope and a signal generator

7. Switch on the signal generator and the brightness control of the oscilloscope. You should observe a vertical line on the screen. If the line is too small or too big (so that it is extending beyond the screen,) adjust the gain control setting to bring it to a moderate height.

8. Turn the time base control on and set the trigger control to automatic. Adjust the x-shift, the y-shift and the time base controls to obtain a stable sinusoidal waveform on the screen as shown in Fig.9.4.

9. Trace the wave form of the signal on a tracing paper.

You can now determine the peak value and frequency of the *AC* signal as follows.

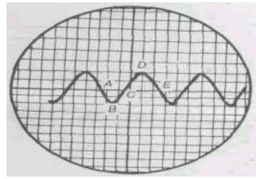


Fig.9.4 Wave form of the signal on the CRO screen

B. Measurement of peak value

1. Note down gain control setting: ……... V/cm
2. Count the number of divisions along the *y*-axis covered between points *B* and *D* of Fig.9.4. Note down the distance *d*, in cm, between these points: ....cm
3. The peak to peak value of the *AC* voltage,

$$V_p = d\,\text{(cm)} \times \text{gain control setting (V/cm)}$$

$$= \text{…………} \text{ V}$$

The peak value of the *AC* voltage is obtained by dividing the peak to peak voltage by 2.

4. Peak value of *AC* voltage = ...…. V.

ms/cm stands for milliseconds per centimetre. Time base control settings are usually in μ s (10^{-6} s), ms (10^{-3} s) and s.

For the gain control setting at 2V/cm, the distance between *B* and *D* should be 4 cm corresponding to the given input signal. Therefore, the peak-to-peak voltage is 2 V/cm × 4 cm = 8 V and the peak value is 4 V.

Note: To measure the distance *BD* accurately, make sure that either B or D touches a horizontal line. To achieve this, use the *y*-shift control knob.

C. Measurement of frequency

1. Note down the time base control setting:............ ms/cm.
2. Use the y-shift to adjust the wave form so that either point *A* or *E* shown in Fig. 9.4 touches a vertical line.
3. Note down the distance between points *A* and *E* along the x-axis: ...…...cm
4. The time period *T* of the signal

= *AE* (cm) x time base control setting (ms cm''^{1}).

= ...…...... ms = ... $\times\ 10^{-3}$ s

5. The frequency of the signal, $f = \dfrac{1}{T}$, where T is in seconds.

For example, if the time base control setting is at 2 ms/cm, and the distance AE = 5 cm,

$$\text{the period of the signal, } T = 5\text{cm} \times 2\times10^{-3}\ \text{s/cm}$$

$$= 10^{-2}\ \text{s}$$

Therefore,

$$\text{frequency of the signal} = \frac{1}{10^{-2}}\ \text{Hz} = 100\ \text{Hz.}$$

Keeping the settings of the signal generator fixed, change the gain control and again obtain a stable waveform. Repeat the calculations above. You should get the same results.

Repeat the entire procedure for at least three different settings of amplitude and frequency of the signal generator and tabulate your results. Compare the values you obtain with the corresponding settings of the signal generator.

For each setting of the frequency of the signal generator, you will have to adjust the time base control knob of the oscilloscope to obtain a stable waveform.

List the precautions you have taken while using the CRO in this experiment.

APPENDIX

	Experiments		Marks
1.	**Measurements in Physics**		**(10)**
		Handling of vernier callipers and screw gauge while taking observations for Observation Tables 1.1 and 1.2	3+3
		Solving SAQ 1 and other exercises given in the text	2
		Viva on care and maintenance aspects	2
2.	**Stationary Waves in Stretched Strings**		**(10)**
		Setting up of experimental arrangement, including handling of sonometer, tuning fork and physical balance	4
		Completing Observation Tables 2.1 and 2.2	2
		Graphing and Calculations	2
		Viva on care and maintenance aspects	2
3.	**Measurement of Thermal Properties**		**(10)**
		Setting up of experimental arrangement for specific heat capacity of water and completing	4

	Observation Table 3.1	
	Setting up of telescope and optical lever arrangement and completing Observation Table 3.2	3
	Graphing and Calculations	1
	Viva on care and maintenance aspects	2
4.	**Investigations with Mirrors and Lenses**	**(5)**
	Activity in Sec. 4.3	1
	Setting up of experimental arrangements and completing Observation Tables 4.1 and 4.2	3
	Viva on care and maintenance aspects	1
5.	**Working with a Spectrometer**	**(15)**
	Adjusting the telescope, prism table, collimator and levelling the spectrometer	4
	Handling of prism, sodium/mercury lamp and observing spectra	3
	Completing Observation Tables 5.1 and 5.2	2+2
	Graphing and calculations	2
	Viva on care and maintenance aspects	2
6.	**Handling and Maintaining a Multimeter**	**(15)**
	Activity in Sec. 6.3	2+1+1
	Measurement of resistance, *AC* and *DC* currents and voltages and testing the continuity of a wire	4
	Testing an electrolytic capacitor, *pn* junction diode, *pnp* and *npn* transistors	4
	Using the multimeter for identification of *p*- and *n*-ends of a *pn*-junction diode and emitter, base and collector terminals *of npn* and *pnp* transistors	1
	Viva on care and maintenance aspects	2
7.	**Fabrication of an Extension Board**	**(10)**
	Identification of live, neutral and earth terminals	1

		of a socket and three core electrical wire	
		Assembling the extension board including the quality of joints, placement of sockets and switches on the board	7
		Viva on care, maintenance and safety aspects	2
8.	**Simple Current and Voltage Measurements**		**(10)**
		Activity in Sec. 8.3 and completing Observation Tables 8.1 and 8.2	1+1+1
		Setting up the experimental arrangements for handling ammeters and voltmeters and completing Observation Tables. 8.3, 8.4 and 8.5	4
		Plotting *IV* characteristics of resistor and a pn-junction diode; obtaining results and calculation of errors	1
		Viva on care, maintenance and safety aspects	2
9.	**Using an Oscilloscope**		**(15)**
	Activity in Sec. 9.3		4+1
	Adjusting the signal generator for a sine wave output		2
	Setting an oscilloscope to display the sinusoidal signal		3
	Measurement of peak value and frequency of *AC* signal		3
	Viva on care, maintenance and safety aspects		2