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UNIT 1 AN INTRODUCTION TO THE PHYSICS LABORATORY

Structure

1.1 INTRODUCTION

In the first course of this programme entitled Good Laboratory Practices (LT-1) you have learnt about a laboratory in general. This course is about the **physics laboratory**. And in the first unit of this course, we give you a general introduction to the physics laboratory. We begin by taking a brief tour of the laboratory, look at what it has and the way things are arranged in it (Sec. 1.2). You already know that every lab has certain utilities like electricity, water and gas supply. So in Sec. 1.3 you will also learn about the utilities that a physics lab has and how these should be maintained.

You will find a variety of instruments of all shapes and sizes in a physics lab. As a technician in the physics lab, you will be responsible for their storage, handling and maintenance. But do not let this fact scare you. All these instruments can be sorted out into a few groups. Then understanding how to store, handle and maintain them becomes far easier. This is what you will learn in Sec. 1.4.

This unit presents a bird's eye view of a physics laboratory. It would be better if you read this unit sitting in a physics laboratory. From Unit 2 onwards we shall start discussing various aspects of a physics lab in detail.

Objectives

After studying this unit, you should be able to:

- state what a typical physics laboratory contains and how things are arranged in it;
- discuss the factors involved in maintaining utilities in a physics lab; and
- classify physics apparatus according to its use.

1.2 KNOW YOUR PHYSICS LABORATORY

Enter your physics laboratory and look around. What do you see? How are things arranged in it? In Fig.1.1, we have put together some photographs of a general physics laboratory. The first thing that may come to your mind is that there is a **large variety of instruments** in the lab. Some of these instruments may be lying on tables. You will see some apparatus kept on slabs around the walls of the lab. And some instruments can be seen in almirahs. There would definitely be water and electric supply in the lab. Inside the lab you would also notice space for lab staff, teachers and students to sit. Some labs with enough space may have separate rooms for the staff.

The **dark room** is not necessarily found in schools which usually have only a general laboratory.

As you walk around the lab, you may discover a **dark room** attached to it. It is used to perform those experiments which cannot be done in the general lab which is usually well lit.

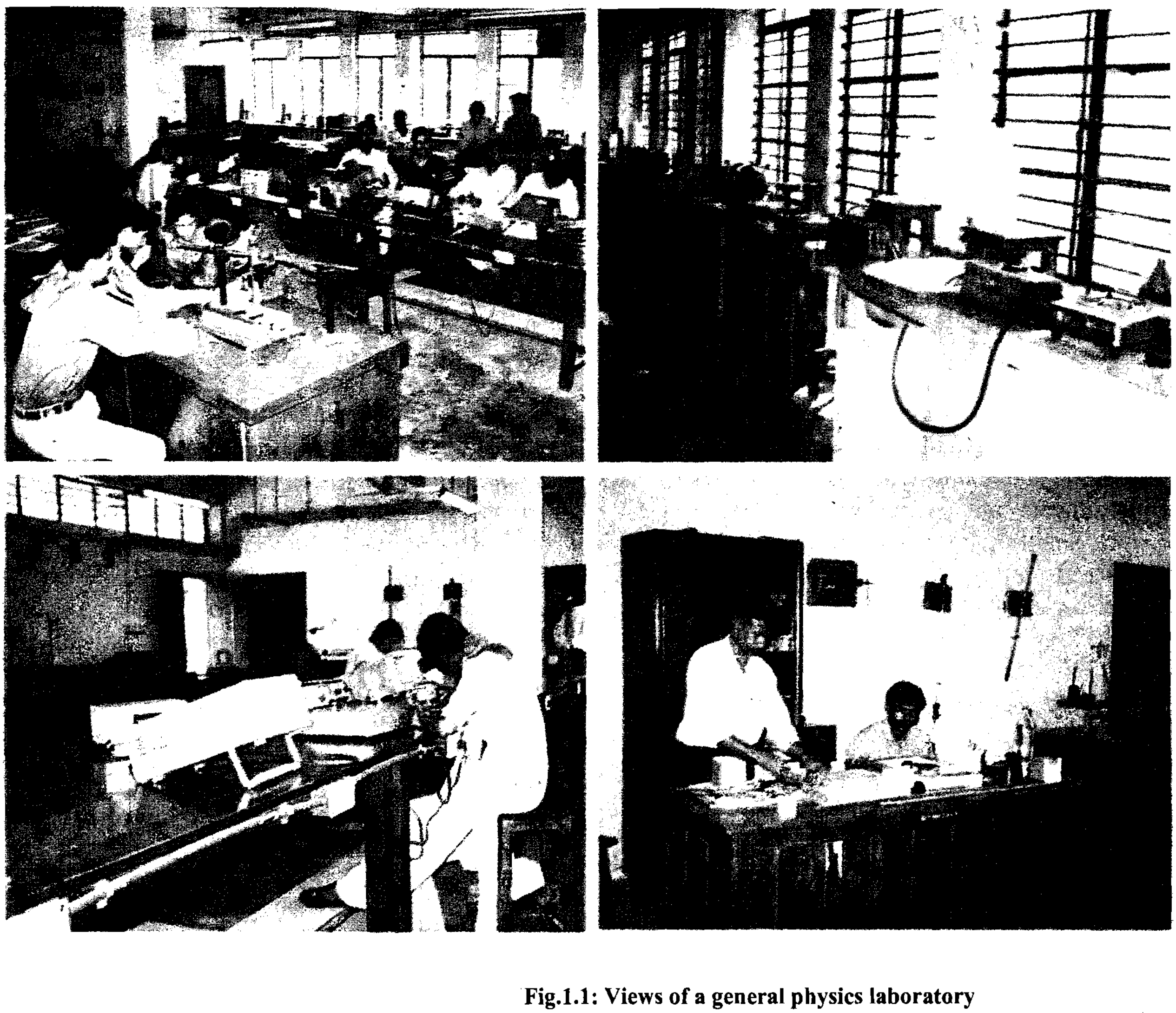


Fig.1.1: Views of a general physics laboratory

We hope that you have formed a general first impression of a physics lab. Let us now get down to the details.

1.2.1 What the Lab Contains

As you have read above and seen in Fig.1.1, a physics lab generally contains

- physics apparatus and tools
- tables to keep apparatus and do experiments on, almirahs and racks to store the apparatus, trolleys to move equipment around and stools and chairs to seat the lab staff, teachers and students
- fixtures like slabs and brackets on the wall, fans, tube lights, etc. and
- utilities like electricity, water and gas supply.

You know very well that electric power supply is essential to any lab. You will surely have an electric mains, a fuse box or Miniature Circuit Breakers (MCBs). You may find wires running on the surfaces of walls. In a newly built lab, the electrical wiring may be concealed inside the walls. There will be electrical fixtures and fittings like sockets, tube lights, bulbs, fans. There will also be water pipes, taps and sinks in the lab. Of course, as you have studied in Unit 12 of the course LT-1, a fire extinguisher is a must in any lab. There may or may not be arrangement for gas supply. All these utilities need to be maintained properly and we will take this up in Sec. 1.3. Right now we take up the question: How are all these things arranged in the lab?

1.2.2 Laboratory Arrangements

Remember that the space in the lab has to be used for many purposes:

- each experiment has to be set up in a certain area;
- students should have enough room to do the experiment and move around;
- equipment has to be stored properly and there has to be some area for carrying out repairs;
- teachers and lab staff should have sitting space.

The lab space has to be used optimally to satisfy all these needs. It is important that these needs are met in a way that the lab does not look cluttered and cramped. In fact, a general physics lab should look spacious, airy, well-lit and neat. The windows in the lab allow in light and air to make the lab well-lit and well-ventilated. **Maintaining cleanliness in the lab and arranging things neatly will be your job.** That leaves the task of managing space. Let us see how it can be done.

The most convenient space for setting up general experiments is on tables and on slabs along the wall. That is why you find huge tables placed in a central area of a physics lab. They are usually of such dimensions (length, breadth and height) that at least two experiments can be set on either side. Thus four or more students can do these experiments conveniently. There are several stools around each table for sitting.

Experiments needing electric supply are usually arranged on slabs. In some labs, electric power connections are also provided on the tables. You may have to use extension boards to provide electric supply on tables. You might also find trolleys in some of the better equipped labs. These trolleys are used to carry some of the heavier instruments which are fewer in number and may need to be moved around.

Space for storing equipment and tools is generally created in one corner of a lab. Almirahs and racks can also be used to partition a huge hall and create sitting space for the lab technicians. Sometimes separate rooms are used as stores. Teachers usually sit in the lab in areas from where they can supervise the entire lab. So they know what is going on in the lab at any time!

You may like to further understand what you have read so far by answering the following SAQ.

SAQ 1: Arrangement in a physics lab

Study Fig.1.2 showing two views of a physics lab and answer the questions following it.

(a)

(b)

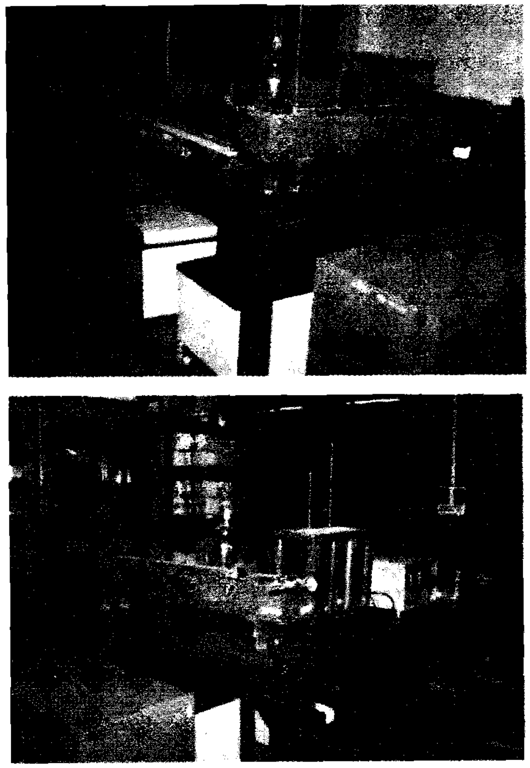


Fig.1.2: A physics laboratory

a) What furniture does this physics lab have?

b) Can the arrangement of the lab be improved? Give suggestions to use the available space in the best possible way.

As we have mentioned in the beginning of Sec. 1.2, in most undergraduate physics labs you will find a dark room for experiments on light and electricity. We now briefly describe what a dark room contains and how it is arranged.

1.2.3 Dark Room Arrangements

As the name suggests, a dark room is a space where no light is allowed from outside. We ensure this by hanging heavy black curtains on the windows or by painting the glasses black. There is, of course, electric supply in the room. However, light is switched off when experiments are being done. We need a dark room to do some experiments on optics and electricity. Experiments on electricity require a ballistic galvanometer and a lamp and scale arrangement. Experiments on optics require special sources of light like sodium lamp and mercury lamp. The lamp is kept inside a rectangular wooden box with slits on all four sides. Spectrometers are arranged around it in such a way that two to four experiments can be done with a single lamp. Of course, all these things are kept on tables in the middle of the room. Experiments requiring optical benches are usually arranged on slabs.

When you go to a physics laboratory for your practical work, visit the dark room and write answers to the following questions:

How has the room been made dark?

____

____

What does it contain?

____

____

Let us now consider the general utilities in a physics lab and learn what is required to maintain them.

1.3 GENERAL UTILITIES IN THE LAB

Electricity, water and gas are the general utilities available in every undergraduate physics laboratory. In Units 11 and 12 of the course LT-1, you have already studied in some detail how to manage and maintain these utilities. Therefore, here we talk about them very briefly.

1.3.1 Maintenance of Utilities

Let us first consider the electric supply.

A. Electric supply

Electricity in a lab is supplied through electrical wires from the mains. **As a lab technician you have to see to it that the electrical wiring, switches, sockets, fittings such as fans, tube lights and bulbs, and other connections in your lab are fault free and well maintained**. So here we will tell you about some possible faults. We will also suggest what you can do to remedy them.

Possible Faults	Action required
• Power Failure	- Check whether there is a general power failure. If so, you can only wait for electricity to be restored! - Check whether the main fuse is in place or the MCB has tripped; if the fuse is blown up, replace the fuse wire (refer to Unit 11 of LT-1) or reset the MCB. If the MCB trips again, call the electrician.

	- There may be a power failure in only one portion of the lab. It may happen due to a short circuit in the wiring of that area. Call an electrician to locate the fault and set it right.
• Damaged or exposed wiring/Sparking	- Check wiring and report frayed or exposed wires so that these are replaced promptly and regularly. - If there is sparking anywhere, switch off the mains and report the fault. Call an electrician to fix it.
• Electric supply failure at specific electric points, e.g., sockets, switches etc.	- Call an electrician to fix the fault.
• A possible fault other than those listed above may arise due to instruments which are not properly earthed. Such instruments may give electric shocks.	- Check whether all instruments are properly earthed (as explained in Unit 11 of the course LT-1) before issuing them to the students to avoid mishaps. You should ensure that all instruments are connected to the mains through three-pin plugs carrying the earth wire.

In addition, make sure that **electrical connecting wires are not located near the water and gas supply.**

B. Water and gas supply

Water in a lab is supplied from water tanks through pipes to sinks. The possible faults in water supply can occur due to leakage or overflow from water tanks or in joints, water pipes or taps. So you have to see to it that

- the tank, pipes and taps are maintained in good condition; and
- there are no leaks, overflows and wastage of water.

If the taps are leaking, you should check and get the washer replaced. If the fault is serious, you may need to call the plumber.

For maintaining the gas supply,

- keep the burners clean;
- check the regulators and pipes for leaks to prevent gas leaks in the lab;
- get the tubes and pipes supplying gas checked regularly and change them if need be; and
- do not use cracked pipes and gas tubes.

Always remember to ensure that the gas supply is turned off before leaving the lab. The consequence of a leaking gas supply would be extremely dangerous. Be extra careful in handling it.

If there is a gas leak in the lab, ask everyone to leave the lab and take the necessary measures explained in Sec. 11.3 of Unit 11 of the course LT-1.

As you have read just now, as a lab technician you are also expected to repair minor faults. You may ask: How may you do it? What tools are needed and how to use them?

We take up these questions now. But before that we want you to answer some questions.

SAQ 2: Utilities in a physics laboratory

a) What general utilities do you expect in a physics lab? List in the form of a table the possible faults that each one of them can develop.

b) What would you do if on entering the physics lab you smelt gas leaking from an LPG cylinder?

One of your duties as a lab technician will be to carry out simple repairs in the laboratory. You will also be required to maintain equipment and replace parts whenever needed. For all these tasks, you will need a set of tools. You should therefore learn about them.

1.3.2 Basic Tools

Basic tools required for small repairs in the physics laboratory are shown in Fig.1.3. These include **files, multipurpose screwdrivers, combination pliers, hacksaw**.

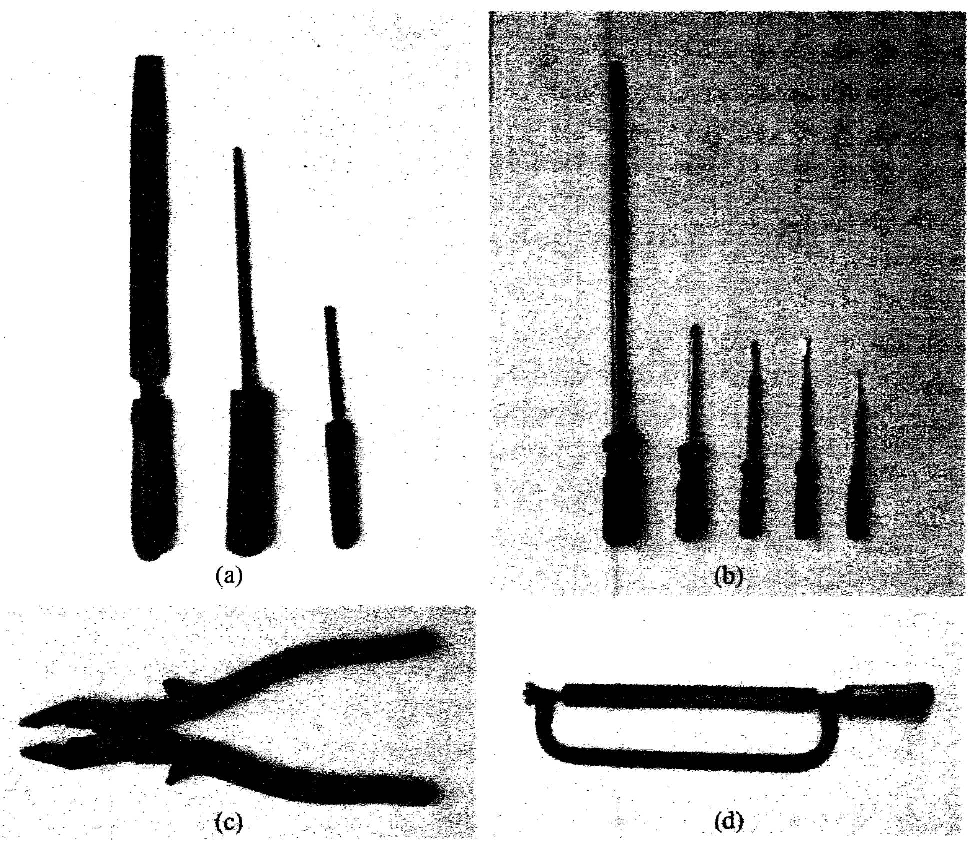
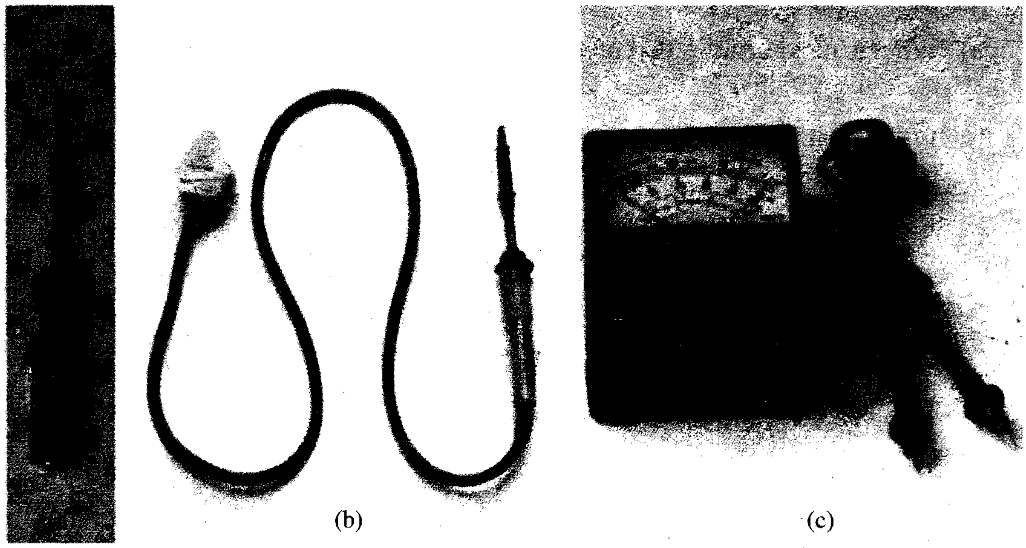


Fig.1.3: Basic tools in a physics laboratory. a) Files; b) screwdrivers; c) combination pliers; and d) hacksaw

These tools are very simple to use. Indeed it would not take you much effort to learn how to use them. You will learn how to handle these tools in various practical sessions of this course. In addition to these mechanical tools, some other devices (Fig.1.4) are needed in the maintenance of electrical and electronic equipment. These are **tester**, **soldering iron** and **multimeter**.

You will learn about them in detail in Units 2 and 6 and Experiments 6 and 7 of this course.



(b) (c)

Fig.1.4: a) Tester; b) soldering iron; and c) multimeter

Your main work in the physics laboratory is to identify, maintain, use and store the **physics equipment** safely and correctly. Therefore, we now come to the most crucial section of this unit.

1.4 PHYSICS APPARATUS

There is indeed a wide variety of instruments in a physics laboratory. However, we can simplify our work by broadly classifying apparatus according to the area of physics in which they are used. Of course, some apparatus can be used in many areas. In this section we first classify the physics apparatus according to their use. You will also learn the precautions to be taken for the proper maintenance of some of the basic apparatus.

1.4.1 Broad Classification

We can classify the apparatus in a physics lab in the following broad areas:

a) Basic/General Apparatus including the ones used for experiments in mechanics, heat and sound.

b) Optical Apparatus.

c) Electrical and Electronic Apparatus.

Let us now consider these one at a time.

A. Basic/General apparatus

Some of the basic apparatus is used across all areas of physics. For example, retort stands, clamps, wooden rulers, stop watches, glassware like beakers, cylinders, flasks and capillary tubes, and springs etc. are used in many experiments. We have shown these instruments in Figs.1.5 to 1.9.

Retort stands are used along with clamps of many types for suspending or holding objects such as simple pendulum, beakers, flasks, tubes, funnels etc. There are different types of clamps for specific tasks (Fig.1.5).

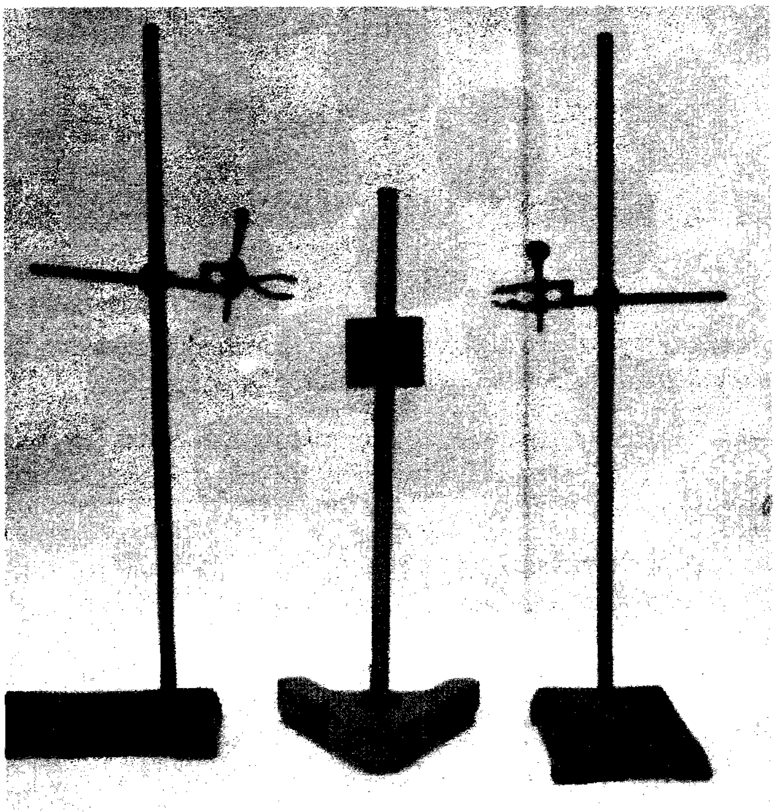


Fig.1.5: Retort stands with clamps of different types

Wooden rulers are available in different sizes (e.g., 30 cm, 50 cm, 1 m). Some have scales on both sides. They are graduated in terms of millimeters and centimetres. Before taking a reading you should ensure that the zero mark is visible on the scales. Otherwise, you should start from another clearly visible mark and correct the reading accordingly. For example, if the reading starts at 1 cm mark and the final mark is 21 cm, then the actual length measured by you is 21 cm –1 cm = 20 cm.

Stop watches (Fig.1.6) are used for measuring short time intervals, e.g., in the determination of period of a pendulum. Stop watches used in general labs usually have start-stop/resetting knobs. They are spring driven; their dial has two hands: one indicating seconds and the other minutes.

You should ensure that rough handling of stop watches is avoided; of course they should not be dropped accidentally to prevent being damaged.

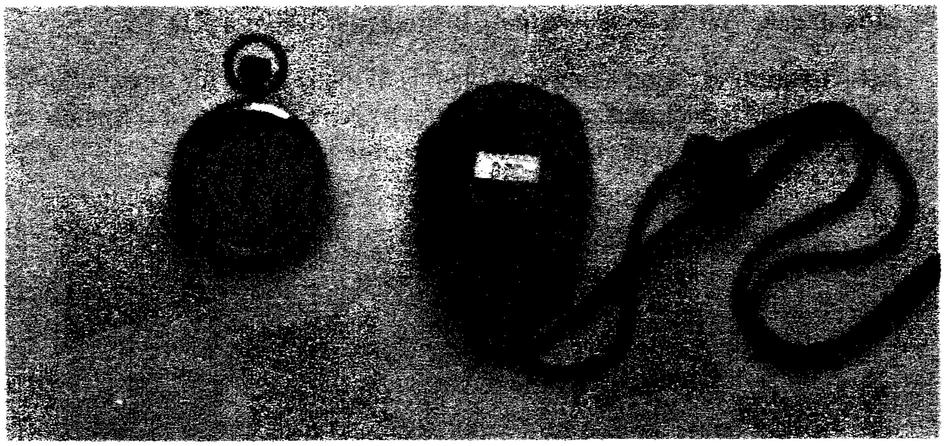


Fig.1.6: Stop watches

Capillary tubes having different internal diameters are used in the measurement of surface tension of liquids.

Springs are used in experiments on oscillations. While using them, you should take care never to overstretch them. This may destroy their elasticity as they will not go back to their original size.

Glassware in the physics lab includes beakers, graduated cylinders and flasks for measuring volumes where you do not require a very high degree of accuracy. They are also used for heating liquids.

You should take the following precautions in handling glassware to avoid breakage:

- Always cool glass vessels slowly.
- Do not place a hot glassware on a damp or cold surface, as sudden temperature change can cause the vessel to crack or break.
- Never heat a glass vessel at a single point as this will increase the chance of its breaking.
- Place a **metal gauze** over the **tripod stand** and place the **bunsen burner** underneath it so that heating is uniform over the base (Fig.1.7)
- Avoid heating a badly scratched or etched vessel as heating efficiency is reduced in such cases.

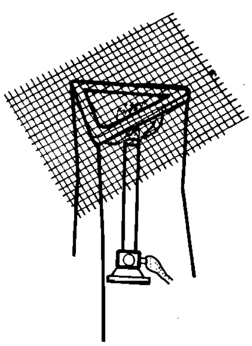


Fig.1.7: Diffusion of heat by use of metal gauze

In addition there are special measuring instruments like **vernier callipers, screwgauge, balances, barometers, thermometers, sonometers, tuning forks,** etc. about which you will study in Unit 3.

B. Optical apparatus

Optical apparatus is used in experiments on light. It includes mirrors (plane and spherical), prisms, lenses, grating, optical bench, spectrometer, microscope, telescope, sources of light, and an arrangement like the lamp and scale arrangement (Fig.1.8). You will learn about these in detail in Unit 4.

While handling mirrors, lenses, prisms etc. always take the following precautions:

- Do not touch them directly with your hands. Hold them only at their edges.
- Do not put them on rough surfaces or else they can get scratched.

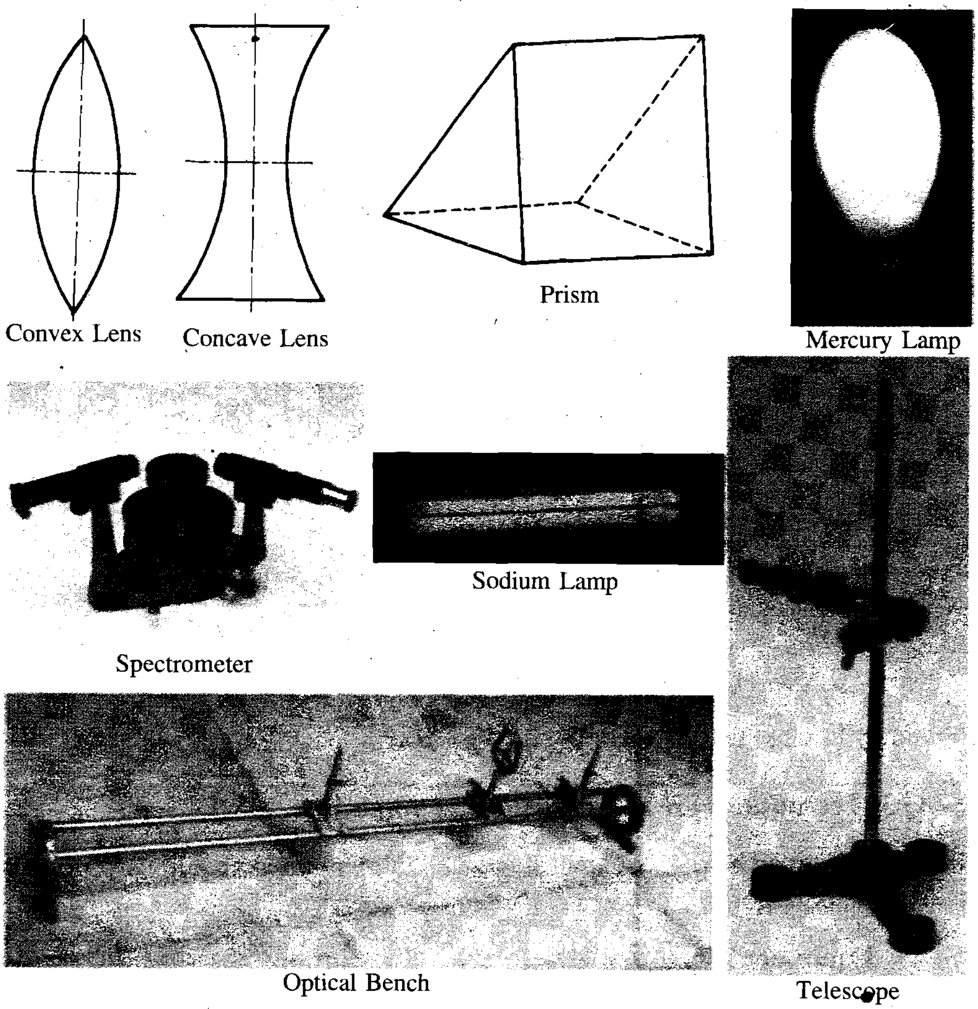


Fig.1.8: Optical apparatus in a physics lab

C. Electrical and electronic apparatus

Electrical and electronic components, devices and instruments are discussed in Units 5 and 6. Here we will list them and provide a picture (Fig.1.9) so that you become familiar with them. These include **cells, batteries, keys, resistors, capacitors** and **inductors** of various kinds, **rheostat, transformer, signal generator** and **power supplies**. There are measuring instruments like **galvanometers, ammeters, voltmeters, multimeters, Wheatstone bridge, Post-office box, potentiometers** and **CRO**. Then there are electronic components like ***p-n* junction diodes** and **bipolar junction transistors**.

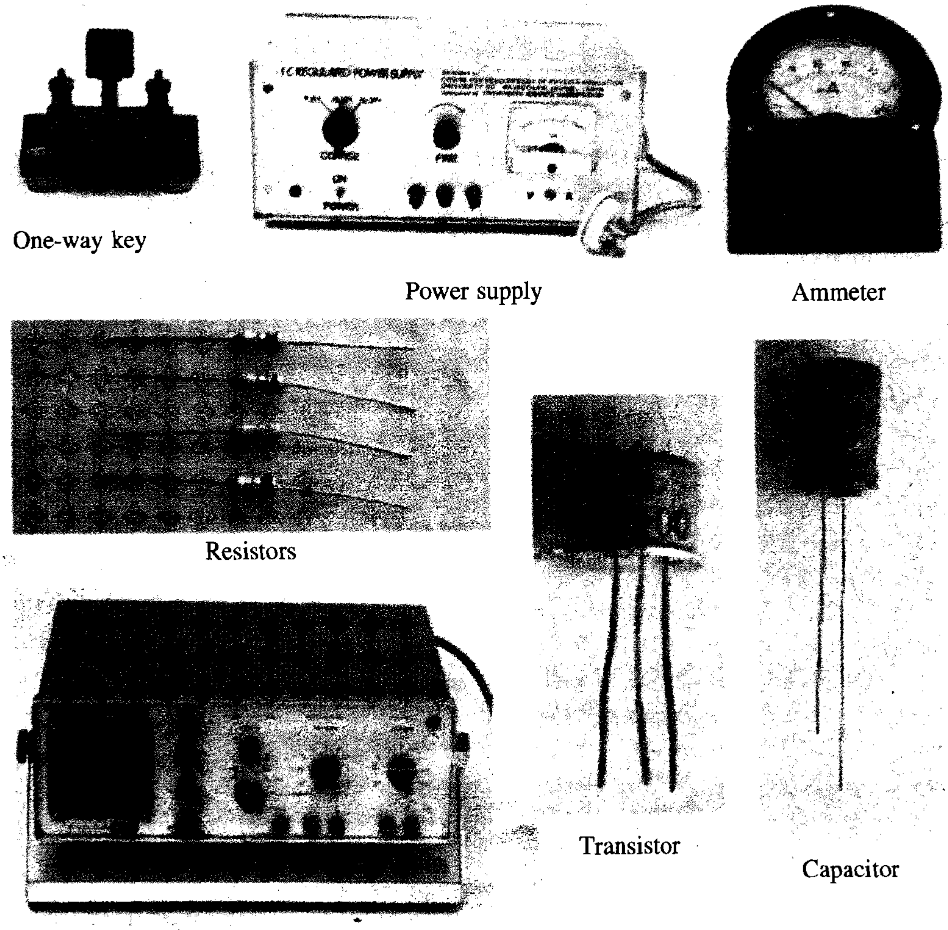


Fig.1.9: Electrical and Electronic Apparatus

You may like to end this section with an SAQ.

SAQ 3: Precautions for handling physics apparatus

In the table given below, list against each equipment the precautions you will take for handling it.

Equipment	Precautions
a) Stop Watch	....
	....
b) Springs	....
	....
c) Mirrors, Lenses and Prisms	....
	....

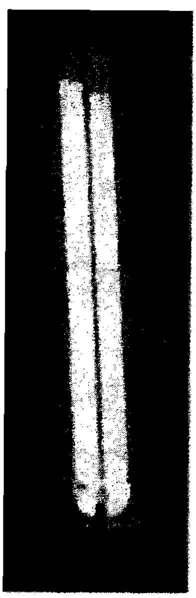
With this brief guided tour of a physics lab, we come to an end of this unit. We now summarise what you have learnt in this unit.

1.5 SUMMARY

- A physics laboratory contains, in general,
  - physics apparatus,
  - furniture and fixtures to do experiments, store and maintain apparatus and seat laboratory staff, teachers and students,
  - utilities like electric, water and gas supplies, and
  - a dark room to do special experiments on light and electricity.
- Physics apparatus can broadly be classified as basic/general apparatus, optical apparatus, electrical and electronic apparatus.
- As a physics laboratory technician you will be responsible for
  - storing, maintaining, handling and using the physics apparatus,
  - carrying out small repairs in the lab,
  - maintaining the utilities, and
  - keeping the lab clean and in good working condition at all times.

1.6 TERMINAL QUESTIONS

1. Identify each of the following instruments. Classify these instruments into the three categories you have studied in this unit.



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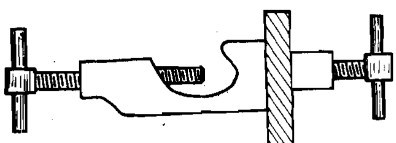

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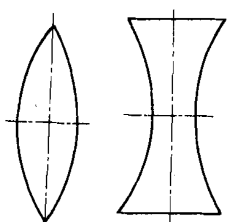

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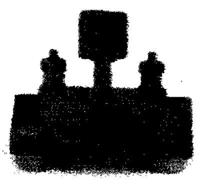

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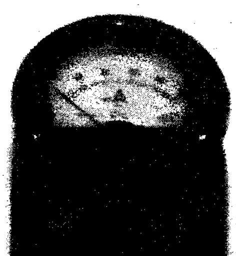

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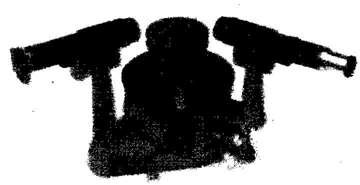

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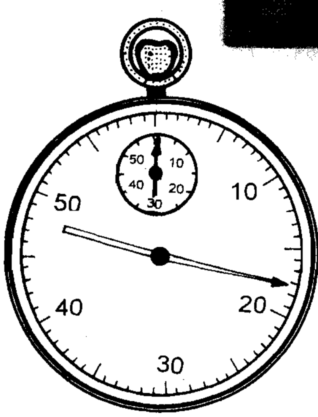

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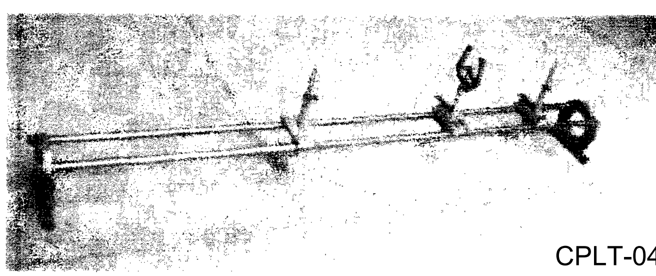


(i)

2. What steps should you take after opening the lab at the start of the day and before locking it up when work ends?

3. List the apparatus kept usually in a dark room attached to the UG physics lab.

1.7 SOLUTIONS AND ANSWERS

Self-assessment Questions

1. a) The physics lab shown in Fig.1.2 has tables, almirahs, stools, racks and chairs.

   b) Yes, the arrangement of the lab can be improved. Some space should be created for repair work in one corner. Since the lab is not so big, most of the equipment should be stored in almirahs. All extra stuff not needed in the lab should be moved out. Some of the racks can also be removed to create additional space for the staff to sit.

   You may have a different answer.

2. a) Electricity, water and gas supplies.

Table 1.1: Possible faults and their location

Location of fault	Possible faults
Electric Supply	There may be no power or electric supply may fail at some points; Fuse may blow up or MCB may trip; There may be a short circuit or sparking; wiring may get damaged; Electrical apparatus may give shocks.
Water Supply	Leaks from the tank, pipes or taps; Overflows from tanks.
Gas Supply	Cracks in the pipes carrying gas; Leaks in gas supply; Faulty regulators, burners.

You can add to the list.

b) If you smell gas leaking from an LPG cylinder in the lab

- immediately ensure that the gas taps of the appliance are in closed position;
- extinguish all fires and flames;
- **do not** light a match stick or turn on the electric supply. If the electric supply is on, then do not turn it off because a spark may lead to fire;
- switch off the pressure regulator;
- move the cylinder to a safe place and do not bring any naked flame or fire near the cylinder;
- open all doors and windows;
- detach the regulator and fit the plastic safety cap on the cylinder valve outlet.

If the gas is being supplied through pipes then close the main valve and follow other relevant precautions listed above.

3. a) Avoid rough handling and sudden dropping to prevent damage.

   b) Avoid stretching them and keep them clean.

   c) Avoid touching the optical surfaces directly with hands; avoid leaving them on rough surfaces and always clean them with appropriate cloth.

Terminal Questions

1. Basic/general apparatus: (b) clamp, (c) stop watch.

   Optical apparatus: (a) sodium lamp, (e) lens, (g) spectrometer, (i) optical bench.

   Electrical and Electronic apparatus: (d) ammeter, (f) one-way key, (h) resistors.

2. Normally on opening the lab you should

   - open the windows to let out stale air;
   - ensure that there are no gas leaks and then turn on the electric mains;
   - get the lab cleaned and dusted for the day;
   - check that all instruments required are in order.

   Before leaving the lab, you should

   - ensure that all instruments are put back in their respective places leaving the lab tidy;

- check that all electric points are switched off, water taps are closed and gas supplies are turned off;
- close the windows;
- switch off the mains power supply;
- lock and seal the lab.

3. Usually, in a dark room of a UG lab we find sodium and mercury lamps, spectrometers, optical benches kept on tables, photocells, lamp and scale arrangement.

UNIT 2 COMMON LABORATORY TOOLS

Structure

2.1 INTRODUCTION

In Unit 1, we have presented an overview of a physics lab and its arrangements. You have also learnt that as a technician in a physics laboratory you will be required to carry out simple repair tasks like cutting, fixing screws, nuts and bolts, soldering etc. To do these tasks skillfully, you should be familiar with some of the basic laboratory tools such as *vice*, *screwdrivers*, *pliers* and *soldering iron*. In Sec. 2.2, we introduce some of these. In Sec. 2.3, you will learn about *different ways of joining materials*, which is an important activity in a physics lab. In the next unit you will learn about the basic apparatus used in experiments in mechanics, sound and heat.

Objectives

After studying this unit, you should be able to:

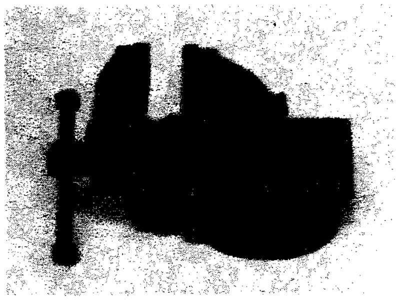
- identify the common hand tools used in a physics lab;
- list basic safety precautions that you should observe while working with common tools;
- state different ways of joining materials;
- describe how to solder a simple joint, and explain the functions of flux, solder and the soldering iron; and
- list the measures necessary for proper maintenance of these tools.

2.2 SOME COMMON TOOLS

While working in the physics laboratory, usually you will be required to handle a **vice**, **screwdrivers**, **pliers**, **hacksaw**, **hand drill**, **files** and a **soldering iron**. If you learn to use these tools and take care of them properly, you will be a more organised and skilled laboratory technician. Therefore, we discuss each of these tools briefly in this section.

A. Vice

Whenever you need to **hold** any material, e.g., a wooden board, a metallic sheet or a rod, to **cut** or to **drill** holes, you would require a vice. There are several types of vice but an engineer's vice with an anvil is the most useful (Fig.2.1). The vice has two *jaws*, one of which is fixed. The other jaw can be moved with the help of *tommy bar* fitted in a movable screw. The vice should be fixed permanently to the edge of a table or the workbench in the lab.



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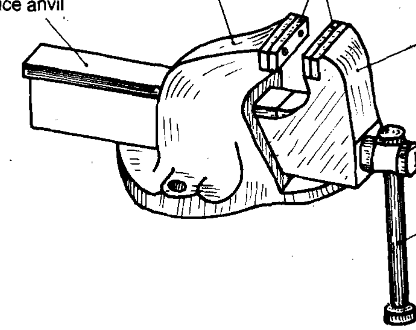


(b)

Fig.2.1: An engineer's vice

While using a vice, you should

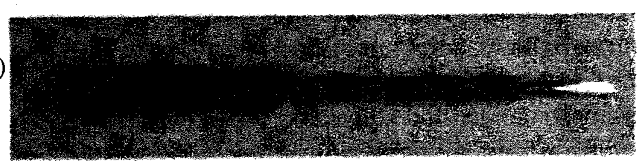
- not overtighten the tommy bar; use only your hand rather than any mechanical device like a hammer;
- use the anvil for light hammering only; heavy blows could distort it and prevent the sliding jaws from moving smoothly;
- cover the jaws with aluminium or lead covers to protect the material surface from being marked.

To maintain a vice in good working condition, you should protect it from dust and oil it periodically.

B. Screwdrivers

A screwdriver is a hand tool designed to turn screws and bolts. It has two parts: a shank and a handle. The shank is made of steel set into a wooden or plastic handle. The tip of shank, i.e., the blade is shaped or flattened to fit recesses in the heads of the screws and bolts. Two types of screwdriver blades are commonly used in a physics laboratory – straight and phillips (see Fig.2.2).

(a)



(b)

Fig.2.2: Two types of screwdriver blades. a) straight; and b) Phillips

A phillips screwdriver is specially designed to fit the heads of phillips screws. These screw drivers are available in several sizes. Each size is numbered and relates the diameter of the blade with the point number. For example, a No.2 point has a $\frac{1}{4}$ in-diameter shank.

- You should always use a screwdriver of correct size to avoid damaging the screwhead.
- **Do not hit the screwdriver handle with a hammer.**
- Keep the screwdrivers in their kit when not in use. In this way you can prevent rusting and damage to the blades.

C. Pliers

Fig.2.3 shows three types of pliers that are used the most. These are combination pliers, long-nosed pliers and side or diagonal cutting pliers.

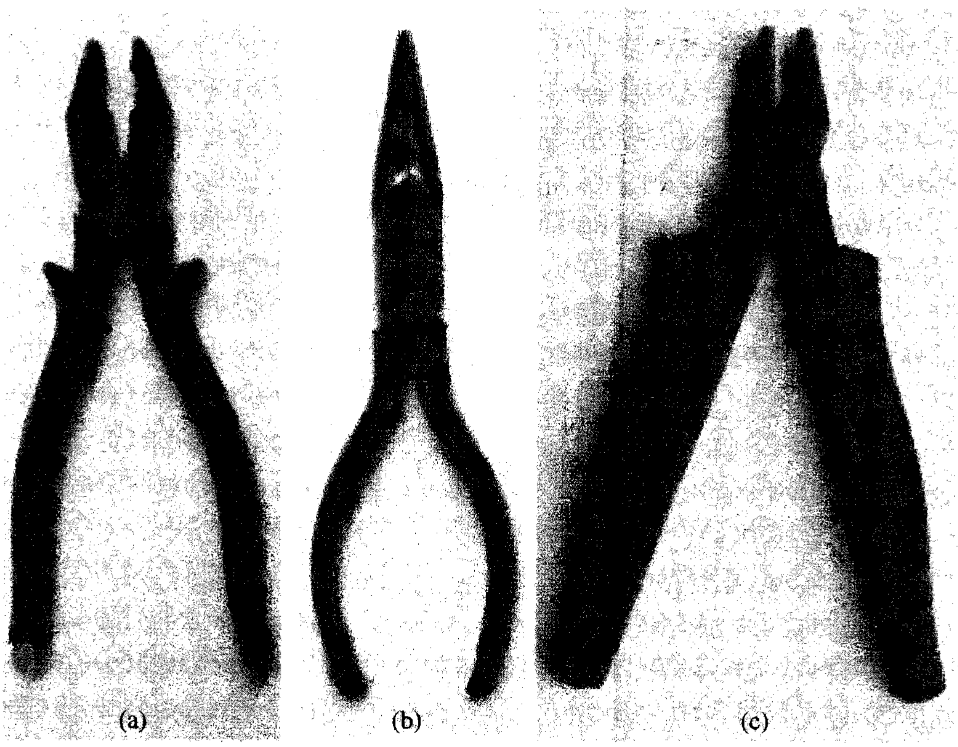


Fig.2.3: a) Combination plier; b) long-nosed plier; and c) side or diagonal cutting plier

Combination pliers are used for holding and gripping small objects where it is inconvenient or unsafe to use hands. Long-nosed pliers are used for placing and removing small items in narrow spaces, e.g., small screws used in electrical and electronic devices. Side cutting pliers are special type of pliers used exclusively for cutting and for removing insulation from the electrical wires.

You should keep the pliers in the kit when not using them. Keep them dust free and oil them periodically to prevent rusting.

D. Hacksaw

The hacksaw is a hand tool used for cutting metal, wood, plastic etc. (Fig.2.4). It consists of a metal frame which has metal clips at its ends to hold the cutting blade. While you use a hacksaw, the workpiece should be held firmly. If you are using a vice, clamp the workpiece so that the cutting line is close to the jaws of the vice.

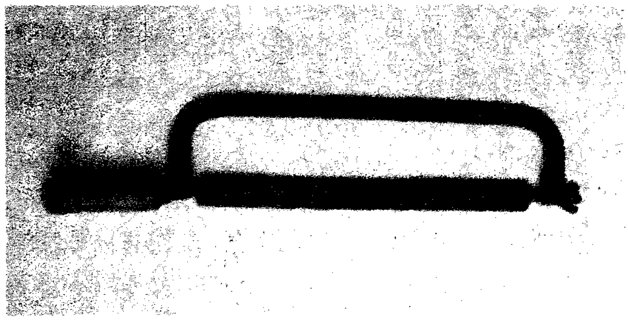


Fig.2.4: Hacksaw

You should

- keep the saw blade lightly oiled to prevent it from rusting;
- be careful not to twist the blade while it is in the workpiece. Otherwise it will break.

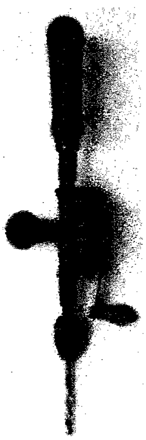


Fig.2.5: Hand drill

E. Hand drill

In the laboratory, you may need to drill holes in wooden or plastic boards or metallic sheets. For this, you would require a hand drill (see Fig. 2.5). A hand drill is used together with drill bits. It is important to use the appropriate drill bit as per the size of the hole and the material being drilled.

Before you begin to drill a hole, it is necessary to "mark the spot". This is done, in the first instance, with a pencil cross and then by marking the centre of the cross with an **indentation** so that the drill makes the hole in the exact spot. For wood and plastic, this is done by a bradawl shown in Fig.2.6. For metals, this is done with a centre punch also shown in Fig.2.6 which is hit, on the blunt end, with a hammer.

(a)

(b)

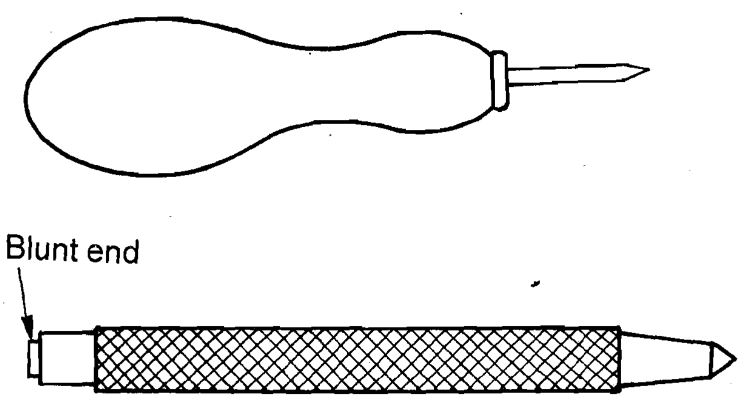


Fig.2.6: Devices for making indentations. a) Bradawl; and b) centre punch

F. Files

Refer to Fig.2.7 which shows some common files. They differ in their shape, size, and type of cut and tooth size etc.File is a hand tool used to remove small amounts of material from a metallic surface. (In some respects, this operation is similar to smoothening a piece of wood.) A file is a hardened steel cutting tool having parallel rows of cutting edges or teeth on its surfaces. The rows are generally diagonal to the edge. One end of the file is shaped to fit into a wooden handle.

Round needle file is useful for enlarging a hole in a cork.

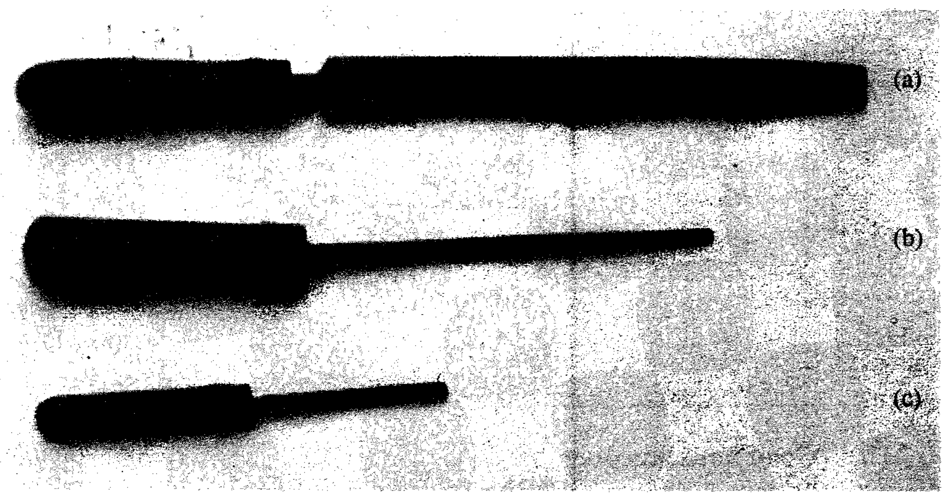


Fig.2.7: Some common files. a) Flat file; b) normal file; and c) flat file of smaller size

Use only those files which are fitted with a handle. This facilitates their handling and also protects your hands. Moreover, you should keep it rust free.

G. Soldering iron

Fig.2.8 shows a general purpose soldering iron. We shall take up the soldering process in the next section while discussing the ways of joining materials.

Fig.2.8: A soldering iron

A soldering iron consists of three basic parts – **handle**, **heating element** and the **bit**. It is preferable to have a soldering iron in which the heating element and the bit can be replaced.

Power consumption of the heating element in a general purpose soldering iron is in the range 15 W–18 W. It generates tip temperatures of approximately 290°C–410°C. Heavy duty soldering irons can consume up to 95W giving a tip temperature in the region of 600°C.

A soldering iron bit is usually made of copper or iron cladded copper. (Iron-clad bits may last 10 times as long as copper bits but are much more expensive.)

When a soldering iron is hot but not in use, you must keep it on a stand to avoid burns.

Switch off the soldering iron when not using it. After use, unplug it and store it only after it cools.

Now we would like you to revise what you have studied so far. So answer the following SAQ.

SAQ 1: Identification of basic tools

Identify the tools shown below (Fig.2.9) and state their uses.

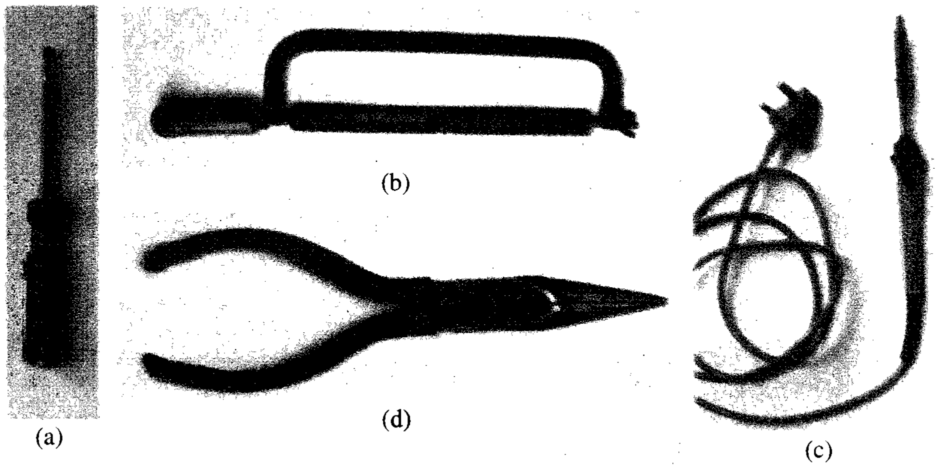


Fig.2.9

The term "Good housekeeping" is used to indicate cleanliness and neatness; a place for everything with everything in its place. The result of good housekeeping is a safe laboratory.

H. Good housekeeping

You will agree that your tools extend your skills and therefore it is only logical to keep them in good working condition. Moreover, you should have easy access to them. Therefore, **you must make sure that all your tools are marked either by engraving or by paint. And these should be kept in a locked tool box or in a locked cupboard or drawer when not in use.**

Next there should be provision for working space. This can be a free–standing unit or a part of a bench in a room. In either case, the work–surface must be firm, level, at a comfortable working height (if standing), well lit and ventilated.

While working with basic tools, you need to take some precautions for personal safety:

- Protect your eyes with safety glasses if there is the remotest chance of sawdust or splinters (wood or metal) becoming airborne.
- Keep your hands out of harm's way should the tool or the workpiece slip.
- While working, wear leather shoes to avoid injury due to any falling tool or something sharp.
- Beware of fine metal shavings and rough edges on freshly-worked metal.
- Always hold your workpiece firmly, preferably by a vice.

So far we have given an overview of the basic laboratory tools. Now you will learn ways in which materials are joined together.

2.3 JOINING MATERIALS

One of the major tasks of a laboratory technician is to maintain the laboratory. Sometimes you may notice that a piece of ply has come out from a table or from a wooden apparatus like sonometer or meter bridge. Obviously you would be required to repair it. Also suppose you are asked to fabricate an extension board (using wood or plastic). This will involve joining different materials. How will you do so? You will now learn about different ways of joining materials.

Normally we use two ways for joining materials; by using adhesives or by using nails, screw, nuts and bolts. For joining metals, we also use soldering. Let us now discuss these in some detail.

A. Adhesives

You are familiar with a variety of adhesives such as glue, fevicol, araldite, quick fix, etc. However, it is important to select appropriate adhesive for a particular job. While selecting an adhesive, you will have to keep three factors in mind: *easy availability*, its *cost* and *suitability* for the task to be done.

You will be required to take the following precautions while working with adhesives:

- Store the inflammable adhesives in a well-ventilated place and away from every source of ignition, say sparks or flames. **Do not smoke while working with such materials.**
- Keep your working area clean and tidy. You should cover your working area with a newspaper and the same should be destroyed afterwards.
- Replace the tops of tubes, tins, etc. immediately after use.
- Avoid obscuring the label with adhesive as the instructions and hazard warnings should be readable at all times.
- If expiry date is given for any adhesive, it should be used only within the expiry period.
- Adhesives such as araldite have a short life once they have been mixed/ activated. Therefore, you should prepare only as much mixture as you are likely to use.
- Always wash your hands after using any adhesive. If an adhesive sticks to your hands, do not touch your face, mouth or food.

B. Mechanical means

There are several mechanical means for joining materials, e.g., nails, screws, nuts and bolts.

Nails are used to join pieces of wood and are usually made of iron or steel or brass. They are available in different sizes (length and diameter.) They may be round or oval with a large, flat head or a smaller cylindrical head, as shown in Fig.2.10. Round and oval nails are available in sizes ranging from ½ inch to 6 inches in length.

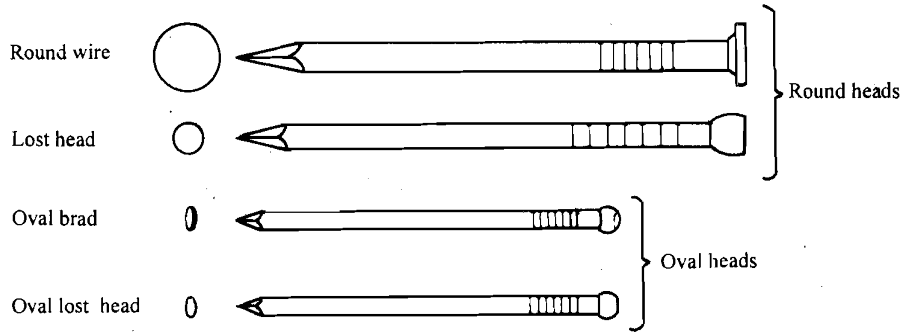


Fig.2.10: Different types of nails

Screws are superior to nails where firm, strong joints between materials are required. They are commonly used for attaching metal components, e.g., hinges, brackets, etc. to wood. They can be removed or tightened, if any adjustment to a workpiece is necessary.

There are a variety of screws made of many materials. They differ in the shape of the head, the means by which they are driven, and the type and size of thread (Fig.2.11). It is a good practice to use screws made of the same metal as the metal workpiece with which they are used.

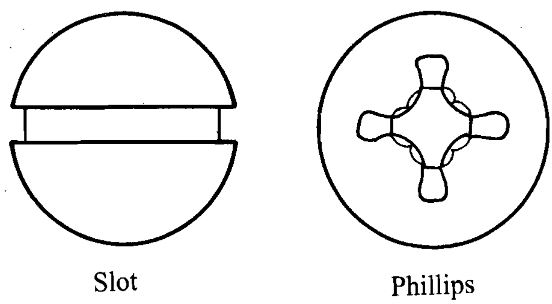


Fig.2.11: Different types of screwhead

Screws with slotted heads should be driven with a straight blade screwdriver. Always use a blade that just fits the slot, without overlapping the ends. This will cause less damage to the head of the screw and make it easier to unscrew, should you wish to do so. You will realise that once the slot has been destroyed, it is very difficult to get the screw out. **Do not fix a screw using a hammer; always use a screw driver**.

Always use a Phillips screwdriver for a screw with a Phillips recess.

Some screws can be used in conjunction with either a nut or a "tapped" hole (a hole with a thread) of equivalent size. Moreover, they can be of the same diameter yet have different threads.

In order to prevent a screw marking a wooden surface or to prevent it from becoming loose, a washer is used. (A washer is basically a circular disc of metal, usually steel or brass, with a hole in the middle.) Washers are available in a range of thickness but are usually ordered by hole size.

Self-tapping screws are used while working with plastics.

C. Soldering

In the physics laboratory you may be required to fabricate an electronic circuit on a Printed Circuit Board (PCB). For this you will have to join the terminals of electronic devices such as diode, transistors or resistors/capacitors/inductors on the board. Will you be able to use the abovesaid methods to join them together? No, in such a situation we use **soldering**. You may now logically ask: What is soldering?

Soldering is the process of joining two metallic pieces together by a third soft metal, called **solder**, which is applied in the molten state. You are likely to use soft soldering in which the joint has little mechanical strength. This is because the solder used is an alloy of lead and tin, both of which are low-strength metals. **You are therefore advised not to pull soft solder joints.**

A soft solder has a relatively low melting point (~ 200°C)

To carry out soldering job you will need a soldering iron, solder and flux. You have learnt about the soldering iron in Sec. 2.2. Let us now learn about the flux.

Flux

Two types of flux are commonly used for soldering; both contain rosin but one is in the form of a jelly while the other is a liquid.

Flux has two main functions. **Firstly**, it cleans the surfaces to be soldered. It is important that the surfaces are free from oil, grease and any surface scale or coating. When the area is heated by the soldering iron, the flux boils and tends to remove small amounts of impurities or oxides that may be present on the surfaces to be joined.

Secondly, as the flux boils, it gives off a vapour which forms a layer over the surface and prevents formation of oxides on the surface.

In all likelihood, for soldering work, you will use a solder which has flux already mixed in it.

Before soldering two pieces, you should "tin" the copper bit of the soldering iron so that it picks up solder uniformly and acts as a "reservoir" of solder. To tin a new bit, or to re-tin an old bit, fix it into the soldering iron handle and heat it slightly. File the end gently, using a fine file, to remove any oxide coating. If the flux is not mixed with solder, dip the bit into flux to a depth of about 15mm. Then heat the iron further and apply solder to the hot bit so that it is evenly covered. Wipe off the excess solder using a piece of damp cellulose sponge. When the solder "takes" to the bit, it gives it a silvery appearance—hence the name "tinning".

When joining two pieces of metal, hold one piece firmly in a vice and the other piece in a pair of pliers. You must make sure that both pieces are clean and free from oil or grease in the area in which you intend to make the new joint.

During soldering, the pieces being soldered get hot enough to cause burns. Some electronic components, e.g. transistors, could be damaged by this much heat. In such cases, a **heat sink** is needed between the pieces to be soldered. This will enable heat to dissipate. The simplest heat sink is a pair of long-nosed pliers which is used to hold one of the pieces being soldered (Fig.2.12). An alternative way is to cool the piece before soldering, using an aerosol freezer spray.

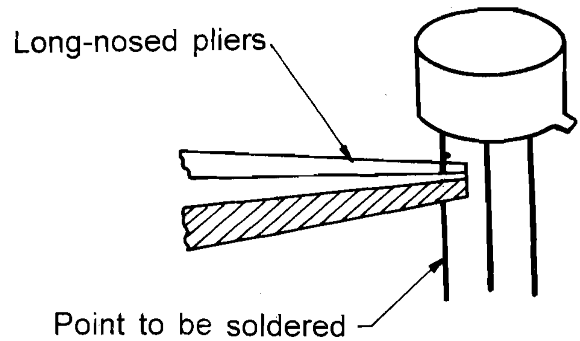


Fig.2.12: Long-nosed pliers as heat sink

You should now answer an SAQ to test your understanding.

SAQ 2: Joining materials

Which method(s) will you suggest for joining the materials given below?

a) A connecting wire and a copper plate.
b) Sunmica and the table top
c) A crack in a plastic dust bin.
d) A CRO and its front panel.

Let us now summarise what you have learnt in this unit.

2.4 SUMMARY

- The **vice**, **screwdriver**, **plier**, **hacksaw**, **drill** and **files** are the common tools required for routine laboratory work. You should take adequate precautions to protect yourself while working with these tools.
- Keep your tools free from dust and grease or oil them properly, if needed.
- Materials can be joined using **adhesives**, **mechanical methods** and **soldering**.

2.5 TERMINAL QUESTIONS

1. Why should you have metal covers for the jaws of a vice?
2. What measures should you take to avoid injuring yourself while working with a soldering iron?

2.6 SOLUTIONS AND ANSWERS

Self-assessment Questions

1. a) Phillips screwdriver, b) hacksaw, c) soldering iron, d) long-nosed plier

	Tools	Use
a)	Phillips screwdriver	To turn screws with Phillips head.
b)	Hacksaw	To cut metal, plastic, wood
c)	Soldering iron	To join metals
d)	Long-nosed plier	To hold small objects used as heat sink.

2. a) Soldering, b) adhesive, c) adhesive, d) mechanical means

Terminal Questions

1. The metal covers are put on the jaws of a vice so that the workpiece is not marked.
2. a) You should always keep the soldering iron on its stand when it is hot to avoid burns.
   b) Keep the soldering iron switched off when not using it.
   c) Unplug it and store it only after it cools.

UNIT 3 BASIC APPARATUS

Structure

3.1 INTRODUCTION

In Unit 1 you were introduced to a physics laboratory, its components and organisation. You know that as a laboratory technician, a part of your responsibility will be to manage the laboratory. You should therefore be able to classify physics laboratory equipments and their components according to their use, store them safely and ensure proper maintenance. (This will reduce costs of repair and replacement.) You can also be asked to set up apparatus for a demonstration in the class.

In this unit we discuss some of the basic apparatus used for *length*, *time*, *mass*, *pressure* and *temperature measurements*. In sections 3.2 to 3.5, you will learn about **vernier callipers**, **screw gauge**, **physical balance**, **stop watch** and **digital timer**, **thermometer** and **barometer** etc. used for such measurements. In Sec. 3.6 you will learn how to obtain the condition of resonance in a resonance tube apparatus as well as a sonometer and how to use it to determine the speed of sound or the frequency of a tuning fork. In the last section, we discuss **permanent magnets** and **electromagnets**. In the next unit you will learn about optical apparatus.

Objectives

After studying this unit, you should be able to:

- identify the appropriate measuring device for a given measurement;
- explain the use of vernier callipers and screw gauge for measurement of length and compare their accuracies;
- identify causes of errors in measurements made using vernier callipers and screw gauge as well as maintain these devices;
- operate and maintain a stop watch;
- explain the use of a physical balance;

- explain the principle used in the measurement of temperature;
- read a Fortin's barometer to measure pressure;
- explain how the study of resonance in a sonometer or a resonance tube facilitates determination of frequency of a tuning fork or the speed of sound; and
- identify permanent magnets and electromagnets and keep them properly.

3.2 LENGTH AND TIME MEASUREMENTS

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 this purpose. For measuring ordinary lengths, we use a measuring tape or metre scale whereas a wrist watch or a clock suffices for routine time measurement. For measuring short lengths/periods, we need an accuracy better than that obtained from a metre scale/wrist watch. This means that these devices cannot be relied upon in such cases and we need more accurate devices. Vernier callipers, screw gauge and stop watch are used depending on the precision required. You may have learnt about these earlier but we begin our discussion by describing these in detail.

3.2.1 Vernier Callipers

Refer to Fig.3.1. It depicts a vernier callipers, which is named after its inventor Vernier. The instrument, made of steel, consists of a fixed scale (M) called the **main scale** (MS), which is graduated into centimetres and millimetres, and a pair of jaws A and B. Jaw A is fixed to the main scale and the jaw B can slide over it. Moreover, jaw B has a subsidiary scale V, called the **vernier scale** (VS), which can slide along the main scale. These scales have distinctly visible graduations. The main scale can be used to measure lengths in the range 0–15 cm. The object whose length is to be determined is placed close-fitted in the gap between the jaws A and B.

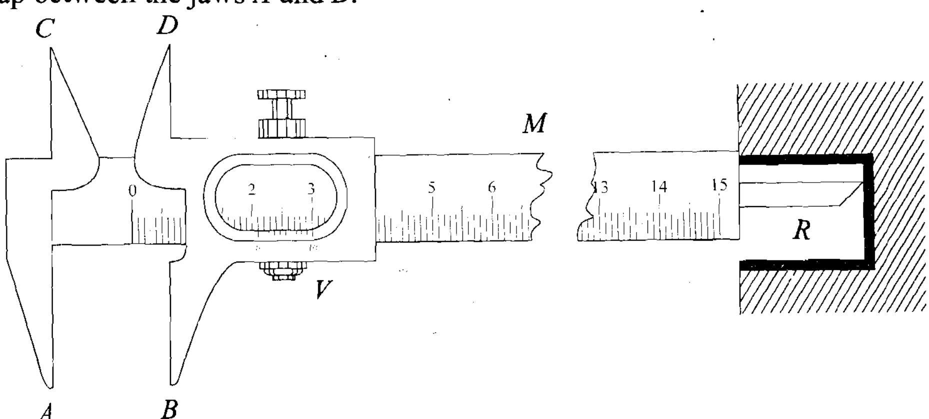


Fig.3.1: A vernier callipers

The vernier callipers also has inside jaws C and D, which can be used to measure internal diameter of a tube. A sliding strip R is provided for the measurement of depths. It is connected to the sliding jaw and slides with it.

When the jaws of the vernier callipers are in contact, the zero mark of the MS should coincide with the zero mark of VS. In some instruments this may not happen. In such a case, the vernier callipers is said to have **zero error**. This must be determined and accounted for while taking readings with the vernier callipers.

Suppose the vernier scale zero is found to stand to the right of the main scale zero (Fig.3.2a). The error is called **positive zero error**. It is obvious that to obtain the correct value we have to apply **zero correction.** If the *m*th division of the vernier scale coincides with a main scale division, the instrument is showing a reading equal to *m* times the least count. For positive error, the zero error is subtracted from any reading taken on the callipers.

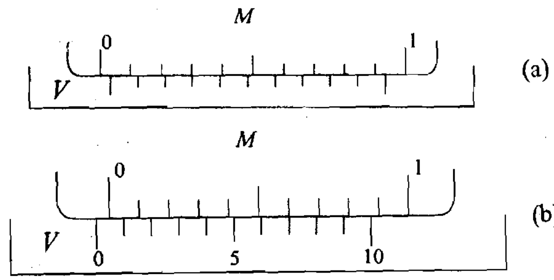


Fig.3.2: a) Positive zero error; and b) negative zero error

In case the zero of the vernier scale falls to the left of the zero of the main scale, the error is called the **negative zero error** (Fig.3.2b). The magnitude of the negative zero error is equal to ($n - m$) times the least count, where *n* is the total number of divisions on the vernier scale and the *m*th vernier scale line coincides with a main scale line. In case of negative zero error, we apply correction by adding a value equivalent to the error, to the observed reading of the instrument. If we signify positive zero error with + sign and negative zero error with – sign, a general rule will be to *subtract the error from the observed reading.*

In a simple vernier callipers, the vernier scale has 10 divisions which are equal to 9 divisions or 9 mm of the main scale (Fig.3.3). Thus, the value of each vernier division is 0.9mm and it is 0.1mm shorter than one main scale division. When the jaws are closed to touch each other, the zero of the main scale should coincide with the zero of the vernier scale. Since a vernier division is shorter than a main scale division by 0.1 mm, the first vernier division will lie 0.1mm left to the first main scale division. If now you move the jaw *B* slowly to the right, such that this 0.1 mm difference disappears, the jaw should have moved 0.1 mm. This also would be the width of the gap opened between the two jaws. Obviously, the smallest length that can be measured is 0.1 mm or 0.01 cm. This is called the **least count** or the **vernier constant** of the instrument. *The least count of a vernier callipers is equal to the difference between the lengths of one main scale division and one vernier scale division.* You will now learn to calculate the least count for any instrument carrying a pair of MS and VS.

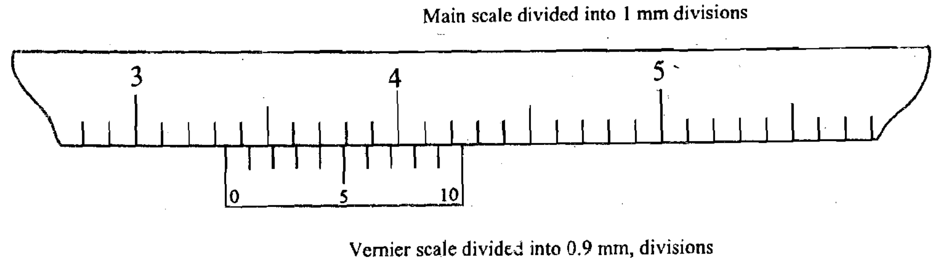


Fig.3.3: Least count of a vernier callipers

A. Calculating the least count

The least count of a vernier device is defined as

LC = Value of one Main Scale Division (MSD) – Value of one Vernier Scale Division (VSD)

If you look at the inset in Fig.3.1, you will note that the value of 10 VSD is equal to the value of 9 MSD. Therefore, we can say that 1 VSD = (9/10) MSD. Hence we can write the expression for least count as

$$LC \equiv 1MSD - 1VSD = 1MSD - (9/10)\,MSD = (1/10)\,MSD$$

For the vernier callipers, the value of 1MSD = 1mm. Therefore,

$$\boxed{LC = \left(\frac{1}{10}\right)mm = 0.01cm} \qquad (3.1)$$

You should note that the vernier scale enables us to make more precise measurement of length compared to the metre rule. In your physics lab, you will come across some instruments in which vernier scale has more than 10 graduations and the value of 1MSD is less than 1mm. One such familiar example is that of travelling microscope where 49 MSD correspond to 50 VSD and 1 MSD = 0.5 mm. To calculate the least count in such cases, it is pertinent to note that the denominator in the parenthesis of Eq. (3.1), is 10, which denotes the total number of divisions on the VS. Therefore, in general, we can write

$$LC = \frac{1}{n} \times \text{value of 1 MSD}, \qquad (3.2)$$

where n is the total number of divisions on the VS. Since $n = 50$ and 1 MSD = 0.5mm in this case, we find that

$$LC = \frac{1}{50} \times 0.5mm = 0.01mm = 0.001cm$$

Other instruments to which a vernier scale is fitted include an analytical balance, a Fortin's barometer and a spectrometer. You will get an opportunity to work with these instruments in your laboratory.

Let us now understand how to read a vernier callipers.

B. Reading a vernier callipers

Again refer to Fig.3.3. You will note that the zero mark of the vernier scale is in-between 3.3cm and 3.4 cm marks of the main scale. It means that the distance between the jaws is more than 3.3 cm but less than 3.4 cm. To know the exact distance between the jaws, we note that the 4^{th} vernier division coincides with a MS division. Therefore the distance between the jaws is

$$3.3 \text{ cm} + 4 \times 0.01 \text{ cm} = 3.34 \text{ cm}$$

The general procedure for taking readings on a vernier callipers can be summarised as follows:

- Calculate the least count of the instrument;
- Note the zero error in the given instrument;
- Take the reading on the main scale;
- Note which vernier division coincides with a main scale division;
- Calculate the vernier scale reading by multiplying the least count with the number of coinciding vernier scale division; and
- Add the vernier scale reading to the main scale reading. This gives the total reading.

To sum up, we can say that **vernier callipers can be used to measure lengths in a range of about 0-15 cm with an accuracy of 0.01 cm.**

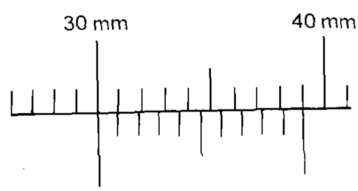
For proper maintenance of a vernier callipers it is important to

- take care **not** to apply excessive pressure on the jaws or overstress them while noting zero error or taking readings;
- store them in the boxes provided by the manufacturers. If the same are not available in the lab, efforts should be made to obtain another set;
- make sure that no part is rusting or getting stuck.

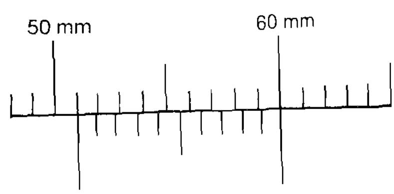
You may now like to answer an SAQ on how to read the vernier callipers.

SAQ 1: Reading a vernier

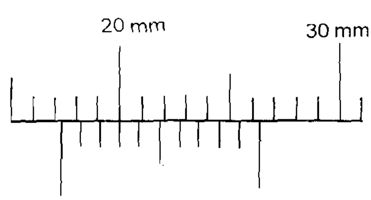
State the readings for the following configurations:

i) 

____________ cm

ii) 

____________ cm

iii) 

____________ cm

You now know that vernier callipers enables us to take observations upto 0.01 cm. When we require accuracy greater than this, we use a screw gauge. You will now learn about it.

3.2.2 Screw Gauge

A screw gauge is shown in Fig.3.4. It consists of a spindle *S*, a U-shaped frame *F*, a hollow shaft *H*, and a cylindrical collar *T*, called the timble. One end of the spindle is an accurate screw which moves hidden inside a nut and the shaft (*H*) is attached to the end *N* of the U-shaped frame. The free end *B* of the spindle moves forward and backward when the screw moves inside the nut. The other end (*A*) of the frame is a butt end and is also called the anvil.

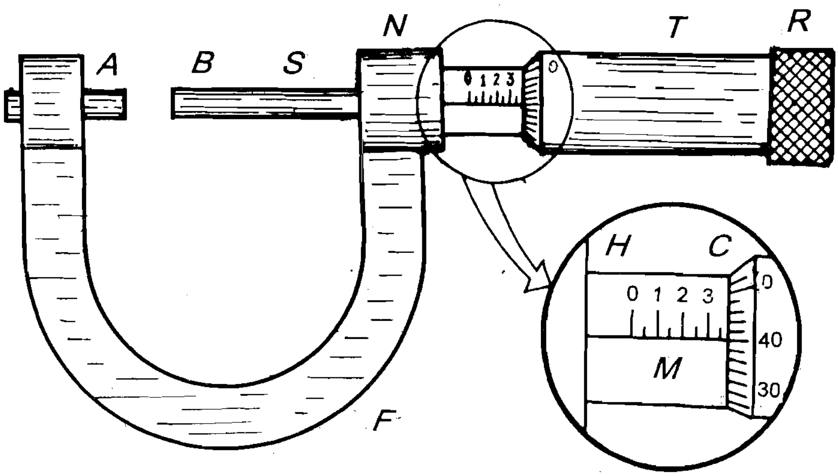


Fig.3.4: A screw gauge

You will note that one end of the timble is divided into a number of equal divisions, say 50, in the form of a circular scale (*C*). The other end carries a holder *R*, called the ratchet, to rotate the timble and the spindle screw attached to it. The ratchet device can turn freely when the pressure on the object is beyond a certain limit. In this way, ratchet minimises pressure and eliminates uncertainties while reading the circular scale. The hollow shaft has a linear scale engraved on it. The linear scale acts as the main scale and is graduated in millimetres. If you rotate the timble with the help of the ratchet, you will note that the circular scale moves over the main scale.

In some screw gauges, a little space may be created due to wear and tear or loose fitting. In such instruments, if the screw gauge is adjusted by turning it in one direction and then rotated back, no linear motion of the spindle may take place even when we move the head. The error due to this is called **backlash error** of the screw.

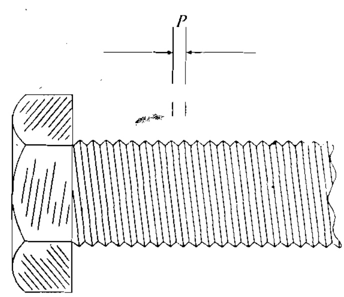


Fig.3.5: Pitch of the screw gauge

The screw of the spindle is the most important part of a screw gauge. It has very accurate threads cut on it which, on rotation, move the screw forward or backward. The distance moved by the spindle in one complete revolution of the screw is called the **pitch** of the screw gauge (Fig.3.5). If we rotate the timble clock-wise, the spindle will move towards the butt end *A*. When the two touch each other, the zero mark on the circular scale should coincide with the zero mark of the main scale.

On one complete anticlockwise rotation, the zero mark on the circular scale will once again coincide with the main scale line, and the spindle end will be separated from the butt end. You can read this separation on the main scale. This is equal to the pitch of the screw. For the inset shown in Fig.3.4, the pitch is 0.5mm. Suppose the timble is rotated through one division only on the circular scale. The distance moved will be only (1/50) times the pitch, that is, (0.5mm)×(1/50) = 0.01 mm or 0.001 cm. Clearly, this is the smallest length that can be measured with a screw gauge. This is its **least count**.

When the butt and spindle ends, *A* and *B*, touch each other and the zeros of the circular and main scales do not coincide, the screw gauge is said to have **zero error** (see Fig.3.6). The zero error is said to be **positive** if the zero of the circular scale is below the zero of the main scale (Fig.3.6a). If the zero of the circular scale is above that of the main scale, the zero error is **negative** (Fig.3.6b). As in the case of vernier callipers, the zero error is taken care of by subtracting it from the actual reading of the screw gauge.

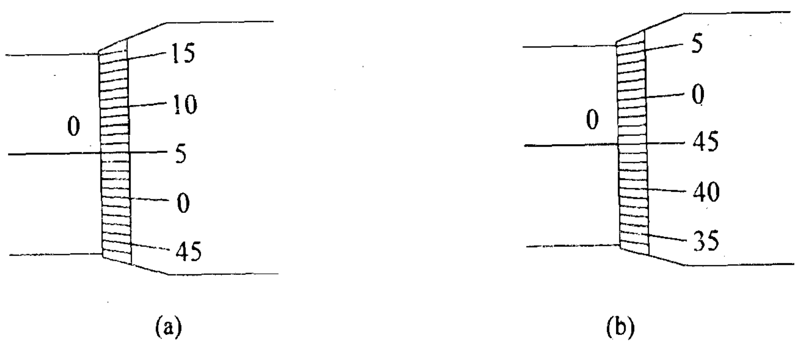


Fig.3.6: a) Positive; and b) negative zero error in a screw gauge

To make measurements with a screw gauge, we insert the object such as a thin wire or a lead shot whose thickness is to be measured between the butt end and the spindle. The spindle is then rotated so that the object touches both the butt end and the spindle end. We obtain the total reading, and hence the thickness by adding the circular scale reading to the main scale reading. The main scale reading can be noted directly from the main scale. The circular scale reading is obtained by multiplying with the least count, the number of circular scale divisions that coincide with the horizontal line of the main scale.

For the inset sketch of Fig.3.4, you can calculate the total reading as follows:

Main scale reading	= 0.35 cm
Vernier scale reading (40 divisions)	= 0.001 × 40 = 0.040 cm
Total reading	= 0.35+0.040 = 0.390 cm

Note that the reading is upto three decimal places. In practice, a screw gauge has a range of about 0–2.5 cm with an accuracy of 0.001 cm. While using a screw gauge, you must

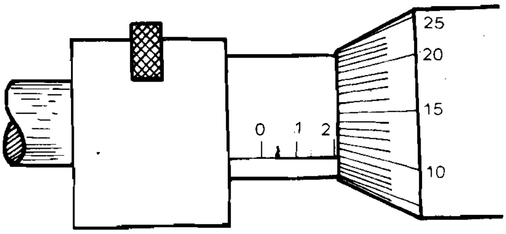
- keep the spindle and the anvil clean; this will help in avoiding false readings;
- avoid overtightening the gauge, otherwise the instrument develops backlash error over a period of time; and
- to reduce back-lash error, the screw must be rotated in the same direction.

The screw gauge is also called micrometer.

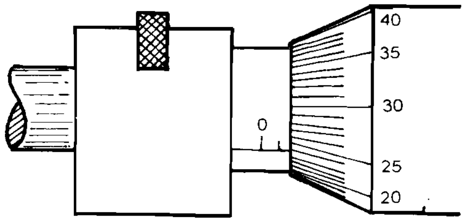
You may now like to answer an SAQ on how to read a screw gauge.

SAQ 2: Reading a screw gauge

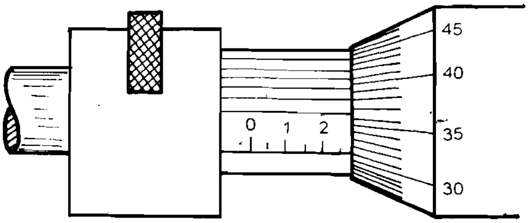
State the readings for the following configurations:



(i)



(ii)



(iii)

i) ....

ii) ....

iii) ....

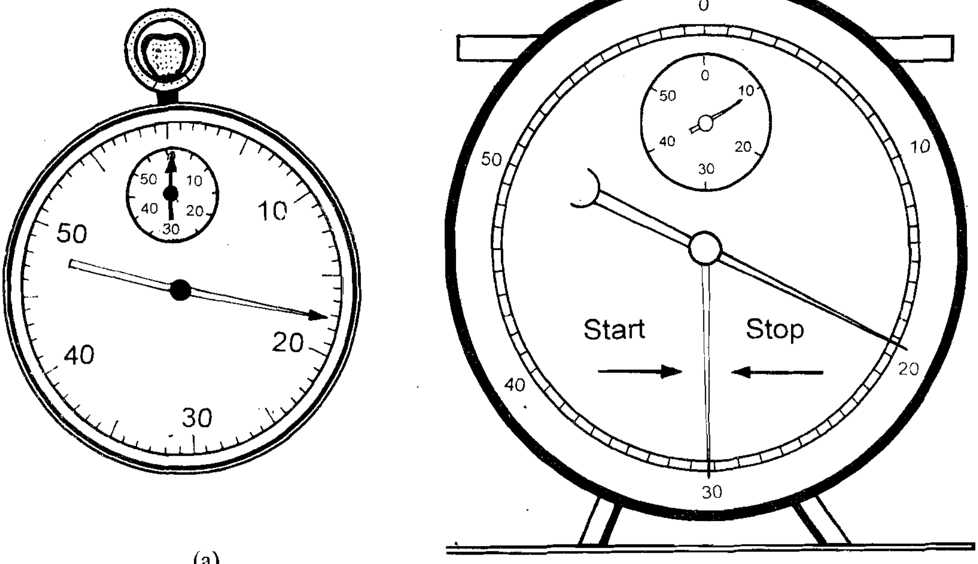
3.2.3 Stop Watch and Digital Timer

You are familiar with wrist watches and clocks. At home we use these to measure time in seconds, minutes and hours. In scientific work we need to measure time to a higher degree of accuracy. You may know that now clocks measuring time with an accuracy of 1 second in 300 years have been perfected. The clocks and watches we use at home have, in general, a least count of 1 second. In a school laboratory, time measurement of one-fifth of a second is sufficiently good for routine experiments. For this we use stop clocks and stop watches.

Refer to Fig.3.7 which illustrates a stop watch and a stop clock. Note that the large dial reads seconds and parts thereof while the smaller dial indicates minutes. Both instruments have start and stop arrangements.

To start the count of time in the stop watch, we press the knob at the top. If the knob is pressed a second time, the watch stops and the time interval can be noted. The indicator needles may be brought back to zero position by fly back when the knob is pressing for the third time. The watch is then ready for use again. In a stop clock the start, stop and fly back action is achieved with the help of a rod which can be pushed side-ways on both sides.

When the seconds needle of the watch completes one round, the minute needle shows one minute, and so on. The net time interval is obtained by adding the two readings.



(a) (b)

Fig.3.7: a) A laboratory stop watch; and b) a stop clock

Ordinary stop watches and stop clocks work on the mechanism of levers, wheels, and gears. When such devices have been in use for long, these may feel fatigue due to wear and tear. You are, therefore, advised that while working with a laboratory watch, **you should not fiddle with its knob unnecessarily**.

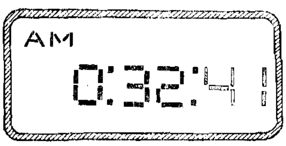


Fig. 3.8: A digital timer

In a physics laboratory we also have digital display clocks (Fig.3.8). Instead of indicating reading by indicator needles, these clocks show it continuously in fluorescent digits. These are used for the measurement of short intervals of time of the order of $(1/100)^{th}$ of a second. It is important to know that **as and when its digits start getting dim, you should get the battery changed.**

So far you have learnt about some instruments used for length and time measurements. You may know that mass is yet another fundamental physical quantity. Let us now know about the instruments used for measuring mass.

3.3 MEASUREMENT OF MASS

From your school physics, you will recall that mass signifies the quantity of matter contained in a body. The SI unit of mass is kilogram (kg). In a science laboratory, you may be required to measure very minute quantities, say a few gram(g) or milligram (mg), using a two pan balance. The measurement of mass of a body is based on the concept of measurement of weight. Weight is expressed in newton (N) and can be measured using a spring balance or a single pan balance, which could be analytical or electronic. The details of single pan analytical and electronic balances are given in Unit 2 of LT-3 course on Laboratory Techniques in Chemistry. In this unit we discuss (double pan) physical balance in detail. Before we do so, it is important for you to understand the principle of measurement of mass.

The weight of a body is defined as the force with which it is attracted by the earth towards its centre. Mathematically,

$$W = mg$$

where m is the mass of the body and g, the acceleration due to gravity. Fig.3.9 shows a single pan balance, where the body to be weighed is placed on the pan of the balance. The downward push on the pan compresses a spring attached below, which in turn, moves the index needle on the graduations. The scale is, in general, marked in kg. As explained above, reading of m kg, read as *weight of* m kg, really means weight of 9.8 m newton in SI unit.

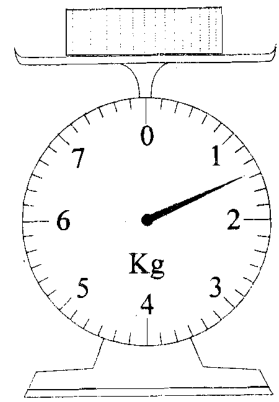


Fig.3.9: A single pan balance

A spring balance, shown in Fig.3.10, consists of a vertical spiral spring made of steel. The upper end of the spring is fixed and the lower end carries a pointer, which projects out of a long narrow rectangular slit in the front plate. A light bar is also attached to the lower end of the spring. The body to be weighed is suspended from a hook attached to the lower end of the bar. The suspended weight pulls the spring downward. The pointer attached to the spring moves on the scale and indicates the weight of the body. Spring balances are graduated in gram or kilogram and indicate weight in terms of mass. It is important to realise here that a spring balance cannot be used for precise measurement.

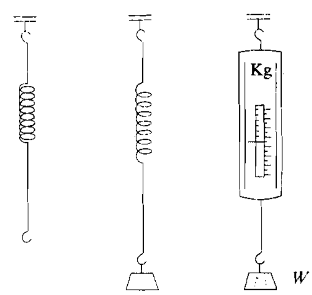


Fig.3.10: A spring balance: Extension is proportional to weight

If two bodies have masses m_1 and m_2, then their respective weights W_1 and W_2 at a place are given by

$$W_1 = m_1 g$$

and

$$W_2 = m_2 g$$

so that

$$\frac{W_1}{W_2} = \frac{m_1}{m_2} \tag{3.3}$$

This result is used in determining the mass of a body by comparing its weight with that of the standard masses with the help of a beam balance, as shown in Fig.3.11.

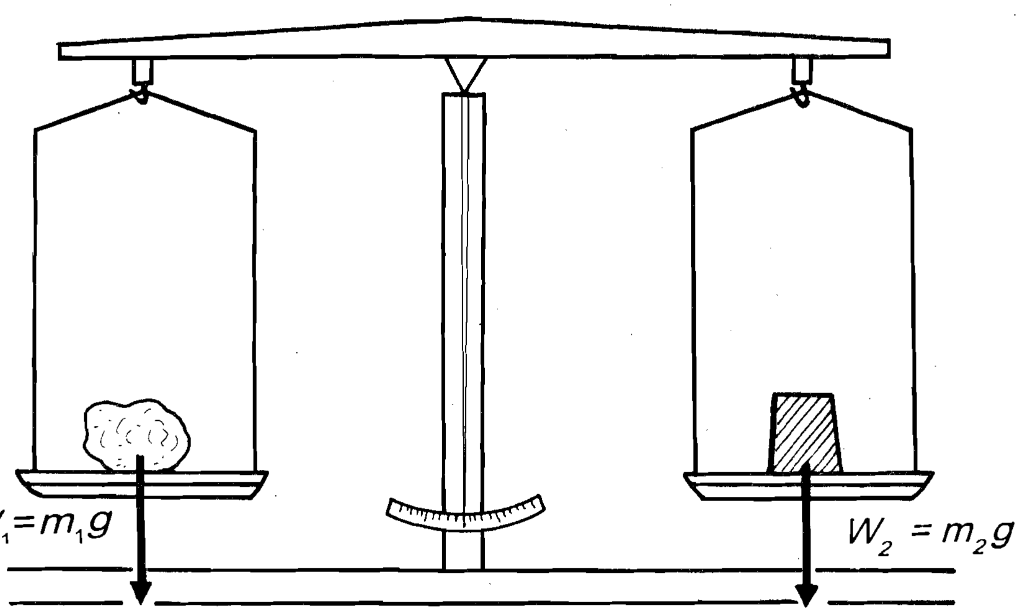


Fig.3.11: Principle of measurement of mass

You may like to attempt an SAQ to know whether you have understood the concepts presented above well.

SAQ 3: Spring balance versus beam balance

Spring balance measures weight whereas beam balance measures mass. Justify this statement.

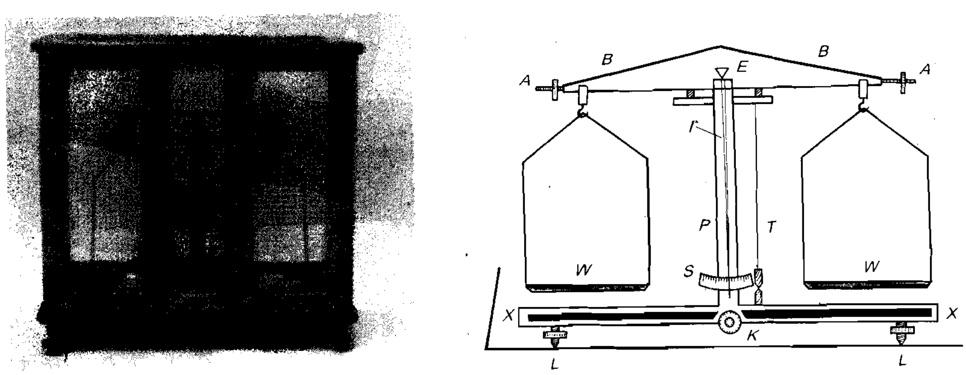
After answering the above SAQ you can readily appreciate that if we use the two pan balance to measure mass at another place, say on the moon, where the value of g is different, the mass of the body would be the same as that on the earth. It is because the value of g gets cancelled from both sides of Eq. (3.3). However, the same does not hold for a spring balance and a different value of weight is obtained at a place with different g.

We now discuss the physical balance.

A. Physical balance

A typical physical balance is shown in Fig.3.12a. It consists of many parts (Fig. 3.12b): a metallic *beam BB*, two pans *W*, a *pillar* or the supporting column *P*, an *index pointer I* and *index scale S*, a *plumb line T*, a *wooden base XX* with *levelling screws L* and a *knob K*. The metal beam is pivoted in the middle about the knife edge of a small wedge- shaped piece *E* of agate material. This provides a hard, non-wearing and frictionless sharp edge for the balance and free swing of the beam on the pillar. The beam has small *adjustment screws AA* at both ends. The two *pans* hang from the two ends of the beam. The pans are also supported on the beam on hard agate knife edges to avoid wear and friction.

While the beam is not in use, it can be lowered by rotating the arresting knob *K*, so that the beam and pans rest on the supports provided. This takes the load off the fine agate edges, protecting them from wear and tear and thereby enhancing the life and quality of the balance.



(a) (b)

Fig.3.12: a) A physical balance; and b) its schematic diagram

The index pointer *I* is fixed at the centre of the beam and above the fulcrum. When the beam and the pans rest on the agate edges, the lower end of the index pointer will swing on the index scale *S*. The whole arrangement is enclosed in a glass panelled box to cut off disturbances arising from air currents (Fig. 3.12a).

Before using the balance, you should *adjust it for horizontal levelling and perfect balance of the pans.* Horizontal levelling should be done with the help of the levelling screws and the plumb line. In correct levelling position, the suspended cone of the plumb line and the cone fixed with the pillar will come in one vertical line. To adjust the beam for perfect balance, raise it by turning the knob *K*. Then adjust the index pointer so that it swings equally on both sides of the zero on the index scale. You may correct any deviation by rotating suitably the beam adjustment screw *A*.

In case the plumb line is not functional, you can level the balance by placing a spirit level on the wooden box. A spirit level is a small container filled with alcohol. An air bubble floating in the alcohol facilitates levelling. For horizontal levelling, the bubble should lie between two lines marked in the middle of the container.

The object to be weighed is placed on the left hand pan and the standard masses on the right hand pan. Forceps are used to handle standard masses so as to avoid their contamination, which may result in inaccuracy. The general procedure for weighing an object can be summarised as follows:

- put standard masses slightly less than the estimated mass of the object;
- raise the beam on the knob and see the swing of index pointer around the zero of index scale; and
- add additional masses, if the swing is unequal and repeat the above step.

The correct mass is indicated by equal swing of the index pointer on both sides of index scale zero.

You must lower the beam on the knob every time you add to or take out masses from the pan. The standard masses kept in a wooden box, called the **weight box** (Fig.3.13), should only be used. Moreover, you should use forceps to handle weights. In a weight box, weights are placed in circular grooves made in order of increasing weights. The weights from 10 - 100 grams are cylindrical in shape and are provided with a small spherical knob at the top to lift them with forceps. Some weight boxes also carry fractional weights of different shapes made of aluminium and marked in milligrams.

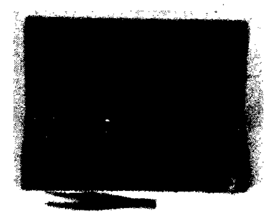


Fig.3.13: A weight box

You may now like to answer an SAQ.

SAQ 4: Measurement of mass

State at least three precautions you should observe while using a physical balance to measure the mass of a body.

So far you have learnt about measurement of three fundamental physical quantities—length, mass and time. You know that the surface of the earth is enveloped by a gaseous atmosphere comprising largely, nitrogen, oxygen, carbon di-oxide, and water vapour. These exert pressure. You may now ask: How do we measure atmospheric pressure? You will learn the answer to this question in the following section.

3.4 MEASUREMENT OF ATMOSPHERIC PRESSURE

The simplest instrument used for measuring atmospheric pressure, called the simple barometer, is shown in Fig.3.14. It has a glass tube inverted in a vessel containing mercury. The pressure exerted by the atmosphere on the free surface of mercury is transmitted equally over its entire volume. This pressure gives rise to an up-thrust at the base of the inverted glass tube and pushes mercury upwards. As a result, mercury rises in the tube till the weight of the mercury column balances the up-thrust. Therefore, the height of this column is a measure of the atmospheric pressure.

The atmospheric pressure was first measured by Torricelli nearly three centuries ago following some observations of the Duke of Tuscany (Italy). The Duke got a deep well dug and found that the suction pumps available at that time failed to lift water to a height more than 34′ (10 m). To understand this curious phenomenon, Torricelli took a long glass tube open at one end and filled it with mercury (Fig. 3.14a). He closed the open end of the tube with his finger and inverted it in a vessel containing mercury. When he removed his finger, he observed that the level of mercury dropped to a certain height leaving an empty space at the top. (This is known as the Torricellian vacuum.) The length of the column of mercury was found to be nearly 76 cm. Later on, he observed that the level of mercury in the tube was independent of its cross-section as well as inclination. This experiment proved the existence of air pressure for the first time.

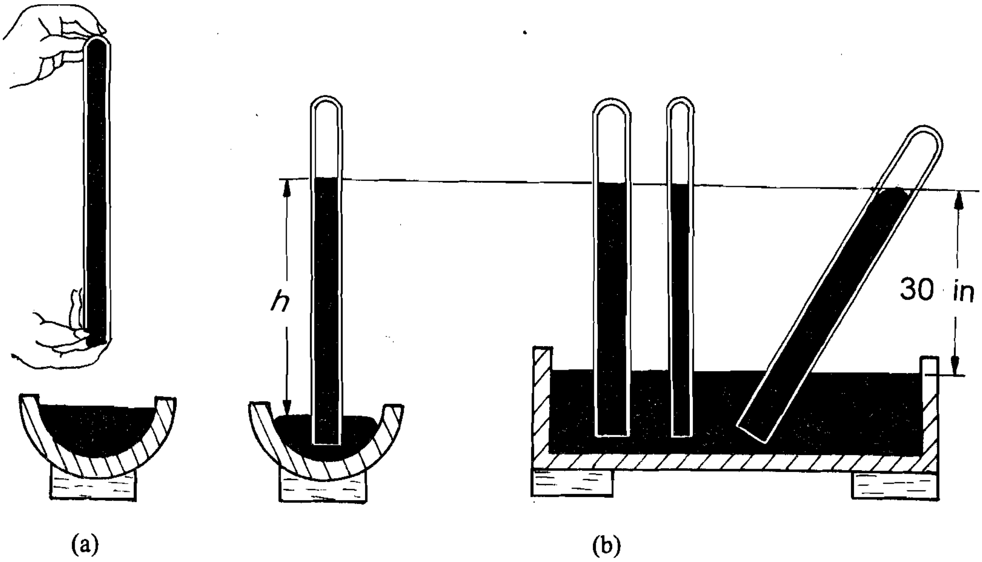


Fig.3.14: a) A simple barometer; b) The vertical height of mercury column is independent of the cross-section and the inclination of the tube.

If the height of the mercury column in the tube above the free surface of mercury in the container is h and the density of mercury is d, then the atmospheric pressure is

$$P = hdg \qquad (3.4)$$

At the sea level, $h = 0.76$ m, and for mercury $d = 13.6 \times 10^3$ kg m^{-3}. Since $g = 9.8$ ms^{-2},

$$P = 0.76 \times 13.6 \times 10^3 \times 9.8 \text{ Nm}^{-2} = 1.013 \times 10^5 \text{ Nm}^{-2}.$$

This pressure is taken as one atmosphere: 1 atm = 1.013×10^5 Nm^{-2}.

SAQ 5: Calculation of atmospheric pressure

Calculate the height of the vertical column of water ($d = 10^3$ kg m^{-3}) supported by the atmospheric pressure.

In answering SAQ 5, you have found that the atmosphere supports a vertical water column of height nearly 10.34 m. It is for this reason that water follows the piston of a suction pump up to this height. And nothing comes out of it, no matter what we do if the depth is greater than 10.34 m.

The simple barometer devised by Torricelli can be used to estimate atmospheric pressure for routine work. To measure air pressure more accurately, Fortin designed a barometer. You will get an opportunity to work with it in your physics lab. You will learn here about its construction and working.

3.4.1 Fortin's Barometer

Refer to Fig.3.15. It depicts a Fortin's barometer. It is very similar to Torricellian barometer, and is based on the same principle. This is invariably used in all physics laboratories.

A Fortin's barometer consists of a nearly 1 m long narrow glass tube of uniform cross-section. The upper end of the tube is closed and the open end is dipped in a reservoir of mercury. The bottom of the reservoir is made of flexible leather, so that the level of free surface of mercury can be adjusted with the help of screw S_1. The entire arrangement is enclosed in a metal case. An ivory pointer projecting downwards is provided at the top of the reservoir. The glass tube is enclosed in a cylindrical metallic tube, usually made of brass. This tube has a small slit and a vernier V is attached at the top end of the mercury column. The vernier can slide with the help of the screw S_2 along a vertical scale S fixed behind the glass tube. This scale is usually graduated in inches as well as centimetres. The zero of this scale coincides with the top of the ivory pointer.

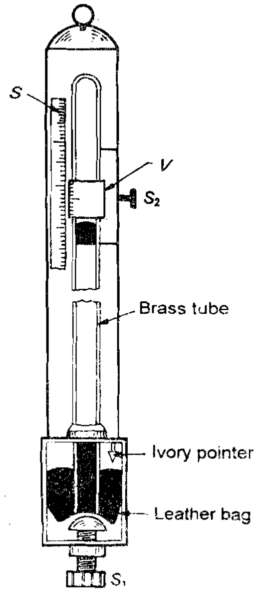


Fig.3.15: A Fortin's barometer

The height of the mercury column can be accurately measured with the help of the vernier-scale arrangement. A thermometer is also placed within the wooden enclosure containing the barometer.

To know the pressure at a place, you should first adjust the position of the screw S_1 to make sure that the tip of the ivory pointer just touches the free surface of mercury. This should be verified by making the tip of ivory pointer and its image in mercury to just coincide. Next adjust screw S_2 so that the edge of the vernier is in level with the upper meniscus of free surface of mercury column in the tube. Knowing this reading, you can calculate the atmospheric pressure using Eq. (3.4).

Fortin's barometer is quite accurate. But it is heavy and cumbersome. Therefore due care should be taken while installing or taking it from one place to another. Moreover, since it uses mercury, which is poisonous, you must clean your hands properly, if there is slightest contact with it.

So far we have confined ourselves to apparatus used in the measurement of physical quantities like length, mass, time and pressure. Another fundamental quantity in physics is temperature and as a lab technician you will use a thermometer to measure temperature. Different kinds of thermometers are used to measure temperature in different ranges. However, the basic principle used in the design of a thermometer is the same: measurement of the temperature variation of a physical property (volume, resistance, thermo-emf etc.) of a given substance. Thermometers that use a liquid (mercury or alcohol) as thermometric substance are known as liquid thermometers and use the property of expansion (change in volume) when heated. In your physics lab you will be required to work with a mercury thermometer. So for ease and convenience, here we shall discuss only mercury thermometers.

3.5 MERCURY THERMOMETER

A mercury thermometer (Fig.3.16) consists of a long capillary tube called a stem whose one end is shaped like a bulb (B). The bulb and a part of the stem are filled with mercury. The other end of the stem is sealed. Near the end of the capillary tube, there is an expansion chamber. This is to save the thermometer from damage in case it gets over-heated. There are graduations along the stem to indicate the temperature (T).

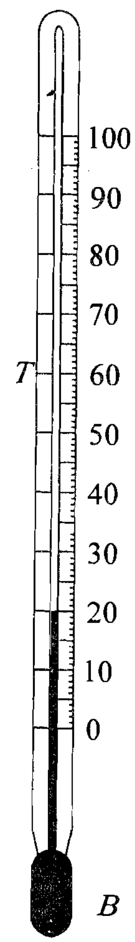


Fig.3.16: A liquid-in-glass thermometer

The sensitiveness of a mercury thermometer can be increased by

- increasing the volume of the bulb; and
- decreasing the size of bore of the stem.

Thermometers used in School or UG laboratories are graduated into equal intervals on a Celsius and Fahrenheit scale. The Celsius scale ranges from 0°C (freezing point of ice) to 100°C (boiling point of water) and the Fahrenheit has markings from 32°F to 212°F. Graduations in both these scales figure on a single thermometer. You can read the temperature in either of the two units and convert it into the other by using the following formula:

$$T(°C) = \frac{T(°F) - 32}{9} \times 5$$

In some thermometers, the least count is 1°. But the least count of a thermometer required for accurate lab work is 0.5°.

So far you have learnt about basic instruments used in the measurement of length, time, mass, pressure and temperature. Now we turn our attention to equipment used in measurement of frequency and speed of sound. In the following section we discuss only the sonometer, resonance tube apparatus, and a tuning fork.

3.6 MEASUREMENT OF FREQUENCY AND SPEED OF SOUND WAVES

Musical instruments like violin, sitar, ektara, harp, veena and bongo use strings, whose end points are tightly fixed. You may recall from school physics that when such strings are set into vibrations, stationary waves are produced due to superposition of incident and reflected waves. The end points act as *nodes* and between any pair of nodes, there is an *anti-node*.

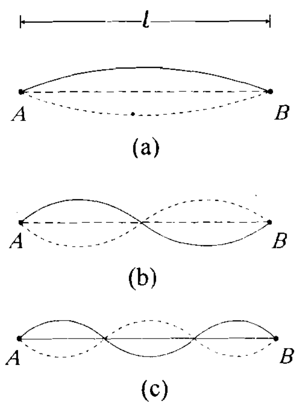


Fig.3.17: Difterent modes of vibration of a string. The end points *A* and *B* correspond to nodes.The displacement is maximum at anti-nodes.

The simplest way in which a string fixed at both ends can vibrate is as just one segment, as shown in Fig.3.17. It is then said to execute fundamental mode of vibration. The length l of the string is one-half the wavelength, and the frequency of the fundamental vibration is given by

$$f_0 = \frac{1}{2l}\sqrt{\frac{T}{m}} \qquad (3.5)$$

where T is the tension in the string and m its mass per unit length. It may be noted here that this is the minimum frequency which the string can produce. In general, the wire may vibrate in two or more segments (Figs.3.17b and c). For n number of segments, the frequency f_n of vibration of the string is

$$f_n = \frac{n}{2l}\sqrt{\frac{T}{m}}; \qquad n = 1,2,3,... \qquad (3.6)$$

It is important to point out that Eq. (3.6) holds only for those strings that are free from all kinks. The simplest apparatus in which you can produce stationary waves is a sonometer. You will now learn about it.

3.6.1 Sonometer

A sonometer consists of a hollow wooden box with a peg P at one end, and a pulley at the other (Fig.3.18). One end of the string is fixed with the peg, and the other end, passing over a smooth pulley, carries a hanger/pan in which weights can be placed. There are two or three holes in the side of the hollow wooden box which is used as a sounding board. The wire passes over two movable wooden blocks W known as bridges. These can slide in between the peg and the pulley.

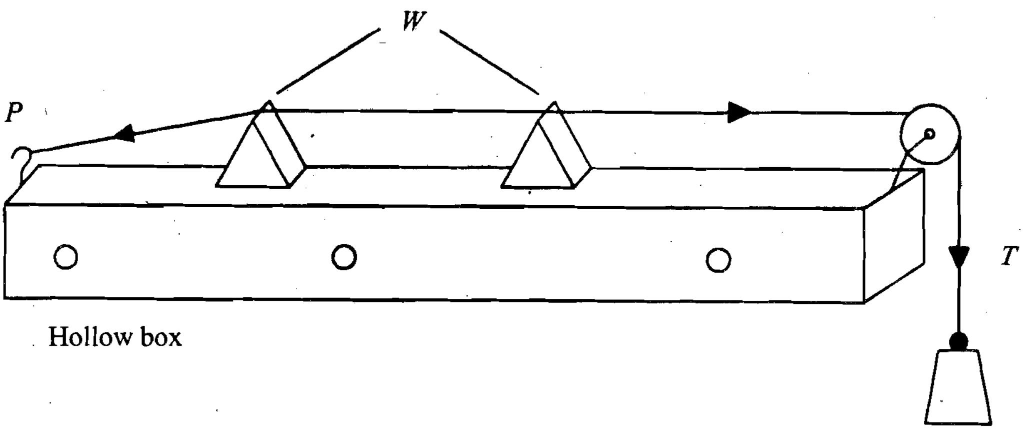


Fig.3.18: A sonometer

To produce stationary waves in a sonometer, we take a tuning fork and make it to vibrate by striking it against a rubber pad. The vibrating tuning fork is placed on the sounding board of the sonometer. The air within the box is set into vibrations and stationary waves are established on the string. You will learn about a tuning fork in Sec. 3.6.3.

While performing an experiment, we place a paper rider nearly mid-way on the string passing over hard wooden blocks. When the rider falls down, the string and the tuning fork are said to vibrate in unison. The position of the rider where the displacement is maximum is said to correspond to the position of an antinode.

Knowing the smallest length for which the rider falls, you can calculate the frequency of the tuning fork using Eq. (3.5).

There is another group of musical instruments like the flute, shehnai, trumpets, where music is produced due to vibrations in air columns. To study stationary waves in air columns in physics lab, we use the resonance tube apparatus.

3.6.2 Resonance Tube Apparatus

The essential parts of a resonance tube apparatus are shown in Fig.3.19a. It consists of a 1m long glass tube whose lower end is connected to a water reservoir. It is fixed on a vertical board, which is provided with a heavy base carrying levelling screws. A metre scale is also fixed on the vertical board. The length of the air column can be adjusted by raising or lowering the water reservoir.

When a vibrating tuning fork of frequency f is held above the upper end of the resonance tube, a sound wave is generated inside the air column. It is reflected from the closed end of the tube. The superposition of incident and reflected waves gives rise to stationary waves. The closed end acts a node whereas the open end acts as an anti-node. The position of the water level is so adjusted that we hear the maximum sound. The air column is then in unison with the given tuning fork. For the fundamental mode of vibration (Fig.3.19b), the length of the air column $l_1 = \lambda/4$, where λ is the wavelength of stationary wave.

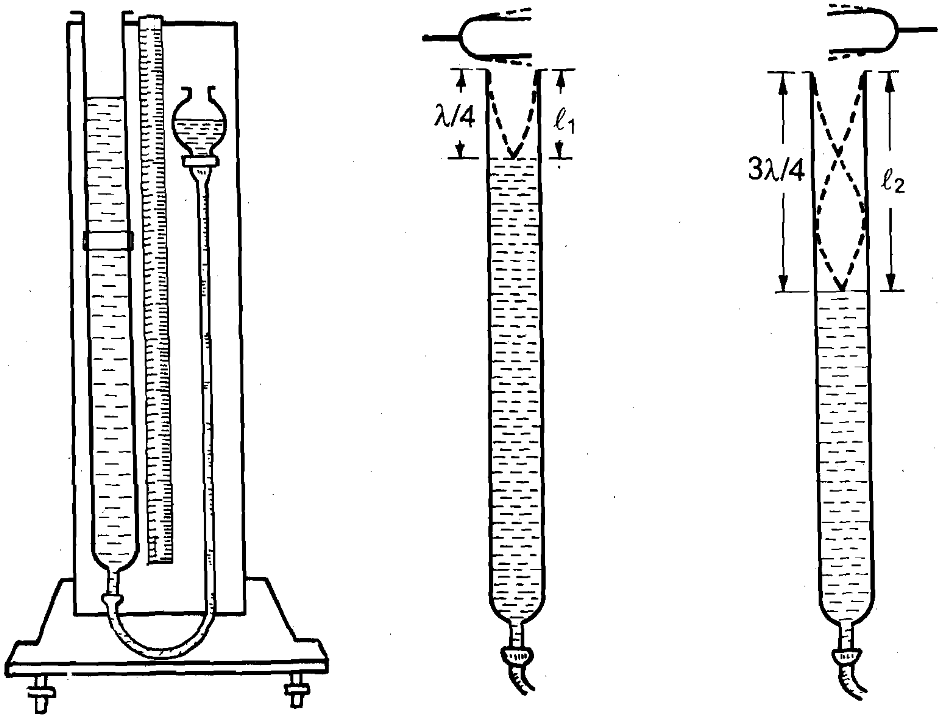


Fig.3.19: a) Resonance tube apparatus; b) fundamental mode of vibration; and c) first higher harmonic in the resonance tube

Next, the position of the water level is lowered till we get another position of resonance with the same tuning fork (Fig.3.19c). This length of the air column is $l_2 = 3\lambda/4$. From these, it immediately follows that $\lambda = 2(l_2 - l_1)$.

Since $v = f\lambda$, we get

$$v = 2f(l_2 - l_1) \tag{3.7}$$

It shows that velocity of sound can be easily determined using a resonance tube. You may like to attempt an SAQ before studying further.

SAQ 6: Sonometer and resonance tube apparatus

a) How are stationary waves generated in a sonometer?

b) When is the air column in a resonance tube said to be in unison with the tuning fork? How do we come to know of it?

You must have realised that we need a tuning fork to generate sound waves in a sonometer as well as the resonance tube apparatus. You may like to know about the tuning fork.

3.6.3 Tuning Fork

A tuning fork is a U-shaped steel bar with a stem at the centre. It has the shape of the letter Y. Its free ends are called prongs. Tuning forks are available in a variety of sizes. Each tuning fork is characterised by a specific frequency, which is engraved near the bend. In general, a tuning fork of low frequency is thin and long. As the frequency increases, the length of the prongs of the tuning fork decreases but their thickness increases (see Fig.3.20). The free ends of the prongs of the tuning fork act as anti-nodes. Another anti-node exists at the point where the stem joins the U-shaped portion. There is a node on each prong in between each free end of the prongs and the point where the stem joins the U-shaped portion. The nodes may not appear to be situated exactly in the middle of each prong. The small difference arises while converting a bar into U-shape.

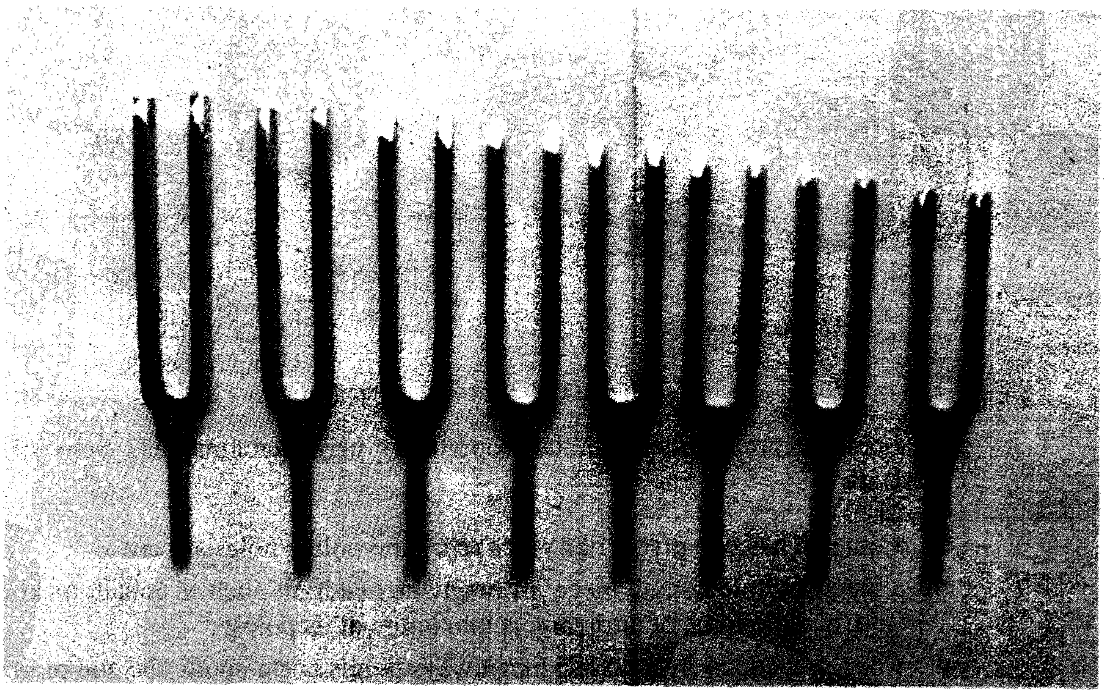


Fig.3.20: Tuning forks of different characteristic frequencies

After the tuning fork has been struck against the rubber pad, its U-shaped portion should not touch any object, otherwise the vibrations will die out. This is because vibrations of prongs are transverse. However, note that the vibrations of the handle/stem continue even when it is held firmly. Do you know the reason? This is because vibrations of the handle are longitudinal.

In the preceding sections you have learnt about basic tools used in experiments in areas of mechanics, heat and sound. Another important category of basic apparatus that are used to study the magnetic properties of materials are magnets. You will now learn about these.

3.7 PERMANENT MAGNETS AND ELECTROMAGNETS

In your school physics curriculum you have learnt about permanent magnets and electromagnets. The permanent magnets are usually in the form of a bar magnet, a horse-shoe magnet and a compass needle. These are shown in Fig.3.21.

In a magnetised substance, the tiny molecular magnets point along one direction. As a result, north as well as south poles of the tiny magnets come together at the ends of a magnet. This causes repulsion, which disturbs their ordered arrangement.

You may recall that a compass needle was widely used in marine navigation. Do you know that small permanent magnets are used in a fridge door to keep it tightly shut? Now-a-days magnets have a variety of uses, specially in electrical and telecommunication instrumentation, medical diagnosis, video and audio recording and computers.

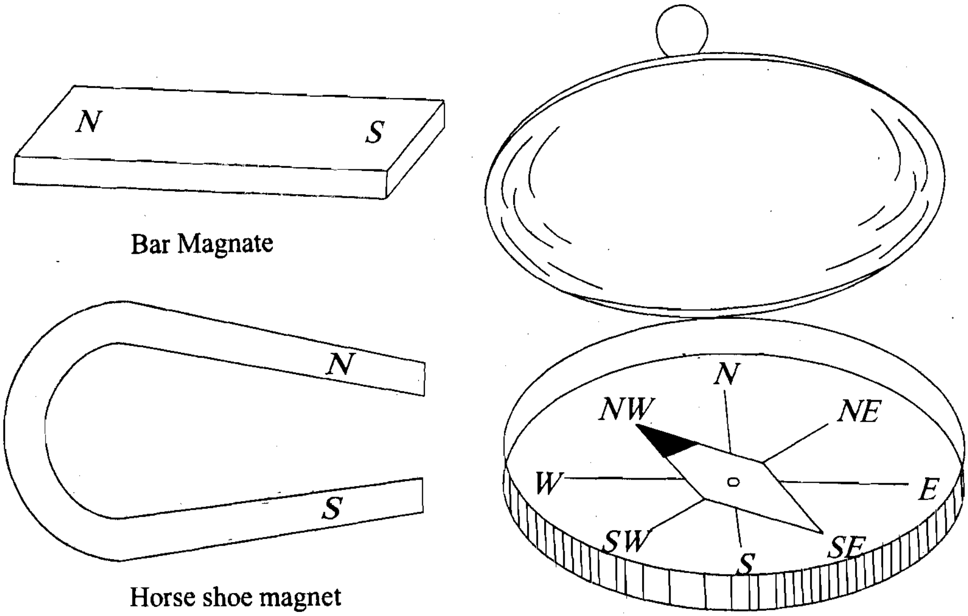


Fig.3.21: Some common magnets

We hope you are familiar with the properties of permanent magnets. Some of these are:

- a magnet has two poles; like poles repel and unlike poles attract;
- a magnet attracts small pieces of magnetic materials such as cobalt, nickel, iron, and the force of attraction is maximum at its poles;
- when suspended freely, a magnet always points north-south; the end of the magnet pointing towards the geographical north is labelled as north pole and the end pointing towards earth's south is the south pole;
- poles exist in pairs; if a magnet is broken into two or more pieces, each piece behaves as a magnet; and
- a magnet can induce similar properties in magnetic materials. This property is used to make permanent magnets.

It is important to note that a permanent magnet can lose magnetism

- if it is dropped or subjected to red-hot temperatures; and
- through **self-demagnetisation** over a period of time.

To save magnets from demagnetisation, we use **magnetic keepers** which are small pieces of soft iron. To store permanent magnets after use, you should keep soft iron pieces at their ends, as shown in Fig.3.22. The soft iron pieces get magnetised due to magnetic induction and reduce repulsive effects.

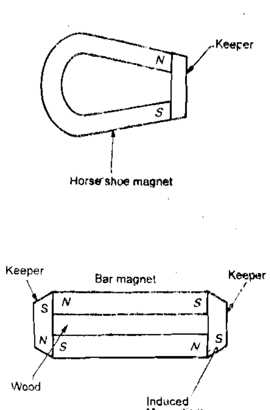


Fig.3.22: Use of keepers to store a magnet

You will agree that the strength of a permanent magnet is small. The most convenient and efficient method to obtain a magnet of high strength is to use the electric current. Such a magnet is known as **electromagnet**. An electromagnet is used in door bells, telephone receivers, loud speakers, electric motors, generators, etc. In an electromagnet, a thin insulated copper wire is wound on a soft iron bar . When electric current is switched on, the bar turns into an electromagnet producing a magnetic field. As soon as the current is switched off, it loses all magnetism. It means that electromagnets are temporary magnets since their magnetic field lasts till the current flows (Fig.3.23). Moreover, the strength of the magnetic field so produced depends on the number of turn of the wire wound over the bar and the magnitude of current through the wire.

You may now like to know: How do we determine the polarity of such a magnet? You can do so easily by gripping the iron bar with your right hand in such a way that the fingers point along the direction of flow of current. The thumb then points towards the north pole of the magnet.

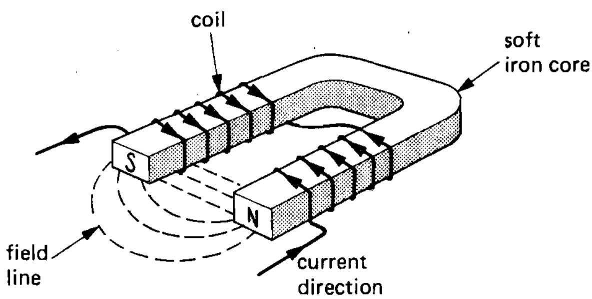


Fig.3.23: An electromagnet

With this, we come to an end of the discussion of the basic apparatus found in a school or UG physics lab. Most of the devices and instruments described here are used in experiments cutting across many areas of physics; hence the term basic apparatus. We now summarise the contents of this unit.

3.8 SUMMARY

- The **vernier callipers** and **screw gauge** are used for length measurements to the accuracy of 0.01 cm and 0.001 cm, respectively.

- The **stop watch** is used for time measurement to the accuracy of one-fifth of a second. A **digital** timer reads time upto the accuracy of (1/100)th of a second.

- The weight of a body can be measured with the help of a **single pan balance, spring** balance. A **physical balance** measures the mass of the body by comparing its weight with standard weights.

- A **simple barometer** and **Fortin's barometer** are used to measure atmospheric pressure. Only the latter is used in physics laboratories as it gives quite accurate measurements.

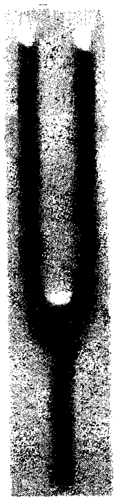
- A **mercury thermometer** suffices in most of the physics experiments requiring temperature measurements.

- Stationary sound waves can be produced with the help of a **tuning fork** in a **sonometer** and **resonance tube apparatus** to determine the frequency and speed of sound waves.

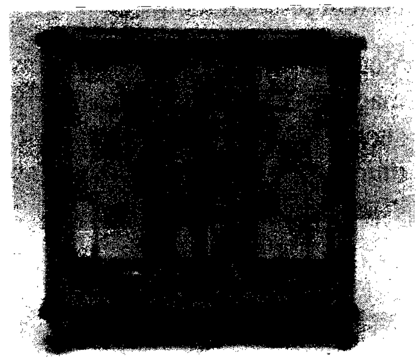
- **Permanent magnets** and **electromagnets** are used in experiments on the study of magnetic properties of materials.

3.9 TERMINAL QUESTIONS

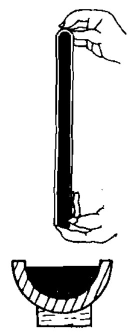
1. Identify each device shown below:



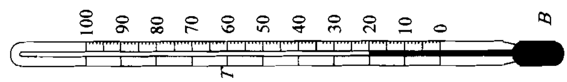
(a)



(b)



(c)



(d)

2. Name the instruments you will require for the measurement of the following physical quantities:

   a) 6.05 cm length
   b) 0.001 s time interval
   c) 1.2059 g mass
   d) speed of sound waves generated in a sitar wire

3. List one major precaution you will take while handling each of the following equipment:

   a) Screw gauge
   b) Mercury thermometer
   c) Permanent magnet

3.10 SOLUTIONS AND ANSWERS

Self-assessment Questions

1. (i) 3.90 cm, (ii) 5.10 cm, (iii) 1.73 cm

2. (i) 0.209 cm, (ii) 0.074 cm, (iii) 0.281 cm

3. In the spring balance, the extension of the spring is proportional to the weight of a body (= mg newton), and not its mass. Therefore, if we take it

to a different place having a different value of g, it will record a different reading for the same object as its weight will be different. In a physical balance, we compare the unknown weight with a known weight by balancing them. Since the factor g cancels out, we end up measuring the mass.

4. a) The physical balance should always be levelled horizontally and the pans should be balanced perfectly.

   b) The beam must always be lowered on the knob every time masses are taken out or put on the pans.

   c) Standard masses should be handled with forceps only.

5. Since atmospheric pressure $= 1.013\times10^5\,\mathrm{Nm^{-2}}$, $d = 10^3\,\mathrm{kg\,m^{-3}}$ and

   $g = 9.8\mathrm{ms^{-2}}$, we have

$$h = \frac{P}{dg} = \frac{1.013\times10^5}{10^3\times9.8}\mathrm{m} = 10.34\mathrm{m}$$

6. a) The wire between two bridges vibrates when a vibrating tuning fork is put on the sounding board. Since the wire is clamped at both ends, the waves get reflected and their superposition gives rise to stationary waves.

   b) When the air column vibrates at the same frequency as that of the tuning fork, resonance is said to occur. We come to know of it when we hear the maximum sound.

Terminal Questions

1. a) Tuning fork
   b) Balance
   c) Simple barometer
   d) Thermometer

2. a) Vernier callipers
   b) Digital timer
   c) Physical balance
   d) Sonometer

3. a) Prevent backlash error by avoiding over-tightening of the spindle.

   b) Avoid touching mercury if the thermometer breaks and if it is touched accidentally, avoid touching any other parts of the body like the eyes, mouth etc.

   c) Prevent demagnetization due to heating, dropping or placement in a high magnetic field.

UNIT 4 OPTICAL APPARATUS

Structure

4.1 INTRODUCTION

In Unit 1 you have learnt that **optical apparatus** are used for conducting experiments with light. Light is responsible for our visual contact with our surroundings. In nature, we observe various interesting phenomena associated with light, such as solar and lunar eclipses, rainbows and mirage. These can be understood in terms of rectilinear propagation, reflection and refraction of light which follow certain basic laws. You can verify these laws by conducting experiments in a laboratory.

In the present unit, you will learn about optical apparatus available in a typical school or college laboratory, their handling and maintenance. In particular, we discuss how image formation by reflecting and refracting surfaces such as mirrors, lenses, prisms or their combination can be used to design optical instruments which extend our reach and enable us to learn more about nature. Finally we discuss light sources used in a physics lab to perform various experiments on optics. In the next unit you will learn about electrical instruments.

Objectives

After studying this unit, you should be able to:

- state the laws of reflection and refraction of light;
- define the terms principal axis, centre of curvature, radius of curvature, focus and focal length for spherical mirrors;
- distinguish between plane, concave and convex mirrors;
- explain image formation by plane, concave and convex mirrors;
- distinguish between convex and concave lenses;

- explain image formation by a compound microscope and a telescope;
- explain the working of a spectrometer;
- list commonly used sources of light in a physics laboratory; and
- state the precautions in handling and maintenance of optical apparatus.

4.2 LAWS OF REFLECTION AND REFRACTION

The optical apparatus we discuss in this unit are essentially image forming devices. Image formation by these devices can be understood in terms of rectilinear propagation of light which means that light travels along a straight line. It can be depicted in the form of rays. Moreover, the following laws hold for propagation of light:

a) Laws of reflection, and
b) Laws of refraction.

You must be familiar with these laws. But we state these to refresh your memory.

A. Laws of reflection

When light incident on a surface is reflected, the following laws hold:

i) The angle of incidence is equal to the angle of reflection.
ii) The incident ray, the reflected ray and the normal to the surface at the point of incidence are in the same plane (Fig.4.1).

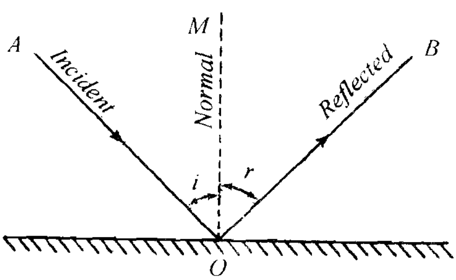


Fig.4.1: Reflection of light from a plane surface. The angle of incidence is equal to the angle of reflection; that is, $\angle AOM = \angle MOB$, and AO, OB and MO are in the plane AOB.

B. Laws of refraction

Refer to Fig.4.2. When light travels from one medium to another, it undergoes refraction at the boundary separating the two media and the following laws hold:

i) The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for any two media; that is,

$$\frac{\sin i}{\sin r'} = \mu \tag{4.1}$$

where μ is the refractive index of medium 2 with respect to medium 1.

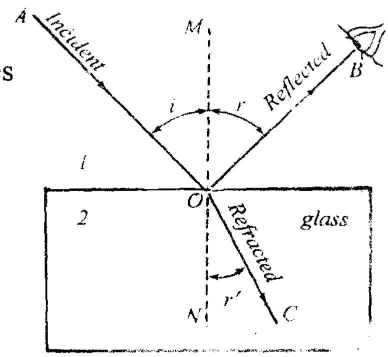


Fig.4.2: Refraction of light

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ii) The incident ray, the refracted ray and the normal *NO* lie in the same plane.

If light travels from a rarer (air) to a denser (glass) medium, it bends towards the normal. Conversely, if light travels from a denser medium to a rarer medium, it bends away from the normal. Note that in the latter case greater the refractive index of the medium of incidence, greater will be the deviation of the refracted ray from the normal. Media whose refractive indices are greater than unity (refractive index of air) are called **optically denser media**. Examples of such media are water, glass, transparent plastics, etc.

When light is incident from a denser to a rarer medium, it is possible that at a particular angle of incidence, the angle of refraction becomes 90°. Such an angle of incidence is called **critical angle**. When angle of incidence is greater than the critical angle, the ray is reflected back. This phenomenon is known as *total internal* reflection. It is responsible for optical illusion in mirage as well as brilliance of diamonds. Now-a-days it is also used in optical communication.

Before you proceed further, you may like to answer an SAQ.

SAQ 1: Reflection and refraction of light

a) Name the phenomenon observed in each of the following:

i) Looking glass used in homes
ii) Spectacles; and
iii) Rear view mirror used in motor cars and buses.

b) Glass is denser than water and water is denser than air. Draw the ray diagram when light travels from

i) water to glass
ii) air to water
iii) glass to air

In a typical physics laboratory, you will come across a variety of image forming optical apparatus such as plane mirrors, spherical mirrors and lenses. Image formation in mirrors is governed by the laws of reflection. In the following section, you will learn how images are formed by plane and spherical mirrors.

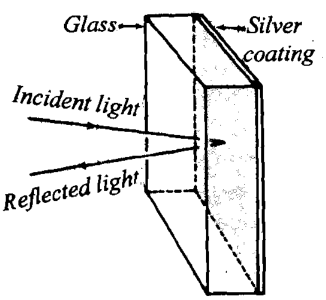


Fig.4.3: An ordinary plane mirror

4.3 IMAGE FORMATION BY REFLECTING SURFACES

You are familiar with a plane mirror. Have you ever thought how an image is formed in such a mirror? You may have observed that it is made of glass with a thin coating of shiny metal on one of its surfaces (Fig.4.3). This coating can be of silver, mercury or aluminium. The same holds true for spherical mirrors as well. In a plane mirror, coating can be applied on either surface of a glass plate. You may now ask: What purpose does the metallic coating serve? This makes it a reflecting surface. We can apply the laws of reflection to understand image formation by such a mirror.

4.3.1 Plane Mirror

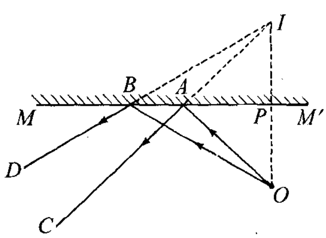


Fig.4.4: Image formed by a plane mirror is virtual

Refer to Fig.4.4. *MM'* represents a plane mirror. A point object *O* is placed in front of it. Light rays emanating from the object *O* are reflected by the mirror and the image appears to be formed behind it. To locate the position of the image, it is sufficient to consider only two incident light rays.

Two incident rays *OA* and *OB* are reflected by the mirror at *A* and *B* along *AC* and *BD*, respectively. If we extend the reflected rays *AC* and *BD* backwards, they meet at *I*. Since the reflected rays do not actually originate from point *I*, it is called the **virtual image** of the object *O*.

If O and I are joined in a straight line, you will note that

i) $OP = PI$, that is, the image I is located as far behind the mirror as the object is in front of it, and

ii) the line OI is perpendicular to the plane of the mirror.

If the object is of finite size, its image is **laterally inverted** and of the same size. Do you know what is meant by lateral inversion of an image? To understand this, you may stand in front of a mirror and raise your right hand. You will note that your image in the mirror raises its left hand. Similarly, if you place the letter E in front of the mirror, its image is seen as Ǝ (Fig.4.5).

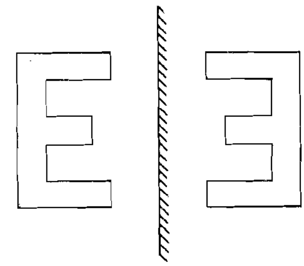


Fig.4.5: Laterally inverted image formed by a plane mirror

To sum up, the image formed by a plane mirror is **virtual, erect, laterally inverted, of the same size** and **located as far behind the mirror as the object is in front of it**.

Many a times, we need to obtain enlarged or smaller images of objects. For example, in the rear view mirror of an automobile, the images formed should be smaller so that the field of view is wide. Spherical mirrors serve this purpose well. We now discuss image formation by such mirrors.

4.3.2 Spherical Mirrors

A spherical mirror is obtained by cutting a piece from a hollow glass sphere and coating one of its surfaces with a shiny metal. In the plane of the paper, we draw them as part of a circle. There are two types of spherical mirrors, namely the **concave mirror** and the **convex mirror,** as shown in Fig.4.6. The characteristics of the image formed by these mirrors are quite different from those of a plane mirror. To study image formation by spherical mirrors, you must recapitulate some of the important terms and definitions associated with them. Now we briefly explain them.

Again refer to Fig.4.6. For both types of mirrors, C is the **centre of curvature;** P, centre of the mirror, is the **pole**; and CP, denoted by R, is the **radius of curvature**. The line AB passing through the centre of curvature (C) and the

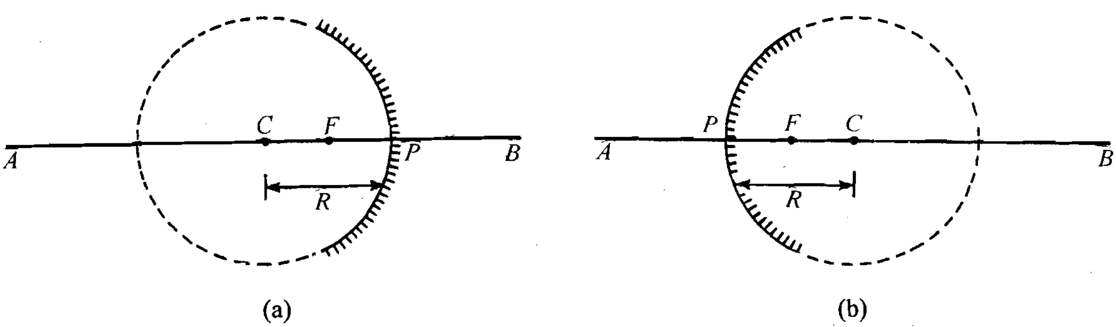


Fig.4.6: a) A concave mirror; and b) a convex mirror

pole (P) of the mirror is called the **principal axis**; F, the mid point of CP, is the **focus** of the mirror; and FP, the distance between the focus and the pole, is the **focal length** f. Obviously

$$f = \frac{R}{2} \qquad (4.2)$$

Now suppose you are given a spherical mirror and you are asked to locate its focus. How would you do it? Refer to Fig.4.7a. It shows parallel rays of light coming from a distant source such as the sun incident on a concave mirror. The reflected rays cross each other at point F on the principal axis. The point F is called the **principal focus** of the mirror. Since a concave mirror converges parallel rays of light at the focus, it is also called **converging mirror**.

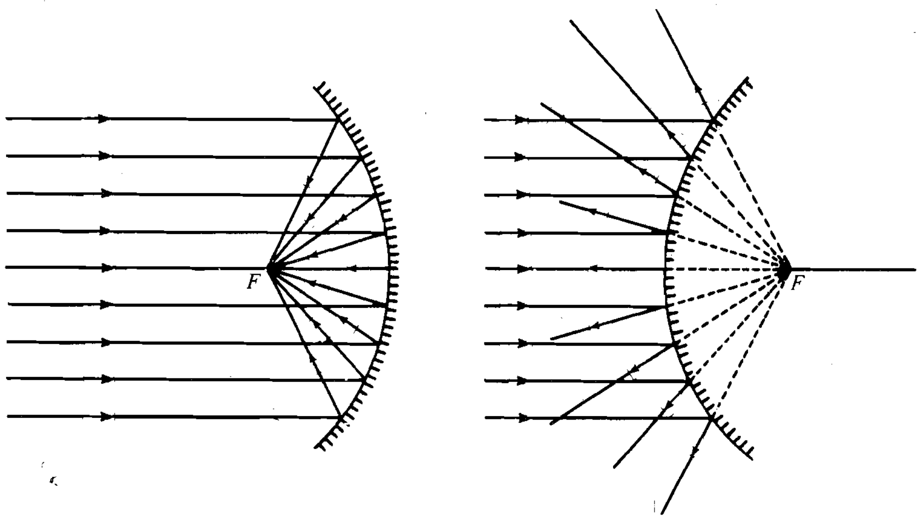


Fig.4.7: Reflection of parallel rays by a) a concave; and b) a convex mirror

For a convex mirror (Fig.4.7b), the reflected rays *seem* to come from a point F on the other side of the reflecting surface. In fact, the rays of light seem to **diverge** from F, the **principal focus** of the mirror. Since the convex mirror diverges parallel rays, it is also known as **diverging mirror**.

You may now ask: How are images formed by spherical mirrors and what is their nature? You may be familiar with the ray tracing method to obtain these images. We now briefly explain it.

Ray tracing method

The ray tracing method is based on the following rules:

Rule 1: The incident ray parallel to the principal axis of a spherical mirror, after reflection, passes (for concave mirror) or *appears to pass* (for convex mirror) through the principal focus (ray 1 in Fig.4.8a, b).

Rule 2: The incident ray passing or appearing to pass through the centre of curvature of a mirror is reflected back along the same path (ray 2 in Fig.4.8a,b).

Rule 3: The incident ray passing (for concave mirror) or *appears to pass* (for convex mirror) through the principal focus is reflected along a line parallel to the principal axis (ray 3 in Fig.4.8a, b).

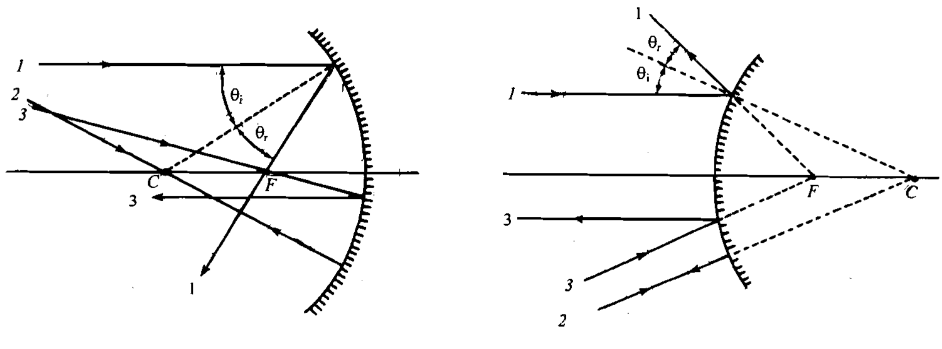


Fig.4.8: Reflection of light by a) a concave mirror; and b) a convex mirror

You should note that

- at least two rays have been drawn from the top of an object;
- it is sufficient to consider only two of the three rays shown in Fig.4.8 to locate the image of the object;
- the third ray may be drawn just as a check; and
- the object is kept on the left side of the reflecting surface and ray diagrams are drawn from left to right.

Now let us apply these rules for locating images formed by a concave and a convex mirror.

A. Concave mirror

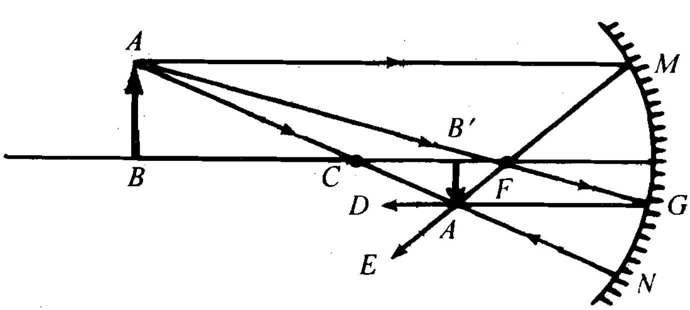


Fig.4.9: Image formed by a concave mirror (Ray tracing method)

Refer to Fig.4.9. Note that an object *AB* is placed beyond the centre of curvature of the mirror. We obtain its image as follows:

1. Ray *AM* parallel to the principal axis passes through the focus *F* on reflection.

2. Ray AN passing through C is incident on the mirror at N and reflected along NA. The two reflected rays ME and NA intersect each other at A'. Thus A' is the image of A. The image of all other points on AB, except B, can be located similarly.

3. Ray AG passing through F is reflected along GD parallel to the axis. Note that GD also passes through A'.

Since object AB is perpendicular to the axis, the image of B is located at B', which is the foot of the perpendicular drawn from A' on the principal axis. *Thus, $A'B'$ is the image of AB.*

Salient features of the image $A'B'$ are that it is located between C and F, it is inverted, smaller in size than the object and real.

In Fig.4.9, we have considered a special case in which the object is located beyond C. However, in practice, objects may be kept anywhere between P and infinity. To gain some practice you may now like to trace the ray diagram for image formation.

SAQ 2: Ray diagram for images formed by a concave mirror

Locate the images of the object AB for the following configurations and state their nature:

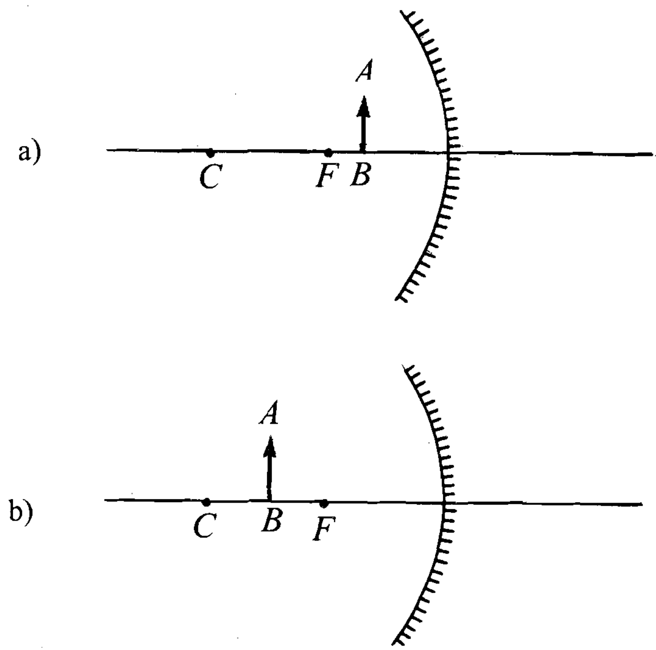


Fig.4.10: Locating image positions for a concave mirror

Now refer to Table 4.1 where we have summarised the position and nature of images formed by a concave mirror for different positions of the object.

Table 4.1: Nature of images formed by a concave mirror

Position of the object	Position of the image	Nature of the image
i) Between focus F and pole P of the mirror	Behind the mirror	Virtual, erect and magnified
ii) At F	At infinity	Real, inverted and magnified
iii) Between F and C	Between infinity and C	Real, inverted and magnified
iv) At C	At C	Real, inverted and equal in size
v) Between C and infinity	Between F and C	Real, inverted and diminished
vi) At infinity	At F	Real, point image

You may note that the height of image varies with the position of the object in front of the mirror. The ratio of the height of the image (I) to the height of the object (O) is defined as **magnification** produced by the mirror. We usually denote it by m. Mathematically, we can also express it in terms of the distances of the image (v) and the object (u) from the mirror:

$$m = \frac{I}{O} = \frac{v}{u} \qquad (4.3)$$

The **focal length** of a mirror is related to image and object distances as follows:

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \qquad (4.4)$$

This relation is known as **mirror formula**. It is valid for concave mirror as well as convex mirror. In order to use this formula, the following **sign convention** is adopted:

a) All distances are measured from the pole of the mirror.
b) Distances measured in the direction of the incident ray are positive.
c) Distances measured upward and perpendicular to the principal axis are taken as positive.

On the basis of this convention, the focal length and radius of curvature of a concave mirror are negative and those of a convex mirror are positive.

To understand these concepts, consider a candle placed at a distance of 15 cm from a concave mirror of focal length 10 cm. In view of the sign conventions, we have

$$f = -10 \text{ cm} \quad \text{and} \quad u = -15 \text{ cm}$$

Inserting these values in the mirror formula, we obtain

$$\frac{1}{v} - \frac{1}{15} = -\frac{1}{10}$$

or

$$\frac{1}{v} = \frac{1}{15} - \frac{1}{10} = -\frac{1}{30}$$

so that

$$v = -30 \text{ cm}$$

And magnification

$$m = \frac{v}{u} = \frac{-30}{-15} = 2$$

That is, the image is real and double the size of the object. Note that mirror formula does not tell you whether the image is erect or inverted. For this, you will have to use the ray tracing method.

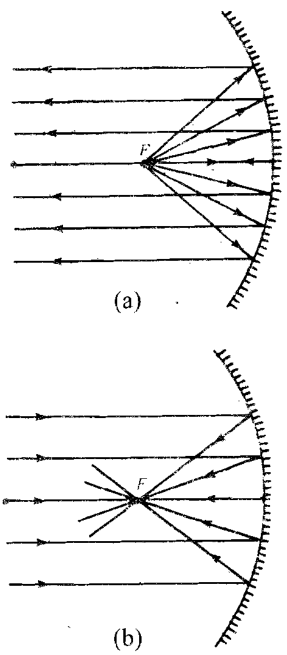


Fig.4.11: a) A concave mirror as a reflector; and b) as a concentrator

Reflection of light by a concave mirror has important applications. As a reflector in a torch, head lights of vehicles and searchlights, it is used to obtain a parallel beam of light. If you place a point source of light at the focus of a concave mirror, as per *Rule* 3 of ray tracing, the reflected rays will be parallel to the axis (Fig.4.11a). As **light concentrator,** it focuses parallel incident rays from a far off source of light at *F* (Fig.4.11b). This property is used in a solar heating system, by an ENT specialist, in reflecting telescope and radio antenna.

Let us now apply the rules of image formation to determine the nature and position of image formed by convex mirrors.

B. Convex mirror

From Fig.4.6b you may note that for a convex mirror, centre of curvature *C* and the focus *F* lie behind the reflecting surface. Fig.4.12 shows an object *AB* on the principal axis of a convex mirror. To discover the nature of image, we use the ray tracing method:

1. Ray *AM* parallel to the axis is reflected along *MD*. If it is extended backwards, it seems to originate from the focus *F*.

2. Ray *AN* which is directed towards *C* is reflected back along the same path. When this ray is extended backwards, it intersects *FMD* at *A′*.

3. As before, you can check the location of *A′* by drawing a ray directed towards the focus.

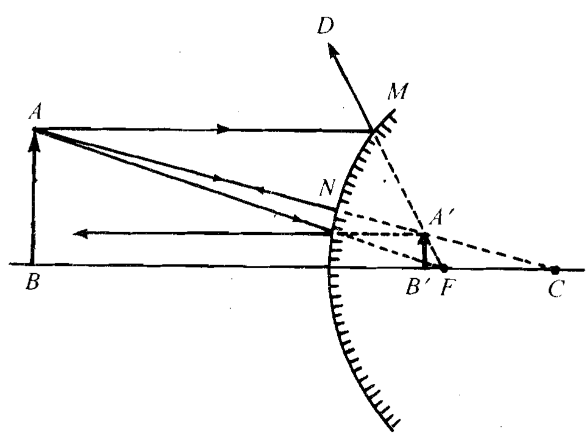


Fig.4.12: Image formed by a convex mirror

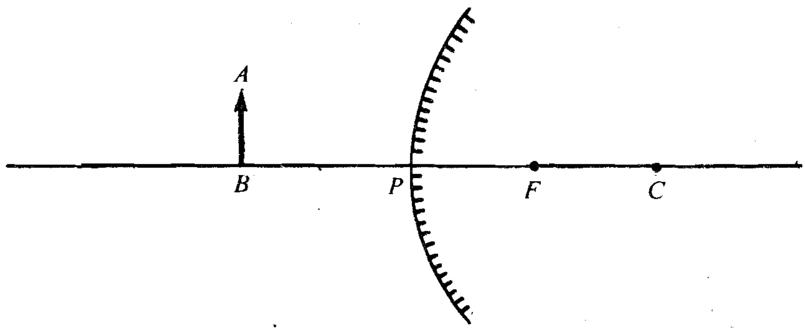
The image $A'B'$ of the object AB is obtained by dropping a perpendicular from A' on the principal axis. You may note that this image is **virtual, erect, diminished** and behind the mirror.

Before proceeding further, you may like to answer an SAQ.

SAQ 3: Image formation by a convex mirror

Determine the position and the nature of the image for the following configurations:

a)



b)

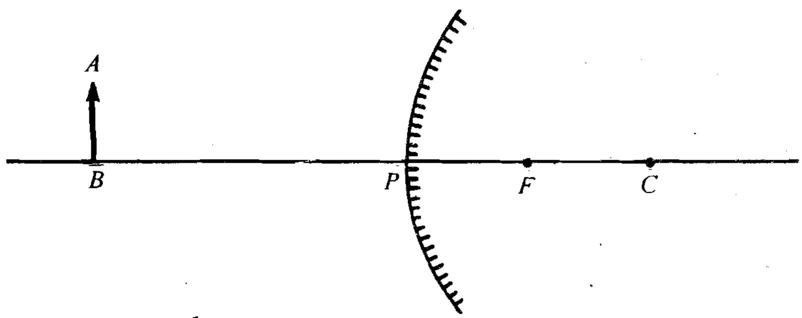


Fig.4.13: Locating image position for a convex mirror

From Fig.4.12 and SAQ 3 you would conclude that **the image formed by a convex mirror is always virtual, erect, diminished, and behind the mirror.** Moreover, as the object shifts towards the pole, the image also shifts towards the pole and its size increases but it will never be equal to or greater than the size of the object, no matter where the object is located. For this reason, a convex mirror forms image of a wider area around the object and is used as **wide angle mirror** (back view mirror) in automobiles..

To master the concepts explained above, you may like to answer an SAQ.

SAQ 4: Distinction between concave and convex mirrors

Suppose you are given a concave mirror and a convex mirror of focal length 20 cm. How would you distinguish between them?

Before we end our discussion about the mirrors, it is important to list a few points pertaining to their handling and maintenance.

Handling and maintenance of mirrors

- The silver coating of the mirrors gets tarnished because of exposure to humidity in the environment. It causes darkening of the edges of the mirror. It is therefore necessary to avoid unnecessary exposure of mirrors. After use, mirrors should be wrapped in a soft cloth and kept in a box.
- The unevenness of the surface of the mirror distorts the image. Therefore, you should protect it from scratches, prevent dust accumulation and avoid touching its surface with fingers.
- Before starting an experiment, the surface of the mirror should be cleaned with a dry, soft cloth.

So far, you have studied about image formation by plane and spherical mirrors on the basis of the laws of reflection. Now you will learn about image formation by refracting surfaces.

4.4 IMAGE FORMATION BY REFRACTING SURFACES

Refracting surfaces used in school and college physics laboratory are of two kinds: prism and lenses. Image formation by these devices is governed by the laws of refraction. Let us first consider the prism.

Monochromatic light is light of one wavelength.

4.4.1 Prism

A triangular prism (Fig.4.14a) has two plane refracting surfaces *PQTS* and *PRMS*. In two dimensions, we represent its principal section by an equilateral triangle. The angle *QPR* is the **angle of the prism (*A*)**.

When monochromatic light ray *BC* is incident on a prism, it undergoes refraction at the two surfaces (Fig.4.14b). As a result, the direction of the emergent ray *ED* changes with respect to the incident ray. You must be familiar with refraction of light by a rectangular glass slab. Recall that the refracted ray emerging from a glass slab is parallel to the incident ray. However, the triangular geometry of the prism makes the refracted ray to deviate with respect to the incident ray. The angle between the emergent ray and the incident ray is called the **angle of deviation**. It is denoted by the greek symbol δ (delta).

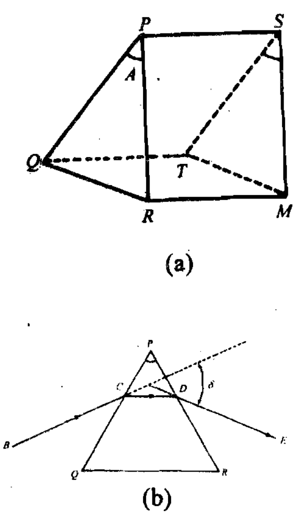


Fig.4.14: a) A prism; and b) refraction of monochromatic light by a prism

You may recall that a beam of white light incident on a prism splits into seven colours: *V*iolet, *I*ndigo, *B*lue, *G*reen, *Y*ellow, *O*range and *R*ed (*VIBGYOR*). This is known as **dispersion** of light. This occurs because each colour has a different wavelength and undergoes different amount of deviation while passing through the prism.

Further, it has been observed experimentally that the angle of deviation δ varies with the angle of incidence. Note that for a particular angle of incidence, the angle of deviation is minimum (δ_m). However, it still has a significant value. When the angle of deviation is minimum, the angle of incidence (i_1) and the angle of emergence (r_2) are equal. Then we say that light is passing through the prism symmetrically. This means that in this state, we can reverse the path of light rays (see Fig.4.15).

The angle of prism and the angle of minimum deviation of a prism are related to its refractive index as follows:

$$\mu = \frac{\sin\left(\dfrac{A+\delta_m}{2}\right)}{\sin\left(\dfrac{A}{2}\right)} \qquad (4.5)$$

While handling prisms you should take the same precautions as were mentioned for mirrors. We now discuss lenses.

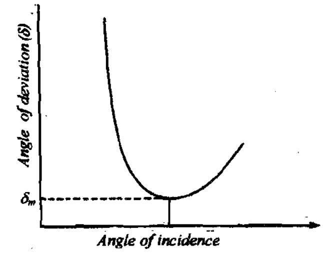


Fig.4.15: Plot of angle of incidence versus angle of deviation

4.4.2 Lenses

Like spherical mirrors, lenses are also divided into two categories, namely the **convex** (or **converging**) lens and the **concave** (or **diverging**) lens (Fig.4.16). You may note that convex and concave lenses are of three types. These are shown in Fig.4.16. You can differentiate a concave lens from a convex lens by touching as well as on the basis of the image formed by them. As is evident from Fig.4.16, the convex lens is thicker in the middle compared to its edges, whereas the concave lens is thinner in the middle. However, if the radius of curvature is very large, as in the case of lenses used in spectacles, identifying them by touch may not be possible. It can then be done only through image formation.

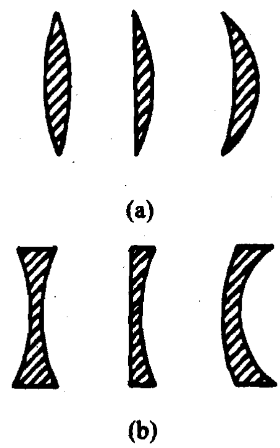


Fig.4.16: a) Convex lenses; and b) concave lenses

You are familiar with the basic terminology used for spherical mirrors. The same holds for lenses as well. However, unlike a mirror, a lens has two centres of curvature; one on either side because a lens is made of two spherical surfaces (Fig.4.17). Moreover, a point at the centre of the lens on the principal axis through which a ray goes undeviated is called the **optical centre** of the lens. The distance between the optical centre and the focus defines the **focal length**. A lens has two foci; one on either side. These are equidistant from the optical centre for thin lenses. The lenses you get in a physics laboratory have focal lengths in the range 15 cm to 35 cm.

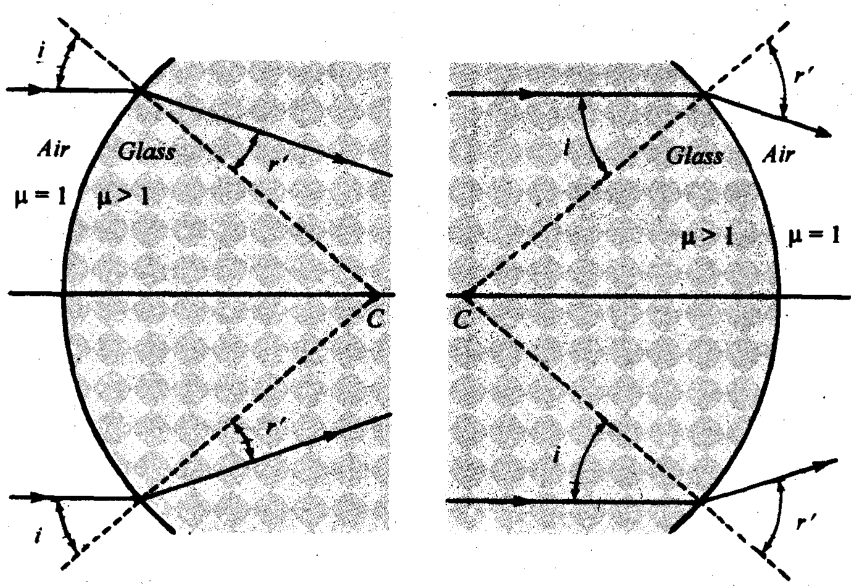
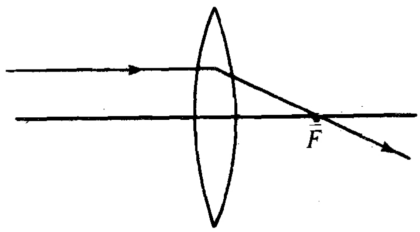
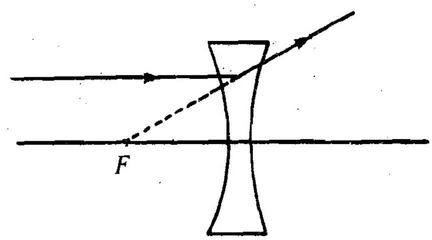
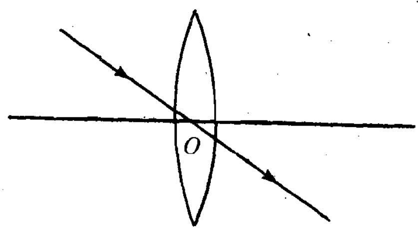
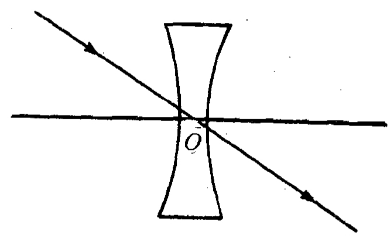
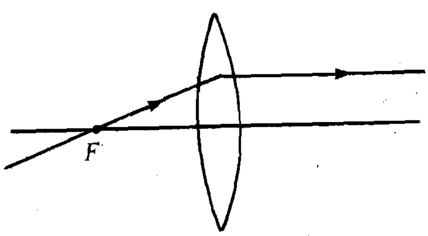
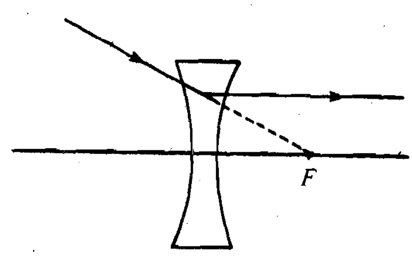


Fig.4.17: The surfaces forming a lens

A. Image formation by lenses

As in the case of spherical mirrors, the location and nature of images formed by lenses can be determined by the ray tracing method. The rules for ray tracing for convex and concave lenses are given in Table 4.2.

Table 4.2: Rules for ray tracing

Convex lens	Concave lens
The incident rays parallel to the principal axis, after refraction, converge at the focus.  **Fig.4.18a**	The incident rays parallel to the principal axis, after refraction, appear to diverge from the focus.  **Fig.4.19a**
The incident rays passing through the optical centre go undeviated.  **Fig.4.18b**	The incident rays passing through the optical centre go undeviated.  **Fig.4.19b**
The incident rays passing through the focus, after refraction, become parallel to the principal axis.  **Fig.4.18c**	The incident rays directed towards the principal focus, after refraction, become parallel to the principal axis.  **Fig.4.19c**

We now apply these rules to determine the nature and location of images formed by a convex lens.

Convex lens

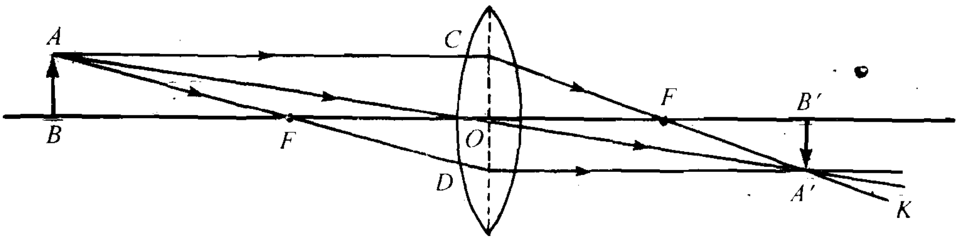


Fig.4.20: Locating the image formed by a convex lens

In Fig.4.20 an object *AB* is placed beyond 2*F*.

1. Ray *AC* parallel to the principal axis converges at *F*.
2. Ray *AO* passes undeviated and intersects the ray *CK* at point *A′*. Thus, *A′* is the image point corresponding to *A*.

You can check that *A′* is indeed the image of *A* by drawing a third ray *AD* passing through *F*. The emergent parallel ray should pass through *A′*.

Thus, we conclude that *A′* is the image of the object point *A*. Similar rays can be traced for each point of the object *AB*. In practice, the image *A′B′* of the object *AB* is obtained by drawing a normal from point *A′* on the principal axis of the lens, as in the case of spherical mirrors. You may note that the image is **real, inverted** and **smaller in size,** as in the case of concave mirror. The location and nature of images formed and the use of lens for different object locations are summarised in Table 4.3.

To determine the location and nature of the image formed by a concave lens for different object positions, you may like to attempt the following SAQ.

SAQ 5: Image formation by a concave lens

Determine the location and nature of the images for the following situations:

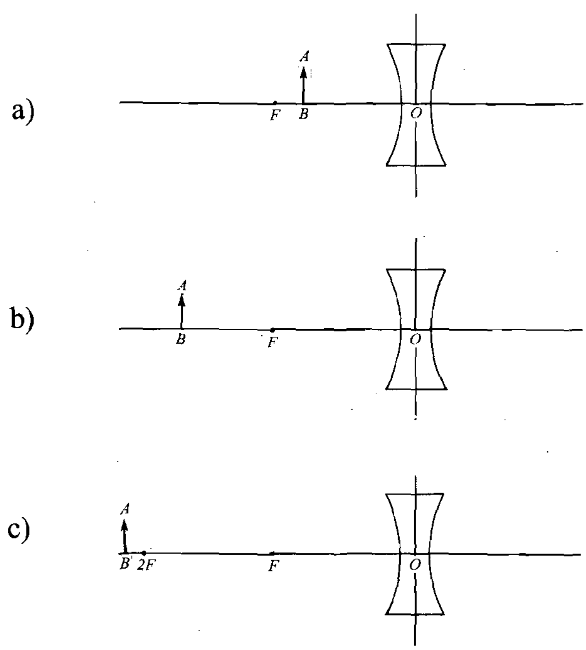
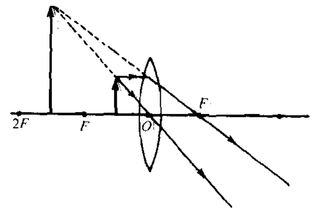
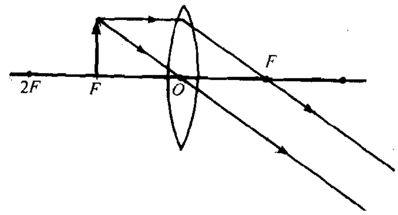
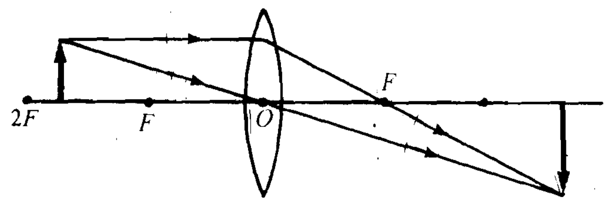
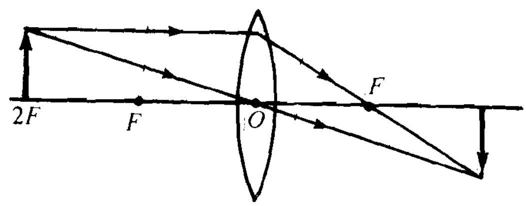
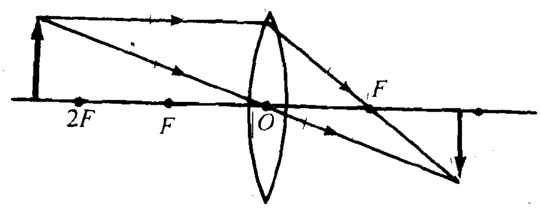
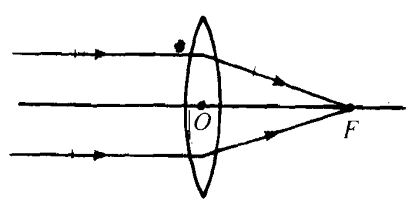


Fig.4.21: Locating image position for a concave lens

Table 4.3: Nature of images formed by a convex lens

Position of object	Image: Position	Image: Nature	Ray diagram
Between F and O	Same side of the lens	Virtual, errect and magnified. Used as a magnifying glass.	
At F	At infinity	Real, inverted, and highly magnified. Finds application in search lights.	
Between F and $2F$	Beyond $2F$	Real, inverted, and magnified. Useful in a projector enlarger.	
At $2F$	At $2F$	Real, inverted, and of the same size. Application in a telescope.	
Beyond $2F$	Between F and $2F$	Real, inverted, and diminished. Useful in a camera.	
At Infinity	At F	Real, point size. Used for light concentration.	

In answering SAQ 5, you may have noted that a concave lens always forms virtual, erect and diminished image of an object, no matter where the object is placed in front of the lens.

For the magnification produced by a lens, Eq. (4.3) holds. However, due to sign convention, the lens formula takes the form

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f} \quad (4.6)$$

where u is the distance of the object from the lens, v is the distance of the image from the lens and f is the focal length of the lens.

B. Power of a lens: diopter

The ability of a lens to converge or diverge light is expressed in terms of its power. It is defined as reciprocal of the focal length of a lens and its unit is **diopter:**

$$\text{Power (in diopter)} = \frac{1}{\text{focal length (in metre)}}$$

The shorter the focal length of a lens, the more it converges or diverges light and the more powerful it is said to be.

While handling lenses, you should take the same precautions as mentioned for mirrors (Section 4.3).

C. Optical bench

In the laboratory component of this course, you will be required to determine the focal length of a lens. For this, you will use an **optical bench** (Fig.4.22). It consists of two graduated parallel metal rods supported at both the ends by stands. The optical bench is provided with sliding carriages called **uprights** for holding lenses, mirrors, pins, etc. Each upright has a sharp line on its base. This mark is called index mark and helps in determining the position of the optical apparatus kept on it.

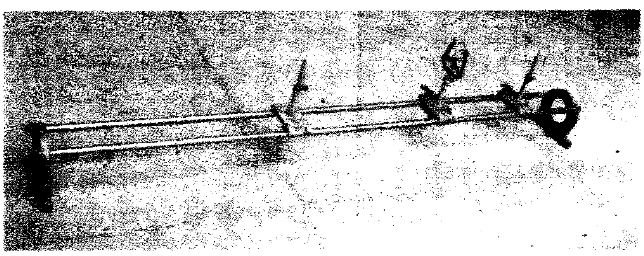


Fig.4.22: An optical bench

So far, you have learnt about images formed by mirrors, lenses and a prism. This knowledge helps us understand the working of optical instruments such as microscopes, telescopes and spectrometers. You will learn about these instruments now.

4.5 OPTICAL INSTRUMENTS

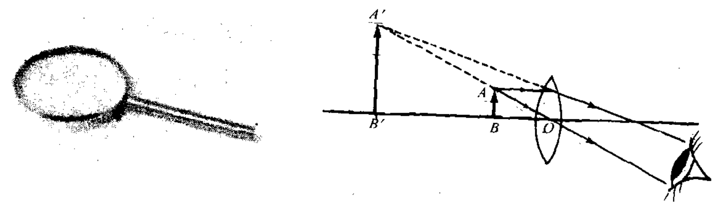
You may have seen a watch repairer using a magnifier to see the minute parts of a watch. A similar instrument is used by medical practitioners, particularly in villages, to diagnose measles. This instrument is essentially a simple magnifier (microscope). Modified versions of a simple microscope are used for biological investigations to examine the presence of bacteria, cells, parasites, etc. We now discuss these in some detail.

4.5.1 Microscopes

A microscope is an optical instrument used for obtaining magnified images of very small objects. The magnified image is obtained with the help of a convex lens or a pair of convex lenses. In the laboratory component of this course, you will get an opportunity to work with two types of microscopes, namely the simple microscope and the compound microscope

A. Simple microscope

A simple microscope is a commonly used **magnifying glass** (Fig.4.23). You know that if an object is located at a distance less than the focal length of the convex lens, it produces an erect, virtual and magnified image.



(a) (b)

Fig.4.23: a) A simple microscope is a magnifying glass; and b) ray diagram showing enlarged image formed by it.

The magnifying power of a simple microscope is given by the relation

$$M = 1 + \frac{D}{f} \tag{4.7}$$

where D is the normal distance of distinct vision (~ 25 cm for human eye) and f is the focal length of the converging lens. A typical magnifying glass has magnification of the order of 25.

The magnifying power of a simple microscope will be greater if a lens of smaller focal length is used. But magnification can not be increased beyond a certain value. This is because serious distortions in the image are introduced when the lens is of very small focal length. Can you say why is this so? The curvature of such lenses is very high. To overcome this limitation we use a compound microscope which has two (convex) lenses. You will now learn about it.

B. Compound microscope

A compound microscope is more frequently used in the Life Sciences laboratory. In a physics laboratory, it is used to determine Young's modulus by bending of beams, the diameter of a capillary and fringe width in Newton's rings experiment. Refer to Fig.4.24a. The main components of a compound microscope are:

- a metal tube which holds two convex lenses, the **objective** L_1 and the **eye piece** L_2;
- a graduated steel beam along which a movable vernier scale arrangement is provided;
- knobs and screws to control the horizontal and vertical movements of the tube; and
- a heavy base with levelling screws.

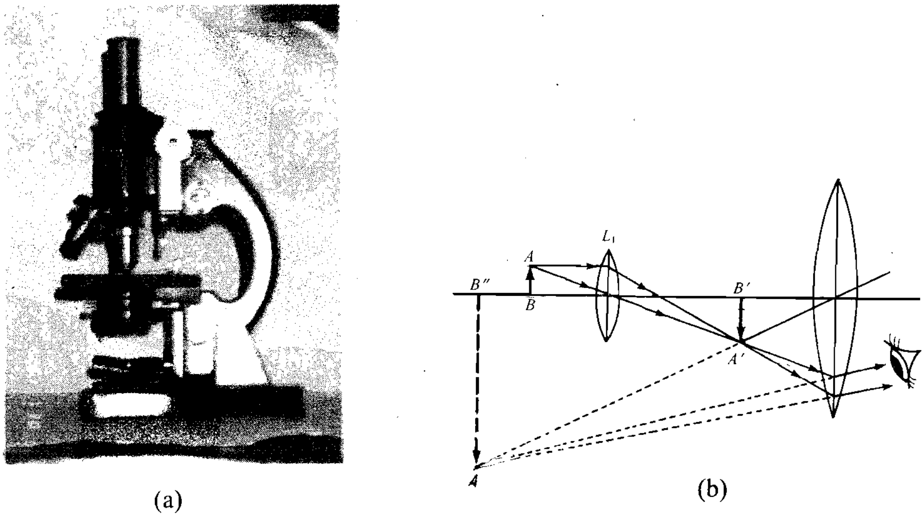


Fig.4.24: a) A compound microscope; and b) ray diagram showing the image formation in it.

To understand how a compound microscope forms a magnified image, refer to Fig.4.24b. The object AB is placed just beyond the focus of the objective lens L_1. From Sec. 4.4.2, you will recall that for the abovesaid configuration, the objective forms a real, magnified and inverted image $A'B'$ on the other side. And the eyepiece is so adjusted that the real image $A'B'$ is located between its optical centre and the focus. As a result, the image $A'B'$ acts as an object for the eyepiece L_2 which forms a magnified, virtual image $A''B''$. When the final image is formed at the normal distance of distinct vision, the compound microscope is said to be in *normal use*.

From the above discussion it is clear that in a compound microscope, magnification takes place in two stages. Mathematically, the **magnifying power** of a compound microscope is given by

$$M = m_o \times m_e = \frac{v_1}{u_1}\left(1 + \frac{D}{f_e}\right) \qquad (4.8)$$

where m_e is the magnification of the eyepiece and m_o is the magnification of the objective.

From this it is clear that for M to be large, f_o and f_e must be small. The magnifying power of a typical UG laboratory compound microscope is of the order of 100. However, it is now possible to have magnification of the order of 2000 using an electron microscope.

Handling and maintenance

a) Since a compound microscope is used for observing very small objects, it must be protected from dust. Therefore, when not in use, it should be covered by a soft cloth or kept in a box.

b) If the microscope is to be moved from one place to another, make sure that you hold it properly; put one hand beneath the base to support it and hold the vertical beam by the other hand. Never lift it by any fragile part!

c) As for any lens, the objective and the eyepiece should not be touched by fingers. These should be regularly cleaned with a soft and dry cloth.

The compound microscope is widely used in a biology laboratory. You will work with this instrument extensively in the course Laboratory Techniques in Biology (LT-02) of this programme.

You may now like to answer an SAQ.

SAQ 6: A compound microscope

You are given two lenses of focal lengths 5 cm and 50 cm. Which lens will you recommend as the eyepiece of a compound microscope and why?

4.5.2 Telescopes

The first telescope was built by Hans Lippershey in 1608. Later Galileo invented a much improved telescope to see heavenly bodies.

You might have used a binocular during a cricket match to see the players in action. It forms enlarged images of distant objects, which are not distinctly visible to the unaided eye, and brings them nearer to the eye. A binocular, which is essentially a telescope, collects light over a large surface and concentrates it at a point producing a brighter image.

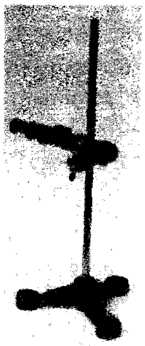
The objective of a telescope has a large focal length and bigger aperture compared to the eyepiece.

You may have learnt that telescopes are classified into two categories: **refracting telescopes** and **reflecting telescopes**. A refracting telescope uses a pair of lenses and a reflecting telescope uses a combination of a lens and a mirror. Refracting telescopes are also of two types: astronomical telescope and terrestrial telescope. In an UG physics laboratory, you will work only with refracting telescopes and for this reason we consider only these here.

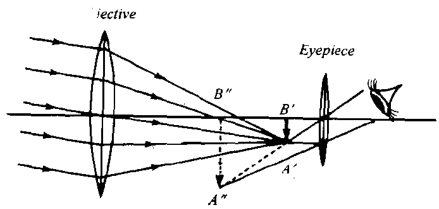
A. Refracting astronomical telescope

Refer to Fig.4.25 which depicts a refracting astronomical telescope. The main components of a telescope are:

- a metal tube which holds the **objective – a convex lens of large focal length** at one end and an eyepiece attached to a draw tube, which can be moved inside it at the other end;
- a steel beam to mount the telescope tube;
- knob to control the distance between the objective and the eyepiece; and
- rack and pinion arrangement to control the movement of the eyepiece.



(a)



(b)

Fig.4.25: a) Refracting astronomical telescope; and b) ray diagram for image formation

To understand how a refracting astronomical telescope produces an enlarged image of a distant object, refer to Fig.4.24b. The objective focuses the parallel rays from a distant object at its principal focal plane forming a real and inverted image $A'B'$. The position of the eyepiece is so adjusted that the image $A'B'$ lies within its focal length. The eyepiece magnifies $A'B'$ further to give a virtual image $A''\ B''$ at the near point of the eyes, as in the case of a simple microscope. The telescope is then said to be adjusted for ordinary vision.

If the image $A'B'$ lies in the focal plane of the eyepiece as well, the image $A''\ B''$ will be formed at infinity and it appears that the distant object is directly visible in a magnified form. **The separation between the objective and the eyepiece is then equal to the sum of their focal lengths.** In this case the telescope is said to be in normal adjustment.

The **magnifying power** of a telescope adjusted for infinity is defined as the ratio of the focal length of the objective to the focal length of the eyepiece:

$$M = \frac{f_o}{f_e} \qquad (4.9)$$

An objective of larger aperture collects more light.

From this relation it is obvious that larger the focal length of the objective, greater will be the magnifying power of an astronomical telescope. And for a given focal length, larger the aperture of the objective, brighter will be the image. It means that we can go deeper into space and see finer details of fainter objects. The largest refracting astronomical telescope with one metre objective is situated at Yerkes observatory in Wisconsin, U.S.

You should note that the final image $A''B''$ formed by a refracting astronomical telescope is **inverted**. Such upside down images are not convenient for viewing terrestrial objects. Also we mentioned at the beginning of this section that a binocular acts as a telescope and yet we observe an erect image. This is achieved by placing a lens between the objective and the eyepiece of a telescope. You may like to draw the ray diagram of such a telescope.

SAQ 7: Refracting terrestrial telescope

Draw the ray diagram for an image formed by a terrestrial telescope.

While answering SAQ 7, you must have noted that the addition of a convex lens increases the length of the tube of a terrestrial telescope. To overcome this problem, it is also possible to use a prism instead of a convex lens. In modern binoculars, a prism is used so as to keep it compact.

In a refracting telescope, images may have coloured fringes around them due to chromatic abberation. To overcome this disadvantage, the objective in a reflecting telescope is replaced by a concave mirror. We would like you to draw the ray diagram for the image formed by a reflecting telescope.

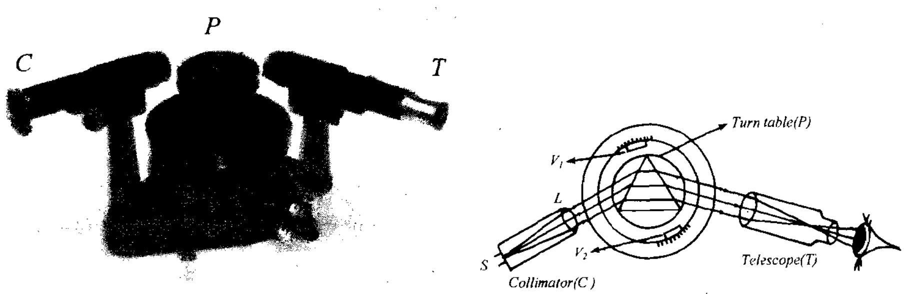
Now-a-days, telescopes which collect radiations other than visible light to obtain magnified images have been built and installed on earth as well as in space.

The spectrometer is another very useful instrument used to analyse visible light in a physics laboratory. Note that a spectrometer is not an image forming instrument. In the lab component of this course, you will be required to do at least one experiment with spectrometer. It is, therefore, important to learn about it.

4.5.3 Spectrometer

Refer to Fig.4.26. It shows the photograph of a spectrometer and a schematic diagram of its important components. The three main components of a spectrometer are:

a) collimator (C)
b) turn-table (P) for keeping a prism or a grating, and
c) telescope (T).



(a) (b)

Fig.4.26: a) Spectrometer; and b) its schematic representation

The collimator consists of a metal tube with an adjustable slit S at one end and a converging lens L at the other. The source of light is placed close to S and the distance between S and L is so adjusted that S is at the focus of L. Then the light rays emerging from the collimator are rendered parallel. That is, the collimator enables us to obtain a parallel beam of light.

The turn-table is also called prism table.

The turn-table P is a circular platform engraved with concentric circles. It is provided with three levelling screws to adjust its height as well as to ensure the flatness of its horizontal surface. Also, it can rotate about a vertical axis passing through its centre. A circular scale graduated in degrees is attached to the base of the spectrometer. The position of the turn-table can be read on this scale with the help of a vernier. The least count of the instrument is usually 30″.

An astronomical telescope T enables us to examine the spectrum produced by a prism or a grating placed on the turn–table. The telescope can also be rotated about the same axis as that of the turn-table. The angle of rotation of the telescope can be measured on the graduated circular scale. The turn table and the telescope can be fixed in any desired position.

Before using the spectrometer, it is important to:

- level the base, prism table, the collimator and the telescope using a spirit level and the levelling screws;
- adjust the eyepiece of the telescope so that the cross-wires are clearly visible; and
- set the telescope so that the image of the distant object coincides with the cross-wires without any parallax.

A. Handling and maintenance of a spectrometer

a) Alignment of the collimator, the turn-table and the telescope is very sensitive. These components should therefore be handled gently. Jerky movement may disturb the alignment of these components.
b) When not in use, the spectrometer should be kept in an almirah to protect it from dust.
c) For smooth movement, the turn-table and the telescope may be oiled.

You have already learnt about a prism and how it disperses white light into its constituent colours. Grating is another device which enables us to obtain and analyse a spectrum.

Fig.4.27 shows the line diagram of a grating. In a college physics laboratory, you will come across a **grating** made of plastic. It is a replica of the original grating made of glass. In its original form, a grating is made by ruling (drawing) a large number of fine, equidistant and parallel lines on an optically plane glass plate with a diamond point. The number of ruled lines varies from 12,000 to 30,000 per inch and the ruled surface varies from two to six inches.

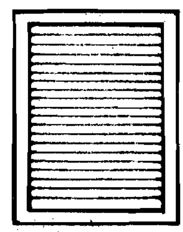


Fig.4.27: Line diagram of a grating

The sum of the widths of a transparent portion (a) and an opaque portion (b) of the grating is known as grating element:

$$\text{Grating element} = a + b$$

If N is the number of ruled lines per inch of a grating, its grating element is given as

$$a + b = \frac{1}{N}\text{ inch}$$

$$= \frac{2.54}{N}\text{cm}$$

You should never touch the ruled surface of a grating with your fingers; always hold a grating by its edges. Also, take utmost care to prevent it from scratches and dusting.

For conducting any optical experiment, we need a source of light. In a physics laboratory, light from different sources is used. You will learn about some of them now.

4.6 SOURCES OF LIGHT

In optical experiments, different types of sources of light are used. For example, in simple experiments like focal length of a lens or a mirror, an ordinary source of light such as an electric bulb will do. However, when we wish to analyse light by determining its wavelength, we require a monochromatic source of light.

Light from natural and artificial sources can be broadly classified into following categories:

1. Light from incandescent sources
2. Light from discharge lamps
3. Light from lasers

In a school/UG physics laboratory, you will have to handle only the first two types of sources of light. Light from the sun or incandescent sources are used in optical experiments where white light is good enough. However, for obtaining light of a given wavelength, we use a sodium vapour lamp or mercury vapour lamp. Let us now learn about these.

4.6.1 Incandescent Sources

Light from an incandescent lamp is emitted when tungsten filament is heated to an appropriate temperature by passing an electric current through it. The filament is housed in an evacuated glass bulb. For avoiding excessive evaporation of tungsten due to heating, the bulb is filled with an inert gas such as argon.

4.6.2 Discharge Lamps

Discharge lamps emit light when an electrical discharge takes place in a gas filled in a tube. Since every substance emits its characteristic wavelength, we can fix the wavelength of the emitted light by putting a known substance in the discharge lamp. Two such substances are sodium and mercury.

A. Sodium lamp

Fig.4.28: A sodium lamp

Refer to Fig.4.28 which shows a sodium lamp. It consists of a U-shaped glass tube T of very special quality. It cannot be blackened by sodium vapours. Two oxide coated electrodes E_1 and E_2 are fixed in the tube. In addition, sodium and neon are also filled in the tube. This tube is surrounded by a vacuum flask P to avoid heat losses. When a high voltage is applied between the electrodes, the neon gas discharge raises the temperature inside the tube. At about 300°C, sodium begins to evaporate and fills the tube. This excitation and subsequent de-excitation of sodium atoms gives a light of intense yellow colour. In fact, the yellow light emitted by sodium consists of two wavelengths known as **sodium *D*-lines** with wavelengths 589.0 nm and 589.6 nm. Thus, when a sodium lamp is used as a source of light, the wavelength of the emitted light is taken to be 589.3 nm; the average wavelength of the doublet.

B. Mercury lamp

The **mercury lamp** (Fig.4.29) used in a physics laboratory also works on the same principle. In this lamp, instead of sodium, mercury atoms de-excite and give out sharp lines corresponding to wavelengths 404.7 and 435.8 nm (violet) 546.1 nm (green) 577.0 and 579.1 nm (yellow) and so on. This means that if we have to use a mercury lamp as a source of monochromatic light, we will have to use **filters** which can stop undesired wavelengths.

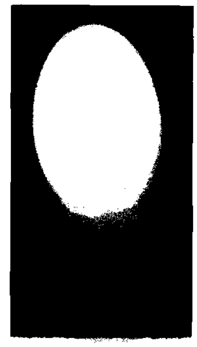


Fig.4.29: A mercury lamp

The discharge lamps are housed in a wooden box which is provided with one vertical slit on each side wall. As a result, at least four optical experiments requiring monochromatic source of light can be performed simultaneously.

C. Handling and maintenance of light sources

a) Since very high voltage is required to start discharge in a lamp, you should be very careful while handling it.
b) Do not touch or move a sodium or mercury lamp soon after it has been switched off. Let it cool!
c) Since vapour lamps are made of glass, you should move it very carefully from one place to another.

Let us now summarise what you have learnt in this unit.

4.7 SUMMARY

- Image formation by optical devices can be understood in terms of rectilinear propagation, laws of reflection, or laws of refraction.

- The image of an object is said to be real when the rays of light **actually meet at** the image location. When the rays of light **only seem to meet at** the image location, the image is said to be virtual.

- The image formed by a plane mirror is erect, virtual, laterally inverted and as far behind the mirror as the object is in front of it.

- The location of an image formed by a spherical mirror can be determined by ray tracing method. For a concave mirror, it depends on the location of the object in front of it. A convex mirror always forms a virtual and diminished image.

- The mirror formula is written as

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

where v is the image distance from the pole of the mirror, u the object distance and f is the focal length.

- Magnification by a spherical mirror is mathematically expressed as

$$m=\frac{\text{height of the image}}{\text{height of the object}}$$

Equivalently, we can write it as

$$m = \frac{v}{u}$$

- A prism and a lens — convex or concave — refract light. Nature of the image formed by a lens depends on the distance of the object from the lens. However, a concave lens always forms a virtual, diminished and erect image.

- The lens formula is

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

where symbols have their usual meanings.

- The magnification produced by a simple microscope (a convex lens) is given by

$$M = 1 + \frac{D}{f}$$

where D is the normal distance of distinct vision and f is its focal length.

- The magnifying power of a compound microscope is equal to the product of magnifications of individual lenses:

$$M = m_o \times m_e$$

- The magnification produced by a refracting telescope is equal to the ratio of the focal length of the objective and the focal length of the eyepiece:

$$M = \frac{f_o}{f_e}$$

- Spectrometer is an optical instrument used for analysing light.

- The sodium and mercury lamps give sharp lines of fixed wavelengths.

4.8 TERMINAL QUESTIONS

1. The focal length of the objective of an astronomical telescope is four times the focal length of its eye-piece. If the focal length of the eye-piece is 2 cm, calculate the magnification produced by the telescope.

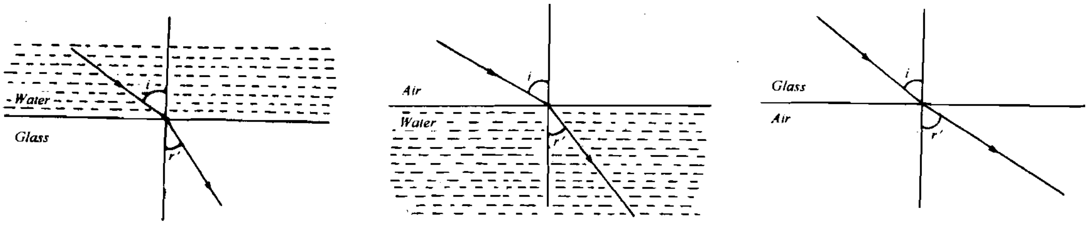
2. 5 cm high object is placed in front of a concave mirror of focal length 10 cm and its 1 cm high image is projected on the screen. Locate the position of the object.

4.9 SOLUTIONS AND ANSWERS

Self-assessment Questions

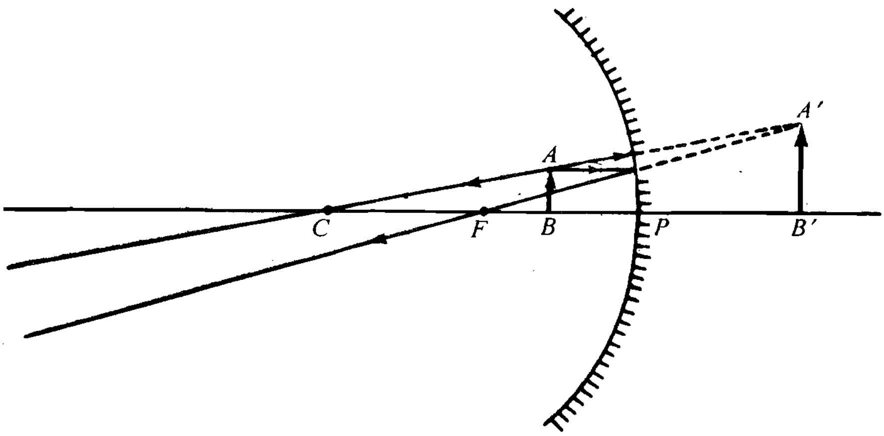
1. a) i) reflection, ii) refraction and iii) reflection

b) See the figures given below:



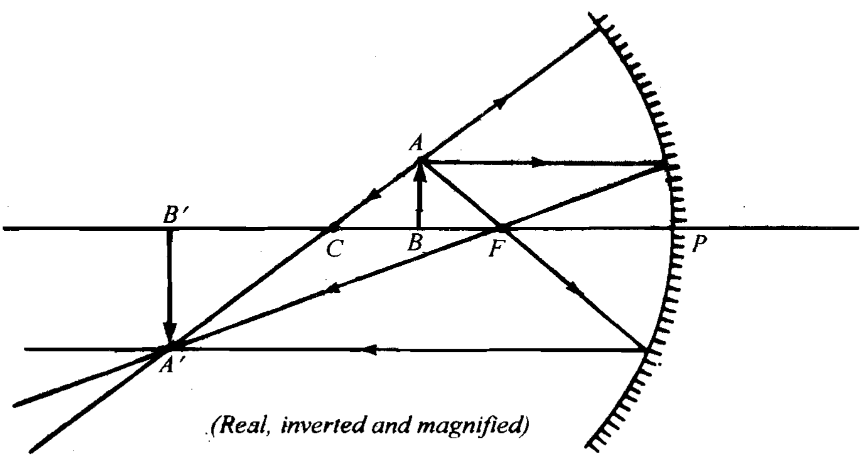
(i) (ii) (iii)

2. a)



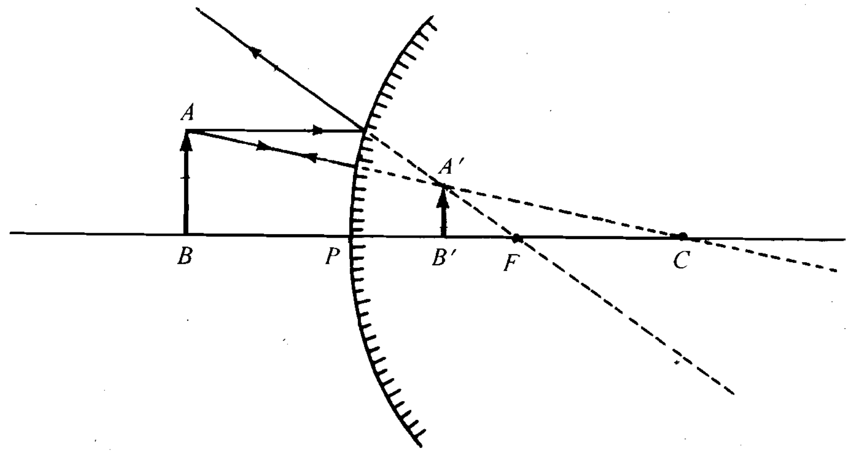
(Virtual, erect and magnified)

b)



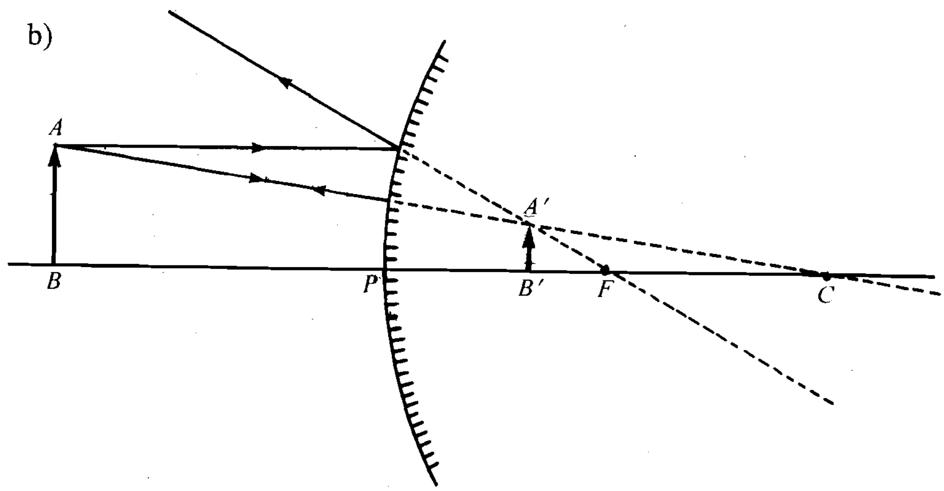
(Real, inverted and magnified)

3. a)



(Virtual, erect and diminished)

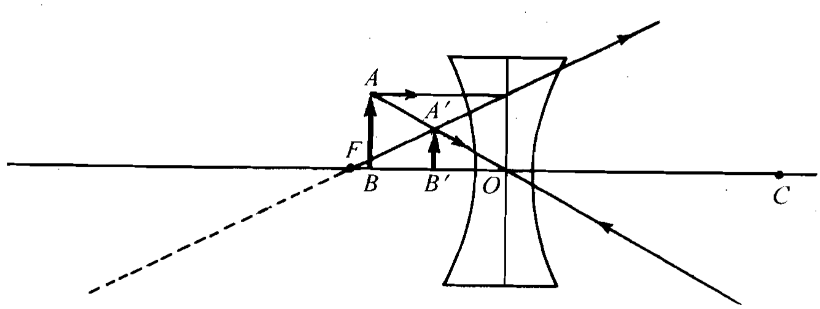
b)



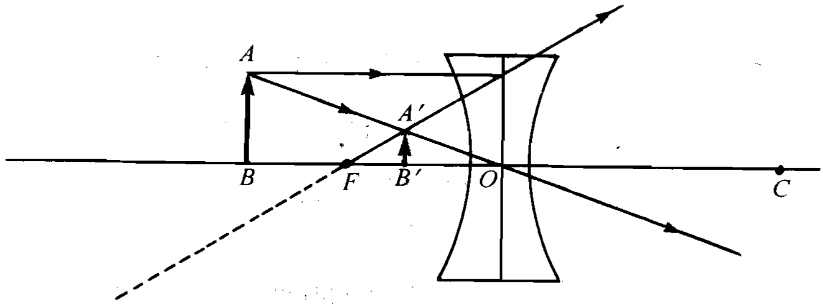
(Virtual, erect and diminished)

4. As you know, convex mirror always forms an erect image of an object placed anywhere. On the other hand, a concave mirror forms an erect image only when the object is located at a distance less than the focal length. Thus we can place an object at a distance of 30 cm or 40 cm from the mirrors and the mirror which forms an erect image is the convex mirror. The other mirror is the concave mirror.

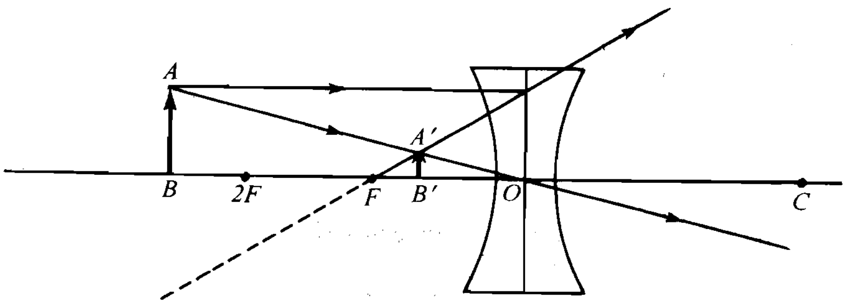
5. a)



b)



c)



You may note from these ray diagrams that a concave lens always forms virtual, erect and diminished image, no matter where the object is placed in front of the lens.

6. The lens of smaller focal length, 5 cm is recommended as the eyepiece of the compound microscope. This is because the magnifying power of a compound microscope is inversely proportional to the focal length of the eyepiece.

7.

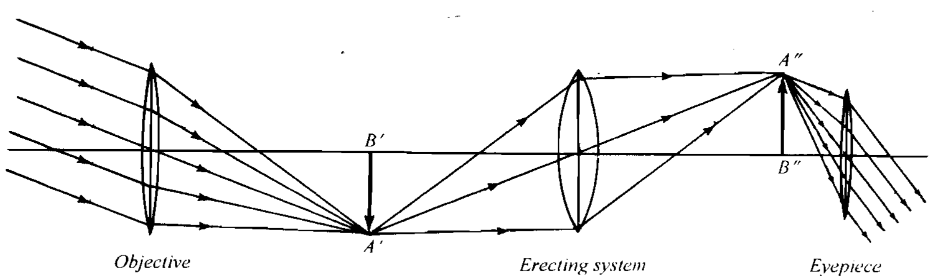


Image formed by a terrestrial telescope

Terminal Questions

1. We have

$$f_e = 20\,\text{cm} \text{ and } f_o = 4 f_e = 4 \times 20\,\text{cm} = 80\,\text{cm}$$

Magnification of a telescope is given as

$$M = \frac{f_o}{f_e} = \frac{80(\text{cm})}{2(\text{cm})} = 40$$

2. We know that magnification produced by a concave mirror is given by

$$m = \frac{v}{u} = \frac{I}{O}$$

$$\Rightarrow \quad \frac{v}{u} = \frac{1}{5}$$

$$\text{or} \quad v = \frac{u}{5}$$

Using mirror formula, we can write

$$\frac{1}{u} + \frac{5}{u} = \frac{1}{15} \Rightarrow \frac{6}{u} = \frac{1}{10} \text{ or } u = 60\,\text{cm}$$

UNIT 5 BASIC ELECTRICITY AND ELECTRICAL COMPONENTS

Structure

5.1 INTRODUCTION

In Units 3 and 4, you have studied about the basic apparatus used in experiments on mechanics, sound and light. We now turn our attention to basic electricity, electrical components and devices. In our everyday life, we come across electrical appliances such as bulbs, tube lights, fans, electric irons, and room heaters. These appliances have electrical components like resistors, capacitors and inductors. In order to understand how these components function, we devise experiments involving simple electrical circuits.

A physics lab has quite a few experiments on electricity. You should, therefore, have a sound knowledge of electrical apparatus, its maintenance and safety requirements. In Sec. 5.2, we explain the **basic terminology of electricity**. We also discuss the **electrical components**, both **resistive** and **reactive**, used in such circuits. In Sec. 5.3, we discuss sources of direct current, such as **primary** and **secondary cells**, which are commonly used in experiments on electricity.

In Unit 1, you have learnt that the supply of electricity is absolutely necessary for operating a physics lab. Therefore, in Sec. 5.4 you will learn about the **safety and maintenance aspects of electric supply**. In the next unit, we discuss electrical and electronic devices and instruments.

Objectives

After studying this unit, you should be able to:

- define direct and alternating current, potential difference, resistance and power;
- identify common electrical components and their symbols;
- state how various components are connected in a given circuit diagram;
- explain the action of primary and secondary cells; and
- locate simple faults in the laboratory wiring and list the steps required to get them rectified.

5.2 SIMPLE ELECTRICAL CIRCUITS

We are all familiar with electrical circuits in household electricity and domestic appliances like electric iron, radio, television set, etc. You may have realised that some of them are quite complicated. To understand how they work we need to know the vocabulary of electricity. In this section we introduce basic terms such as electric current, potential difference (voltage), resistance and power. It is quite possible that you are already familiar with these terms. But we discuss them in brief to enable you to refresh your memory.

A. Electric current

From your school physics, you may recall that current is the rate of flow of electric charges. We denote it by the symbol I. Mathematically, we write

$$I = \frac{Q}{t} \qquad (5.1)$$

where Q is the charge transferred in time t. The unit of current is ampere (A). By definition, one coulomb is the charge passing any point in a circuit when a steady current of 1 ampere flows for 1 second through the point.

There are two types of currents:

- **Direct current**: It results when the charges flow in one direction only (Fig.5.1). Note that in Fig.5.1a, the magnitude as well as the direction of the current remains the same. But in Fig. 5.1b, the magnitude of the current changes but the direction does not.

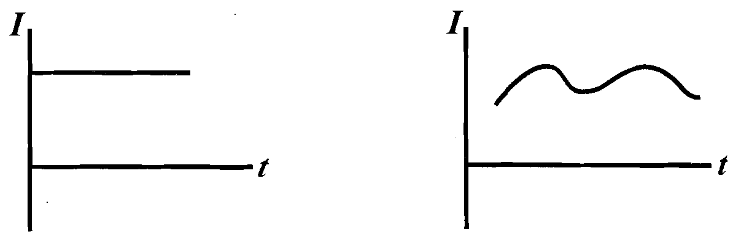


Fig.5.1: Plot of direct current with time

- **Alternating current**: It results when the direction of flow of charges reverses periodically (Fig.5.2). Note that the current increases from zero

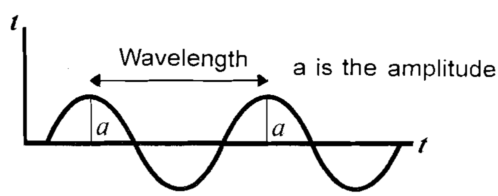


Fig.5.2: Variation of alternating current with time

to a maximum positive value and decreases back to zero; then it flows in the opposite direction similarly attaining a minimum value and then increasing to zero. This process continues. The symbol for *AC* is ~ . Cells and batteries produce *DC*; generators can produce *DC* as well as *AC*. The mains supply is *AC*.

In order to flow, electric current must have a complete path of conductors. This path is called a **circuit**. Moreover, a circuit must contain a source of electrical energy, which provides the **potential difference** or **voltage** needed for current to flow. You may now logically ask: What is potential difference?

B. Potential difference

The potential difference or voltage between any two points is defined as the amount of work required to move a unit positive charge from one point to another. Mathematically, we write

$$V = \frac{E}{Q} \tag{5.2}$$

where E is the work done in carrying charge Q from one point to another.

The unit of potential difference is volt (V). By definition,

$$1\ \text{volt} = \frac{1\ \text{joule}}{1\ \text{coulomb}}$$

You may recall that the unit of work is joule, abbreviated as J.

If a potential difference V is applied across a conductor, a current I will flow in it. The amount of potential difference required to produce a given current in a circuit depends on a property of the conductor called **resistance**.

C. Resistance

Materials such as copper, silver, aluminium which allow current to pass readily through them are called conductors. Conductors can be of any shape such as a wire, strip or a rod.

The resistance of a conductor is the ratio of the potential difference across it to the current flowing in it. Mathematically,

$$R = \frac{V}{I} \tag{5.3a}$$

where V is the potential difference and I the current.

We can understand resistance as a measure of opposition offered by a conductor to the flow of charge. The unit of resistance is ohm. It is denoted by the Greek letter omega (Ω).

By definition,

$$1\Omega = \frac{1\text{V}}{1\text{A}}$$

Eq. (5.3) can also be expressed as

$$V = I\,R \tag{5.3b}$$

This equation represents Ohm's law.

Ohm's Law

The potential difference across a conductor is directly proportional to the current flowing through it if its temperature and other physical conditions remain the same.

The resistance of a given material is directly proportional to its length and inversely proportional to its cross-section. Mathematically, we write

$$R \propto \frac{\ell}{A}$$

or

$$R = \rho \frac{\ell}{A} \tag{5.4}$$

where ℓ is the length of the wire and A, the area of cross-section. ρ is called the resistivity. It is characteristic of the material of the wire. For a given material, at a fixed temperature, only length and area of cross-section of a wire are important. Thick wires have lower resistance compared to thin ones. This is why you find that conductors which are used to carry high currents are thick and have low resistivity, for example, the ones used in electric motors. Conductors supposed to carry small currents are thin since they offer high resistance, for example, wires in a circuit board in the radio or the TV.

The current carrying capacity of a wire is also expressed in terms of the gauge of the wire. You will learn these details in Experiment 7. While handling resistance wires you should take care that their length or cross-section is not altered in any manner. In general, the resistance of good conductors can be assumed to be constant over a small range of temperatures. Still you should take the precaution when using any resistance that it does not get heated up.

Power is another important term used in electricity.

D. Power

Power is defined as the rate of doing work. It can also be thought of as the rate of conversion of electrical energy into other forms of energy.

Mathematically, we write

$$P = \frac{E}{t} \tag{5.5}$$

If E is in joule and t in second, the unit of power is watt (W). From Eq. (5.2) we note that $E = Q\,V$. Therefore,

$$P = \frac{QV}{t} = IV \qquad \left(\because\ I = \frac{Q}{t}\right) \tag{5.6}$$

You may have seen voltage and power ratings engraved on various electrical appliances. For example, room heaters usually have coils of rating 220 V and 1000 W or 1 kilowatt (kW). In the laboratory, you will come across voltage and power ratings of a power supply, signal generator, oscilloscope, etc.

The amount of energy consumed by an electrical appliance is usually expressed in terms of kilowatt hour. One kilowatt hour is the amount of energy consumed by an appliance of 1 kW rating for 1 hour.

You may now like to answer an SAQ based on these definitions.

SAQ 1: Basic electrical terminology

a) Which of the following statements are true?

(i) Current is the rate of flow of electricity.

(ii) Current $= \dfrac{\text{Power}}{\text{Potential difference}}$.

(iii)Resistance is a measure of the opposition offered to the flow of electric current through a conductor.

Correct the false statement(s).

b) Suppose a metal wire is stretched so that its length increases to twice its original length and cross-sectional area decreases to half its original value. How will the resistance of the wire change?

You have learnt that current can flow only in a complete electrical circuit. An electrical circuit consists of several components and devices which we now discuss. Broadly, these can be classified as resistive and reactive. The most common resistive components are resistors, keys, rheostats, resistance coils and resistance boxes, connecting wires. The reactive components include capacitors, inductors and transformers. Let us first consider resistive components.

5.2.1 Resistive Components

In Fig.5.3 to 5.7, we show the resistive components commonly used in a physics lab. Let us take them up one by one.

A. Carbon resistors

These are tiny cylindrical resistors usually made of carbon. In a circuit, these are denoted by the symbol -/\/\/-. The value of their resistance is fixed and given by coloured stripes marked on their body. This is also called its *colour code*. It helps us calculate the resistance of a resistor:

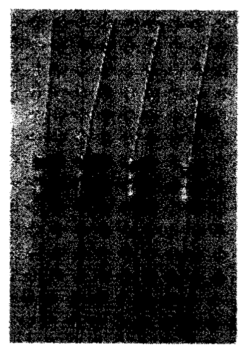


Fig.5.3: Colour code of a carbon resistor

$$R = AB \times 10^{C}\,\Omega, D \qquad (5.7)$$

where A, B, C, D are coloured stripes (see Fig. 5.3) and D is the tolerance code which specifies the extent of error in the resistance. The values for different colours are given in Table 5.1.

Let us take an example for calculating the resistance of a resistor from its colour code.

If A is white, B brown, C red, and D silver then the resistance of the resistor is

$$R = 91 \times 10^2,\ 10\%\ \Omega$$

since white ≡ 9, brown ≡ 1, red ≡ 2 and silver ≡ 10%.

You may memorise the colour code with the help of the following line: *BBROY* of *G*reat *B*harat has a *V*ery *G*ood *W*ife. You can see that each capital letter stands for numeral 0,1,2…,9 in succession. You can also make up your own sentence with these initial letters.

Table 5.1: Colour codes of resistors of resistance $R = AB \times 10^{C}\,\Omega, D$

For the digits A	B	C		
Black 0	Brown 1	Red 2	Orange 3	Yellow 4
Green 5	Blue 6	Violet 7	Grey 8	White 9
Gold (C only) 1,	Silver (C only) 2			
Tolerance Code (D):	Silver 10%	Gold 5%		

You will be required to calculate R of many such resistors. So you should have enough practice of using Table 5.1. Try the following SAQ.

SAQ 2: Calculation of resistance from colour codes

a) Calculate the values of resistors having the following colour codes:

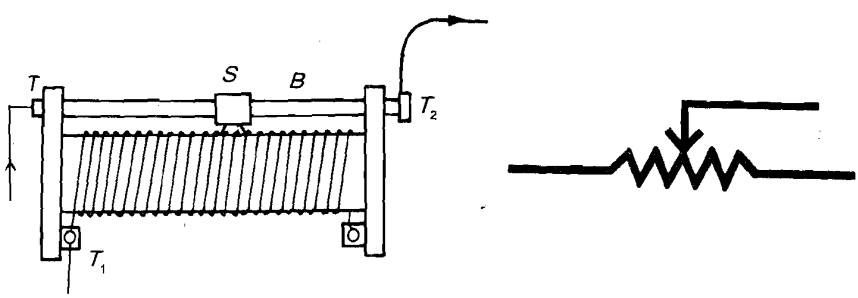
	R_1	R_2	R_3	R_4
A	red	brown	orange	grey
B	brown	blue	red	white
C	orange	green	violet	yellow
D	gold	silver	silver	gold

b) What is the colour code of the following resistors?

$R_1 = 21 \times 10^9, 5\%\Omega, R_2 = 30 \times 10^6, 10\%\Omega, R_3 = 56 \times 10^3, 5\%\Omega, R_4 = 79 \times 10^2, 10\%\Omega.$

B. Rheostat

A rheostat is a variable resistor (Fig.5.4). It allows us to put a variable length of resistance wire in the circuit. Its symbol is shown in Fig.5.4b.



(a) (b)

Fig.5.4: a) Schematic diagram of a tubular rheostat; and b) its symbol

In the tubular rheostat used in a physics lab, a coil of wire is wound on a non-conducting cylindrical tube (Fig.5.4a). The turns of the coil are insulated from each other. A metal rod (B) is mounted on top of the tube. There are three terminals—one fixed at each end of the coil (T_1 and T_2) and one at the end of the rod (T). Connection is always done between T and either of the terminals T_1 and T_2. A slider (S) mounted on the metal rod always touches the coil at some point. A rheostat can be used in an electrical circuit in three ways:

i) as a variable resistance;
ii) as a fixed resistance; and
iii) as a potential divider.

In order to use a rheostat as a variable resistance in a circuit, we connect T and T_2 in the circuit so that current enters through the terminal T, passes through the rod B, the slider S and the wire and flows out through the terminal T_2. As we move S along the rod, the length of the wire changes and so does the value of the resistance. This changes the value of the current in the circuit. If the slider is at the extreme left, the entire resistance of the coil is included in the circuit. When is its resistance zero? When the slider is at extreme right!

When we connect the terminals T and T_1 in the circuit, the rheostat functions as a fixed resistance. You would see the specifications of a rheostat written on it, e.g., "4 ampere" and "Ohm 18". This is the maximum current allowed to flow through the rheostat and the resistance offered by it at that value of current.

When a rheostat is to be used as a potential divider, terminals T_1 and T_2 are connected across the terminals of a battery through a key. As a result, the emf of the cell is distributed along the length of the wire. The terminals T and T_1 or T_2 are then connected in the circuit.

You have to be careful in moving the slider S across the rheostat. Do it carefully so that the wire does not wear down or get heated.

Variable resistance in a circuit can also be provided by a **rotary** rheostat. These are commonly used as fan regulators to control fan speed.

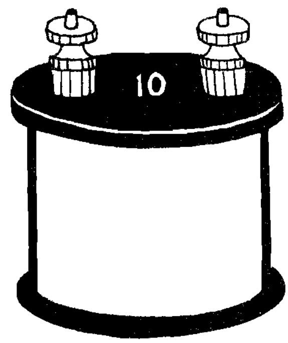
C. Resistance coil and resistance box

In the lab you will find a variety of resistance coils and resistance boxes containing resistances of fixed magnitude.

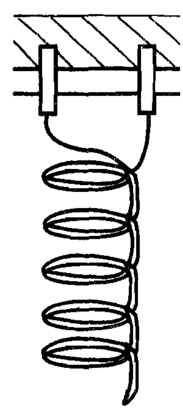
A **resistance coil** (Fig.5.5) is made up of manganin or constantan wire and its resistance is usually a multiple of 1Ω. The wire is covered by an insulator and wound over a bobbin which is placed within a cylinder made of an insulating material. The free ends of the wire are soldered to two screws on top of the cylinder. Resistance coils of different values in the range of a few ohm to a few kilo-ohm are available. Their values are written on top of the cylinder.

A **resistance box** enables us to introduce known values of resistance in a circuit. There are two types of resistance boxes: **plug type** and **dial type**.

In a **plug type resistance** box, a number of resistance coils are connected in series. Fig.5.6a shows how it looks from outside. Its inside structure is shown in Fig.5.6b. The free ends of each coil are soldered to two adjacent pieces of brass blocks kept at a small distance. These blocks are fixed on an ebonite plate with a gap between them into which a plug P fits in. The magnitude of each resistance coil is written on its side on the ebonite plate.

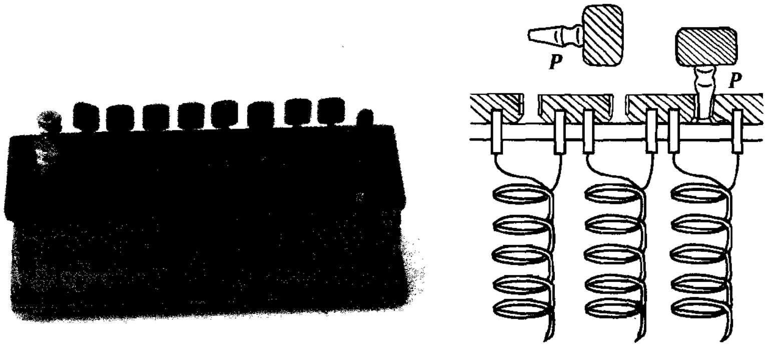


(a)



(b)

Fig.5.5: a) Resistance coil; and b) internal structure of the coil



(a) (b)

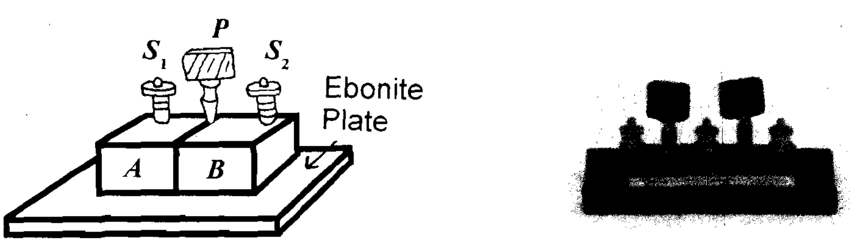
Fig.5.6: a) Resistance box; and b) its inside structure

The resistance box is connected in the circuit through its terminals *A* and *B*. When we take out the plug from any gap in Fig. 5.6b, current flows through the coil. Thus the resistance of that particular coil is included in the circuit. As long as the hole is plugged, current flows through it and not through the coil. By taking out other plugs, we can introduce other resistances in the circuit. Since the resistance coils are in series, we add the resistance of all coils from which the plugs have been taken out. For example, if we take out 3 plugs from gaps marked 1Ω, 5Ω and 50Ω, the total resistance introduced in the circuit is 1Ω + 5Ω + 50Ω = 56Ω. We can change the resistance by taking out other plugs or plugging in air gaps. Resistance boxes come in various ranges from a few ohms to several thousand ohms. You may also note that the word 'infinity' is inscribed on a resistance box. This means that there is no coil between those gaps.

You may also come across a dial type resistance box, which has a rotating slider instead of plugs. As we rotate a knob, the slider moves over brass studs and its position on the dial indicates the resistance in use.

D. Keys

In Fig.5.7, we show the one-way and two-way keys commonly used in physics labs. Their symbols are also shown. These enable us to start and stop current flow in a circuit. When the key plug is inserted, a key introduces almost no resistance in the circuit by itself. But if you take out the plug, air fills the gap offering infinite resistance; no current flows across the key. Thus, the key works as a switch allowing current to pass only when the plug is inserted in the gap.



(a) (b)

Fig.5.7: a) One-way plug key; and b) two-way plug key

In the **plug key** of Fig.5.7a, *A* and *B* are two thick metallic blocks fixed on an ebonite plate with a small gap between them. A plug *P* fits into this gap. Two screws S_1 and S_2 are used to connect the key in the circuit. When the plug P is inserted, the circuit is complete and current flows in it. When the plug is taken out, the circuit is broken and no current flows in the circuit. A plug key is used when we need continuous current in the circuit. The two-way key shown in Fig.5.7b works on the same principle. As the name suggests, a two-way key provides two alternative options for current flow.

When we require current to flow for short periods we use a **tap key** (Fig.5.8). It has two screws S_1 and S_2 and a springy brass strip P fixed on an ebonite base. P is attached to the screw S_2 at one end and has a cap on the other end with a pin at its bottom. A button is fixed on the base right beneath the pin and connected to the screw S_1. When the cap is pressed, the pin touches the button and the circuit is complete. When the cap is released, the brass strip moves up and the contact is broken.

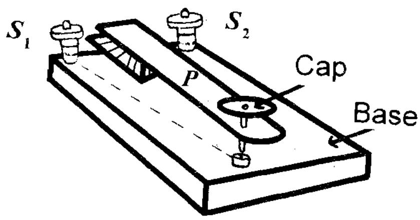


Fig.5.8: A tap key

While working with resistance boxes and plug keys, you should take care to insert the plugs properly. While inserting a plug, put it in its gap and then turn it slightly. While taking it out, turn it slightly and pull it out. Loose plugs can introduce large resistance and even create troubles like incomplete circuit, heating etc. After taking a plug out, do not let it be soiled by dust. Put it in a clean place. Also do not mix up plugs of one instrument with the other.

Apart from the resistive components discussed so far, the connecting wires in the circuit may also introduce some resistance, albeit almost negligible since they are made of good conductors like copper or aluminium.

This completes our discussion on resistors. You may like to revise these concepts. The following SAQ will help you do so.

SAQ 3: Resistive components in a circuit

a) In a resistance box, what is the resistance when
   i) all gaps are plugged
   ii) the plugs from gaps marked 10Ω, 50Ω and 100Ω are taken out?

b) Match the entities in column I with their descriptions in column II.

Column I	Column II
i) Rheostat	(A) Single fixed valued resistance
ii) Resistance box	(B) Switch to provide continuous current in the circuit
iii) Plug key	(C) Switch to provide short bursts of current in the circuit
iv) Resistance coil	(D) Offers variable resistance
v) Tap key	(E) Assembly of many fixed resistances
vi) Two-way key	(F) Assembly of colour coded resistors
	(G) Switch to provide current flow along two different paths

---

So far you have studied about resistive components in an electrical circuit. We now proceed to discuss the reactive components.

5.2.2 Reactive Components

The common reactive components used in a physics lab are capacitors, inductors and transformers. Let us first consider the capacitors.

A. Capacitors

A capacitor is a device designed to store electrical charge and energy. It is used in electrical power storage systems. It blocks the flow of direct current but allows alternating current to flow through it. That is why it is used in electrical circuits having an AC power source.

Capacitors are based on the principle that if a conductor is given a charge, it induces an equal and opposite charge on another insulated conductor kept near it. The capability of a capacitor to store charge is described as its **capacitance**.

You now know that potential of a conductor changes when it is given a charge. If potential changes by an amount V due to charge Q, its capacitance C is given by

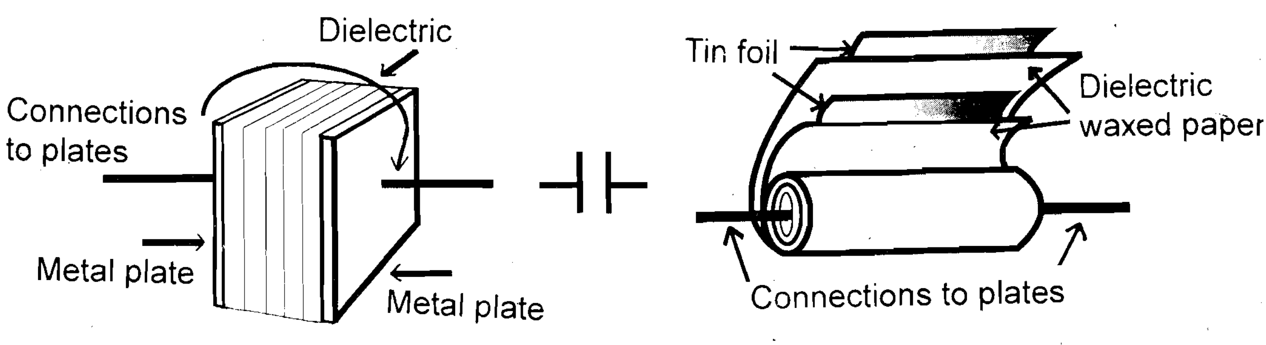
$$C = \frac{Q}{V} \tag{5.8}$$

If V is in volt and Q in coulomb, C is given in farad. Large capacitors have a capacitance of a few farad. However, in most common circuits, capacitances of the order of microfarad ($1\mu F = 10^{-6}F$) or picofarad ($1pF = 1\times10^{-12}F$) are used.

Many types of capacitors are used in the laboratory. The **parallel plate capacitor** is one of the simplest capacitors (Fig.5.9a), in which two parallel plates are separated by a thin layer of an insulator or air. The capacitance of such an arrangement is given by

$$C = \frac{\varepsilon A}{d} \tag{5.9}$$

where ε is the dielectric constant of the insulating material, A is the area of the plates and d is the distance between them. Eq.(5.9) tells us that C will be large when ε and A are large and d is small.



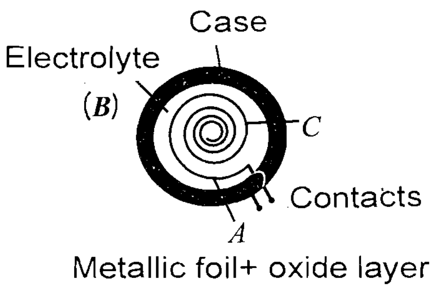
(a) (b)

Fig.5.9: a) Parallel plate capacitor and its symbol; and b) a waxed paper capacitor

A **waxed paper capacitor** (Fig.5.9b) consists of two long strips of tinfoil as plates. These are rolled into a small cylinder with waxed paper between them.

Different types of capacitors have different insulators (called **dielectrics**) between their plates.

Yet another kind of capacitor, made in the form of a roll of different layers of material as plates (Fig.5.10), is the **electrolytic capacitor**. *B* is a separator coated or soaked in electrolyte (e.g., paper coated or soaked in ammonium borate), *A* and *C* are usually made of aluminium foils with oxide layer and serve to store charge. An electrolytic capacitor has a fixed capacitance and the largest capacity to volume ratio.



(a)

(b)

Fig.5.10: a) An electrolytic capacitor; and b) its symbol

An electrolytic capacitor can be connected in the circuit in only one way: its positive end marked + should always be connected to the positive terminal of the power source. Some electrolytic capacitors can be destroyed by only 1V in the reverse direction. Hence, it is important to know the polarity of the electrolytic capacitor, i.e., which terminal is positive and which is negative. Fig.5.10b also shows the symbol for an electrolytic capacitor. Normally, a red dot or the symbol (+) is used to show the positive end and a black dot or symbol (–) signifies the negative end of an electrolytic capacitor.

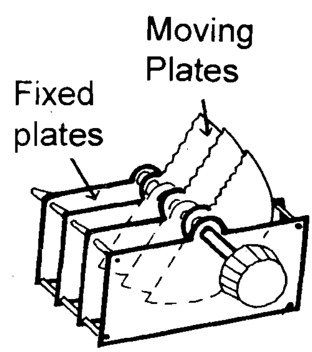


Fig.5.11: A variable capacitor

A **variable air capacitor** has two sets of flat parallel metal plates separated by air (Fig.5.11). Each set consists of several plates joined together to give one large plate. One set of plates is fixed and the other can be rotated, varying the area of overlap and hence, the capacitance. Such variable capacitors are used in radio receivers to tune-in to a particular radio station.

Various kinds of capacitors used in a physics lab are listed in Table 5.2 with their characteristic features. This information will be useful when you work in the lab.

The capacitance of a capacitor is affected by leakage: Whenever a capacitor is charged it leaks a small amount of charge from one plate to another.

Since capacitors store electrical charge, you should always be careful while working with them. Sometimes even when a circuit containing capacitors has been switched off, the capacitors in it may remain charged for sometime. Therefore, you should **never touch these capacitors. Sudden accidental discharge can prove fatal.**

To overcome this problem, a permanent megaohm ($1M\Omega = 1 \times 10^6\Omega$) resistor is connected across large capacitors. This discharges them slowly after the circuit has been switched off. So if you have to discharge a large capacitor, always use a resistor of at least 10kΩ. You should also remember to connect electrolytic capacitors in the right way as mentioned earlier.

You should now review your progress through this section with the help of the following SAQ.

SAQ 4: Working with capacitors

a) A capacitor is marked 1000 μF. What is its capacitance in farad? What is the charge on it at 50V?

b) List the precautions you should take in handling (i) an electrolytic capacitor and (ii) a capacitor carrying a high charge.

---

pF refers to picofarad and μF to microfarad:
$1pF = 1\times10^{-12}F$
$1\mu F = 1\times10^{-6}F$

Table 5.2: Characteristic features of capacitors

Type	*Characteristics*	*Typical Ratings*
Air dielectric	Have metal vanes to vary capacitance for tuning circuits.	0 to 500 pF per device 0 to 50 pF for small trimmers
Paper	Large size, high capacity, reliable.	2, 4, 8 μF 15% tolerance* 600 V *DC* (250 V *AC* r.m.s.)
Mixed dielectric	Typically, mixed paper and polyester film, with foil connection.	0.01 to 1 μF 1000 V to 600 V *DC* 20% tolerance
Electrolytic	Construction. Aluminium foil electrodes, dielectric layer of aluminium oxide connected to negative electrode through special paste. Greatest capacity/volume ratio of all capacitors.	32 μF to 5000 μF. 500 V *DC* to 100 V *DC* + 50% + 100% – 25% tolerance – 25% tolerance
Ceramic	Have high capacity/volume ratio. Not very stable: capacity varies with temperature.	0.001 to 0.01 μF 750 V *DC* + 50% – 25% tolerance 0.1 to 0.47 μF 10 V *DC*
Mica	Very stable. Sintered mica: most stable capacitor.	Close tolerance Silver mica 2.2 to 10000 pF 500 V *DC* 1% tolerance
Polyester	Small size, wide temperature range. Recovers rapidly from changes in environmental conditions.	0.001 μF to 2 μF 750 V *DC* to 250 V *DC* (300 V *AC*) (125 V *AC*) 20% tolerance
Polycarbonate	Has electrical properties between those of polyester and polystyrene types.	1 to 10 μF 60 V *DC* 5% tolerance
Polystyrene	Used similarly to mica types but not so stable.	10 to 10000 pF 125 V *DC* 2% tolerance
Tantalum	Small size, low leakage. Has long shelf life and high reliability.	47 μF to 0.47 μF 6 V *DC* to 35 V *DC* 20% tolerance

* Tolerance refers to the error in the capacitance

Let us now take up the study of inductors.

B. Inductors

An **inductor** is a coil of wire wound either on an iron rod or has an air core. It opposes any **change** in the current flowing through it and is said to possess an **inductance**. The unit of inductance is henry. Let us understand how an inductor works.

Electric current in a coil produces a magnetic field **B** around it. We associate a magnetic flux with the magnetic field. When the magnetic field through a coil of area A is perpendicular to it, the magnetic flux is given by

$$\phi = BA \tag{5.10}$$

If the current through the coil changes, so does the magnetic field through it and the magnetic flux inducing an electromotive force in the coil. This is known as the phenomenon of **electromagnetic induction**. If E is the induced electromotive force across the inductor and L the inductance of the coil, then

$$E = -L\frac{\Delta I}{\Delta t} \tag{5.11}$$

where ΔI is the change in current through the inductor in time Δt. The minus sign shows that E opposes the change in current. It is also called the **back emf** of the coil.

The effect of an inductance in a circuit is to oppose the change in the current – when the current is increasing, it acts to decrease it and vice versa. You may have seen that if we try to stop current in a very short time, a spark appears. This is because rate of change of current becomes large and a very large back emf is produced. The large induced current so generated can destroy delicate electronic devices. **Therefore, you have to be extremely cautious while switching off circuits containing large inductors.**

In your everyday experience you may have seen a spark when you turn off the switch connected to an electrical appliance such as a toaster, a mixer, a geyser or an iron. There is an inductance in the circuit which opposes the decrease in current. It keeps the current flowing even if it has to jump the gap in the circuit causing the spark. Similarly, when we switch on the current in a DC circuit containing an inductor, its presence delays the rise of current to its steady state value. In an AC circuit, the current is changing all the time. The presence of inductance induces a current opposing this change.

There are several types of inductors in a laboratory (Fig.5.12). The inductance of an inductor depends on its geometry, i.e., its length, area and number of turns per unit length. Even a single length of wire possesses some inductance. Resistors in the form of coils are usually wound with two layers of wire. The first layer is wound from one end to another and the second layer returns. Thus the currents have opposite sense in the two layers resulting in negligible inductance.

Fig.5.12: Inductors in a laboratory

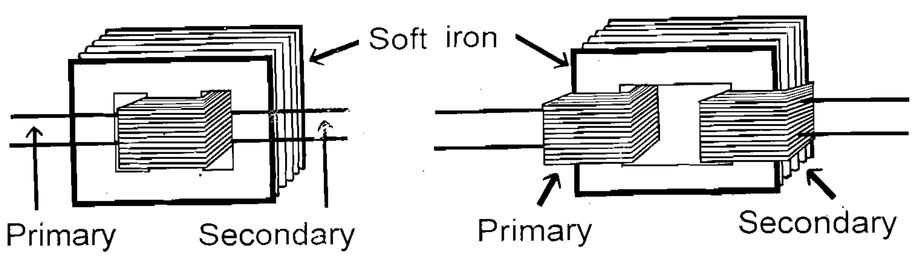
The action of an inductor is based on the phenomenon of self-induction. That is, the *changing current in a coil induces an emf in the coil itself.* Suppose another coil were kept close to this coil. Would the change in the first coil induce an emf and a current in the second coil? The answer is yes. This effect is called **mutual induction**. It forms the basis for a very important device used in the distribution of electricity, namely, the **transformer**. The transformer is also used frequently in the physics lab. So you should learn about it.

C. Transformer

In mutual induction, a continuously changing current in one coil produces a changing magnetic flux in another coil kept close to it. This varying flux generates an alternating emf in the second coil. The frequency of the emf induced in the second coil is the same as that of the current in the first coil. The induced emf also depends on the number of turns in the second coil. In a transformer, the first coil is called the **primary coil** and the second one, the **secondary coil**. By varying the number of turns in the secondary coil, we can increase or decrease the emf induced in the coil. This is the basic principle on which a transformer works.

A transformer changes an alternating voltage from one value to another. The transformed voltage can be greater or smaller than the applied voltage, depending on the number of turns in the secondary coil.

In general, the two coils in a transformer are wound on a soft iron core either one on top of the other (Fig.5.13a) or on separate sides of the core (Fig.5.13b). Notice that a transformer has four terminals – two for applying primary voltage and two for drawing output at the secondary.



(a) (b)

Fig.5.13: Transformers of different kinds

The voltage applied to the primary coil (V_p) is related to the voltage in the secondary coil (V_s) by the equation

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad (5.12)$$

where N_s is the number of turns in the secondary coil and N_p, the number of turns in the primary coil. If N_s is greater than N_p, the transformer is known as a **step up transformer** since the emf in the secondary coil (V_s) will be *greater* than that in the primary (V_p). In the **step down transformer**, N_s is less than N_p and hence the emf in the secondary coil is *less* than that in the primary.

Transformers are used extensively in power distribution systems. For transmission of power from the generating station, the voltage is *stepped up* to a high value of about 22,000V. It is carried in high tension wires to the distribution station. There it is stepped down to the mains voltage of 220V by a step down transformer for which the ratio of number of turns in the primary to the number of turns in the secondary is

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{22000}{220} = 1000.$$

That is, for every turn on the secondary, there are 1000 turns on the primary coil.

Transformers usually operate at 95% to 98% efficiency. Between 2 and 5 per cent of transformer efficiency is lost through:

- the electrical resistance of copper wire coils;
- magnetic flux losses due to poor design of the core; and
- currents induced in the core (called eddy currents).

These losses appear as heat. Though the basic principle of all kinds of transformers is the same, they differ in terms of their construction and rating, according to the use they are put to. So you should know about transformer ratings.

D. Transformer ratings

Transformers usually have a certain rating given as the primary voltage/secondary voltage and power value. For example, if a transformer rating is given as 540V/8V 1 watt, it means that voltages in its primary and secondary coils are 540V and 8V, respectively and the power of the transformer is one watt. The power of the transformer, assuming no power losses is given by

$$P_t = \text{Power in primary} = \text{Power in secondary}$$

or

$$P_t = V_p \times I_p = V_s \times I_s \qquad (5.13)$$

where I_p and I_s are the currents in the primary and secondary coils, respectively. Thus one watt power rating in the above example means that the current in the primary and secondary coils should not exceed the values

$$I_p = \frac{1\text{W}}{240\text{V}} = 4.1\times10^{-3}\text{A} = 4.1\text{mA}\text{, and } I_s = \frac{1\text{W}}{8\text{V}} = 0.125\text{A}\text{, respectively.}$$

It does, the coils would melt due to the heat produced. One of the usual causes of power failures, particularly in cosmopolitan cities, is the burning down of transformers in power transmission systems. In order to avoid such a happening in the lab, always operate the transformer within the given ratings.

Before studying further would you like to quickly answer an SAQ to check whether you have grasped the ideas presented in this section.

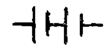
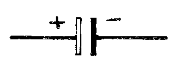
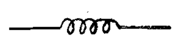
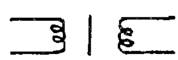
SAQ 5: Inductors and transformers

a) What is the effect of an inductor in an electrical circuit?

b) A transformer has a rating 240V/12V 1watt. What is the maximum current that can be allowed in the primary and secondary coils?

So far you have learnt about various components of an electrical circuit. In Table 5.3 we present their symbols for ready reference.

Table 5.3: Symbols of circuit components

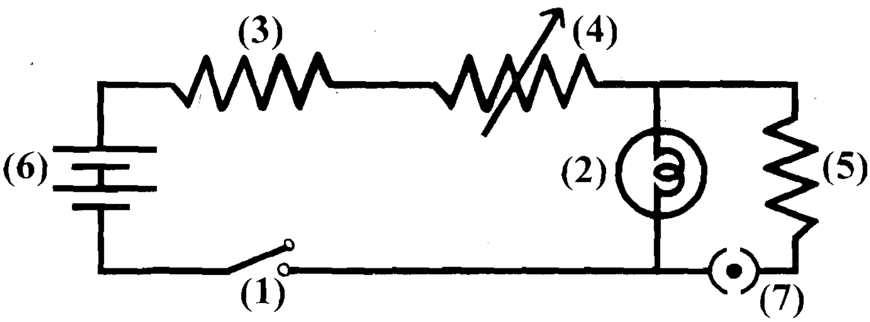
Component	Symbol
Battery	
Fixed resistor	
Variable resistor	
Connecting wires	
Crossed out/Unconnected wires	
One-way key	
Two-way key	
Capacitor	
Electrolytic capacitor	
Inductor	
Transformer	

Note that two different symbols are used to indicate wires that cross but are not connected. Either of these may be used. However the symbol ψ is more commonlv used.

You may now like to attempt an SAQ to identify components in a circuit.

SAQ 6: Identification of components in a circuit

Study the circuit diagram shown below. Identify each component from its symbol.



In an electrical circuit, the components can be connected in two ways: in series and in parallel.

Series and parallel circuits

In a series circuit, the components are connected one after the other and there is only one path for current to flow (Fig.5.14).

In a parallel circuit components are joined side by side. The current splits and flows along the branches (Fig.5.15). The parallel circuit differs from the series circuit in that more than one path is provided for current flow.

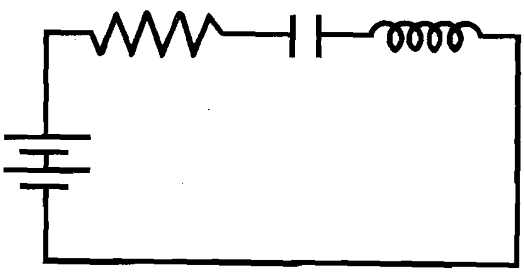


Fig.5.14: A series circuit

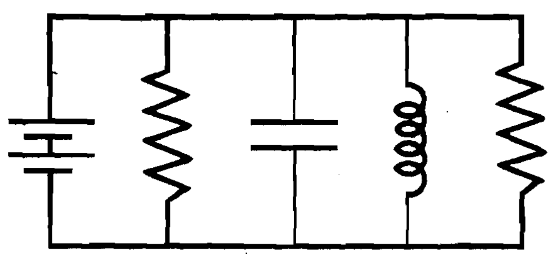


Fig.5.15: A parallel circuit

You know that potential difference in a *DC* circuit is provided by a cell. Cells are of two types – primary and secondary. They differ in their construction and working. Since you will be required to handle them in the lab, you should know about them.

5.3 PRIMARY AND SECONDARY CELLS

There are many types of cells, such as the simple Voltaic cell, Daniell cell, Leclanche cell, lead acid accumulator, nickel-iron cell, nickel-cadmium alkaline cell. But the basic principle underlying these devices is the same: Chemical energy is converted into electrical energy. Let us understand this with the help of the simple Voltaic cell.

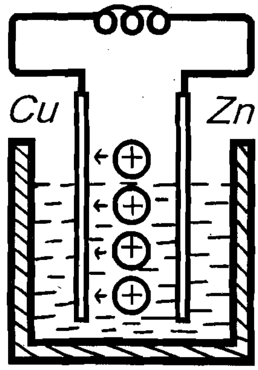


Fig.5.16: A simple Voltaic cell

Refer to Fig.5.16. You will note that a simple voltaic cell has three basic parts:

i) a pair of dissimilar metal plates, e.g., zinc and copper plates, called **electrodes**;

ii) a dilute acid solution, e.g., dilute sulphuric acid, called **electrolyte**; and

iii) non-conducting container, say of glass, called the **cell**.

Two metallic screws, called **terminals**, are provided at the top of the electrodes for circuit connections. When sulphuric acid is diluted by adding water, the SO_4^{--} group of atoms separate from the two hydrogen atoms taking two electrons with them:

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{--}$$

When the zinc plate is dipped in the electrolyte, zinc atoms go into the solution in the form of Zn^{++} ions, leaving behind two electrons on the plate. The zinc ions Zn^{++} combine with SO_4^{--} to form zinc sulphate:

$$Zn^{++} + SO_4^{--} \rightarrow ZnSO_4$$

The electrons from the zinc plate pass through the wire and reach the copper plate. At the same time, the hydrogen ions $(2H^+)$ leave the solution and deposit themselves on the copper plate. Here they receive the electrons from the copper plate and become neutral molecules of hydrogen gas:

$$2H^+ + 2e^- \rightarrow H_2$$

The gas can be seen in the form of bubbles at the copper plate. By losing electrons, the copper plate becomes positively charged and is called the **anode**. The zinc plate is negatively charged and is called the **cathode**. Thus a current flow is established from the zinc plate to the copper plate along the wire. This cell provides a voltage of 1.08V.

A cell like the simple Voltaic cell is known as primary cell. This cell cannot be recharged easily. When its output drops, it should be discarded or reassembled.

In the Leclanche cell, zinc reacts with ammonium chloride to liberate ammonium ions

$Zn + 2NH_4Cl \rightarrow ZnCl_2 + 2NH_4^+$

Ammonium ions gain electrons at the carbon rod forming hydrogen and ammonia:

$2NH_4^+ + 2e^- \rightarrow 2NH_3 + H_2$

Manganese dioxide oxidises hydrogen to form water and ammonia gas reacts with zinc chloride.

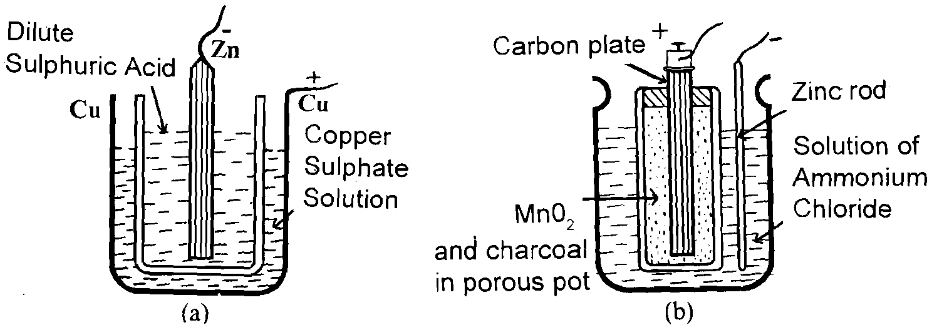


Fig.5.17: a) Daniell cell; and b) Leclanche cell

Daniell cell and Leclanche cell are the other primary cells, apart from the simple Voltaic cell, that are used in the laboratory (Fig.5.17). The details of these two types of cell are given in Table 5.4.

Table 5.4: Daniell and Leclanche cells

Type of Cell	Cathode	Anode	Electrolyte	Container	Output (V)
Daniell	Zinc	Copper	Sulphuric acid	Copper can	1.1
Leclanche	Zinc	Mixture of Carbon and Manganese dioxide	Ammonium Chloride Solution	Glass jar	1.5

Primary cells need little effort for maintenance but there are some points which you should be aware of. **It is a good practice to soak the porous pot in pure water before using for a wet experiment. It will still be better to soak them in the electrolyte they are to contain for a few hours before they are required for use**. This ensures that it will fulfil its function as soon as the experiment begins.

Let us now consider the secondary cells. In a secondary cell, the chemical reaction responsible for the current can be reversed. Therefore, it can be recharged. **To recharge a secondary cell, current from an external source is passed into it in the direction opposite to that in which the current is supplied by the cell**. Therefore, secondary cells act as storage batteries for electrical power and operate by charge-discharge process. Batteries used in automobiles are examples of secondary cells.

When two or more cells are connected one after another, the arrangement is called a battery. It is denoted by the symbol

The commonest secondary cells used in the lab are the lead-acid accumulator and the nickel-iron (NiFe) or nickel-cadmium alkaline cells. Nickel-cadmium cells are available in several designs and sizes. The most common types are cylindrical cells and the button cells used in quartz wrist watches showing the variation of alternating current with time. Table 5.5 gives a summary of these cells.

RIL-039

Table 5.5: Secondary cells

Type of Cell	Anode	Cathode	Container	Electrolyte	Output (V)
1. Lead–acid accumulator	Pb_3O_4	PbO	Glass/Plastic vessel	Sulphuric acid	2.0
2. NiFe cell	Nickel	Iron	Steel	Potassium hydroxide	1.2
3. Nickel cadmium alkaline cell	Nickel	Cadmium	Steel	Potassium hydroxide	1.2

These cells require regular maintenance, which involves

- keeping the top and terminals of the cell clean;
- topping up the electrolyte in lead-acid cells to the level marked on the case with pure water; and
- recharging at regular intervals or, in the case of lead-acid cells, when the relative density of the electrolyte falls below 1.2. (You will need a battery hydrometer to check this.) If the relative density falls below 1.15 the cell is "dead" and will not hold its charge.

You may now like to answer an SAQ on this section.

SAQ 7: Primary and secondary cells

List the main advantage of a secondary cell over a primary cell.

Electrical wiring in series is not suitable for the following reasons:

1. In a series circuit when the switch is closed, all appliances are switched on. They can all either be **on** or **off** together because in the series circuit, current has only one path. This is a highly undesirable situation for a home/laboratory because we do not use all the electrical appliances simultaneously.
2. The amount of current required by one electrical equipment (such as the electric bulb) may be different from that of the another equipment (such as the heater) for their optimum functioning (see margin remarks). This requirement cannot be met in a series circuit because the current is constant throughout.

In the previous sections you have learnt about *DC* circuits and sources of direct current. In a physics lab, you will also use *AC* from the mains supply directly or by converting it into *DC* through a power supply. You will study about power supplies in Unit 6. Here you will learn about the basic features of the electric supply from the mains in a physics lab.

5.4 SUPPLY OF ELECTRICITY IN THE PHYSICS LAB

As you may know, in household electricity, a heavy cable comprising two wires is used. These two wires are insulated from each other. One of these is called the **live** (*L*) wire and another is called the **neutral** (*N*) wire (Fig.5.18). The electric supply being *AC*, 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 sub–station.

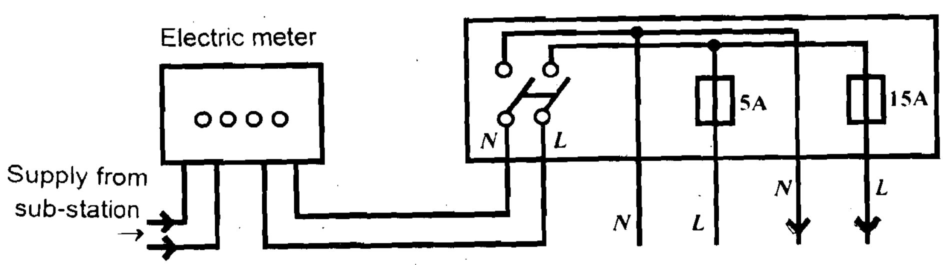


Fig.5.18: Supply of electricity to the laboratory

Similarly, electricity connection to the physics laboratory is provided through a two-core heavy cable. The electricity supplied to the laboratory is used for various purposes such as lighting, running electrical and electronic equipment. Therefore, the laboratory electrical wiring has many sockets (in addition to light and fan points) on the walls into which instruments can be plugged.

Electrical sockets, lights and other points are connected in parallel with the mains supply. In this way, each socket or point can be used independently. For example, in Fig.5.19, even if we leave S_2 in off position and switch on S_1, the bulb will glow because current can take the path *abcd.*

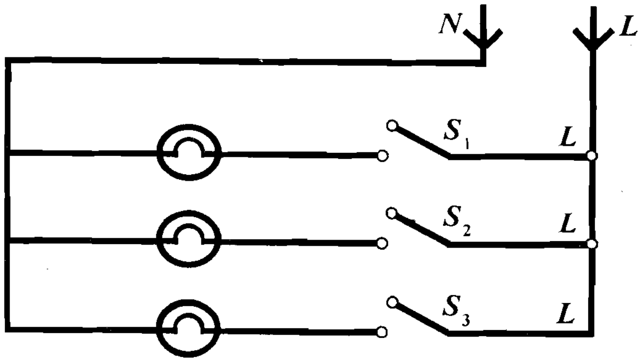


Fig.5.19: Elements in parallel connections with the mains supply

There are separate circuits for low power (wattage) electric appliances such as electric bulb, fan etc. and high power (wattage) appliances such as electric heater. This is because the current required by low wattage appliances is small compared to the high wattage appliances. Therefore, thinner conducting wires can be used for wiring low wattage appliances. From Sec. 5.2 you may recall that current carrying capacity of a wire depends on its gauge. If the same thin wire is used for wiring high wattage appliances, it (wire) may melt (burn out) due to large current drawn by these appliances. Therefore, two separate parallel wiring circuits are provided in the laboratory, one each for **lighting** and **power**.

In Unit 11 of the course LT-1, you have studied in detail about electrical wiring in a lab as well as its safety and maintenance. We repeat the main precautions here to refresh your memory. It is important for you to always keep them in mind while working in a lab. First and foremost, it is important that any connection made to the mains supply are safe for everyone working in the lab.

It is important **to check the laboratory wiring including sockets, plugs and cables at regular intervals** as well as the earthing of each electrical equipment. If you have to wire a plug, make sure that you

- select the wire of appropriate gauge according to the current it needs to carry; and
- connect the wire of correct colour to each terminal of the plug: red for phase/live, black for neutral and green for earth.

You know that in the laboratory wiring system, **fuses** are used for protecting the electric wires and equipment from damage due to overheating caused by excess current flow.

A fuse wire is made of a special alloy (tinned copper) which has **a low melting point.** If excessive current is drawn in the laboratory wiring system for some reason, fuse wire melts, breaking the continuity of the circuit and thus protects the wiring from burn out. You should select the appropriate fuse for 5A or 15A equipment.

When a fuse blows, it is an indication that there is something wrong in the laboratory wiring such as

- large current supply from the electric station;
- short circuit in one or more electric appliance or equipment;
- large current drawn by an electrical equipment in the laboratory.

Therefore, before rewiring the fuse and fixing it in the socket, you must find out the reason of its blowing and get it corrected. Otherwise, the moment you fix the rewired fuse, it will again blow.

Now-a-days, MCBs (Miniature Circuit Breakers) are used in place of fuse. MCBs are designed to break the circuit and stop the current flow when the current exceeds a predetermined value. An MCB differs from a fuse in that it 'trips' to break the circuit and it may be reset, while a fuse melts and must be replaced. Most MCBs can be reset by hand. When the circuit breaker is reset and if the overload condition still exists, the circuit breaker will trip again to prevent damage to the circuit.

Any fault must be rectified by a qualified electrician only.

In Table 5.6 we give a summary of the typical problems in lab wiring and remedial measures.

Table 5.6: Remedial measures for problems in laboratory wiring

Item	Type of inspection/test	Frequency of inspection/ test	Item fails if:	Remedial action
Plugs	a) Visual	When used	a) Cracked or incorrectly connected	Replace
	b) Dismantle and inspect	Annually		Rewire
Leads	Visual	When used and annually	Outer insulation is damaged	Replace
Outlets	a) Visual	When used and weekly	Damaged	Contact Electrician
	b) Check plug to test internal wiring	Annually		Contact Electrician

We now summarize what you have learnt in this unit.

5.5 SUMMARY

- **Current** is the rate of flow of electric charges. There are two types of electric current:

  direct current which results when charges flow in one direction only and **alternating current** which results when the direction of flow of charges reverses periodically.

- **Potential difference** or voltage between any two points is the amount of work required to move a unit positive charge from one point to another.

- **Resistance** of a conductor is a measure of the opposition offered by the conductor to the flow of charge. It is given by the ratio of the potential difference across a conductor to the current flowing in it:

  $$R = \frac{V}{I}$$

  where R is the resistance of the resistor, V is the voltage across it and I is the current through it.

  At a given temperature, the resistance of a conductor is given by

  $$R = \frac{\rho \ell}{A}$$

  where ρ is resistivity, ℓ the length and A, area of cross-section of the resistor.

- **Power** is defined as the rate of doing work and is given by

  $$P = VI$$

- The commonly used *resistive components* in an electrical circuit are **resistors, rheostats, resistance coils, resistance boxes** and **keys**. All these components obey **Ohm's law** which states that:

  The potential difference across a conductor is directly proportional to the current flowing through it if its temperature and other physical conditions remain the same.

- A **capacitor** is a device that stores electrical charge and energy. If the potential on a conductor changes by an amount V when it is given a charge Q, its capacitance C is defined by

  $$C = \frac{Q}{V}$$

  The capacitance of a **parallel plate capacitor** is given by

  $$C = \frac{\varepsilon A}{d}$$

  where ε is the dielectric constant of the insulating material between plates, A is the area of the plates and d is the distance between them.

- An **inductor** is a coil of wire which opposes any *change* in the current flowing through it. It is said to possess an **inductance** L given by

$$E = -L\frac{\Delta I}{\Delta t}$$

where E is the **emf** induced in the coil, ΔI is the change in current in time Δt.

- A **transformer** is a device based on mutual induction. It is an arrangement of two coils wound on a soft iron core. It transforms an alternating voltage from one value to another given by

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

where V_s, N_s and V_p, N_p are the voltages and number of turns in the secondary and primary coils, respectively. In a **step up** transformer $N_s > N_p$ and $V_s > V_p$. In a **step down** transformer $N_s < N_p$ and $V_s < V_p$.

- A **cell** or **battery** is used to provide potential difference in a *DC* circuit. Cells are of two types: **primary** and **secondary**. The underlying principle is same in both: Chemical energy is converted into electrical energy. The primary cells used commonly in a physics lab are **simple Voltaic cell, Daniell cell** and **Leclanche cell**. The lead-acid accumulator, nickel-iron cell, nickel-cadmium alkaline cell are some of the **secondary cells**.

- **Electricity** to the lab is supplied through a two-core heavy cable. One of the wires is **live** which is alternatively at positive and negative potential of 220V with respect to the **neutral** wire. All points in the laboratory are connected in parallel with the mains supply. Electrical wiring, sockets, plugs, cables, and electrical equipment in the lab should be checked at regular intervals. Any fault must be rectified only by a qualified electrician.

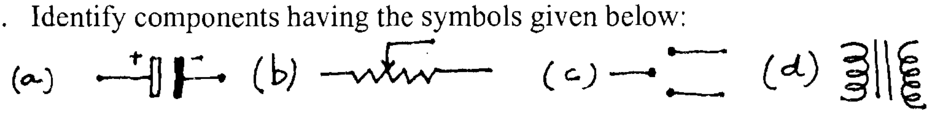
5.6 TERMINAL QUESTIONS

1. Draw a circuit connecting

   a) resistor R, capacitor C and an inductor L in series with a battery B.

   b) three resistors R_1, R_2, R_3 in parallel with a cell.

2. Identify components having the symbols given below:



3. Explain the two major differences between a transformer and an inductor.

4. State the type of wire (thin or thick) that you will recommend for use in the fuse for the following:

   a) Lighting circuit

   b) Circuit containing electric heater, soldering iron, etc.

5. What remedial measures will you take in the case of the following faults in the laboratory wiring:

   a) Smell of burning in a 5A plug,

   b) Sparking from a 15A socket?

5.7 SOLUTIONS AND ANSWERS

Self-assessment Questions

1. a) (i) partly; current is the rate of flow of electric charges, (ii) and (iii)

   b) Since $R = \frac{\rho \ell}{A}$, the material of the wire being the same, the new R will be

$$R' = \frac{\rho \times 2\ell}{A/2} = \frac{4\rho\ell}{A} = 4R$$

   So the resistance of the wire will become 4 times its original value.

2. a)

$$R_1 = 21 \times 10^3,\ 5\%\Omega$$

$$R_2 = 16 \times 10^5,\ 10\%\Omega$$

$$R_3 = 32 \times 10^7,\ 10\%\Omega$$

$$R_4 = 89 \times 10^4,\ 5\%\Omega$$

   b)

	R_1	R_2	R_3	R_4
A	Red	Orange	Green	Violet
B	Brown	Black	Blue	White
C	White	Blue	Orange	Red
D	Gold	Silver	Gold	Silver

3. a) (i) Zero, (ii) 160Ω

   b) (i) *D*, (ii) *E*, (iii) *B*, (iv) *A*, (v) *C*, (vi) *G*

4. a) Capacitance is $1000 \times 10^{-6}\text{F} = 10^{-3}\text{F}$.

$$Q = CV = 10^{-3} \times 20\text{C} = 2 \times 10^{-2}\text{C}$$

   b) (i) Always connect it with the correct polarity.

   (ii) Never touch it. Always keep a megaohm resistance connected across it.

5. a) An inductor opposes the change in the current in a circuit.

   b) $I_p = \dfrac{1\text{W}}{240\text{V}} = 4.1\text{mA}$

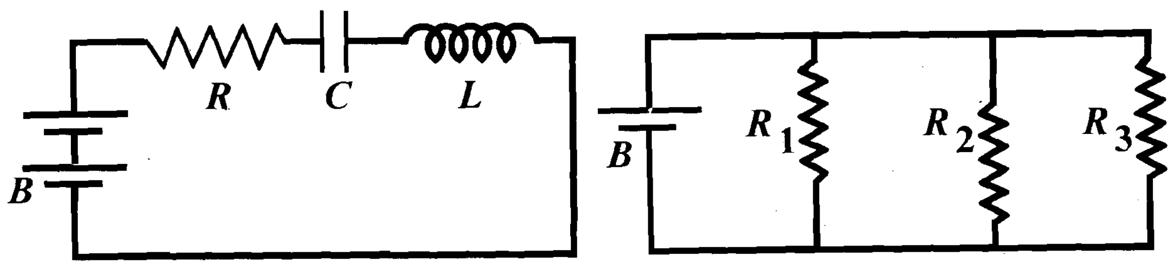
   $I_s = \dfrac{1\text{W}}{12\text{V}} = 0.083\text{A}$

6. (1) Switch, (2) Lamp, (3) Fixed resistance, (4) Variable resistor, (5) Fixed resistance, (6) Battery, (7) One-way key

7. A primary cell cannot be recharged easily. It has to be discarded or reassembled when its output drops. Therefore, it has a very short life. A secondary cell can be recharged and lasts much longer as compared to a primary cell.

Terminal Questions

1. See Fig.5.20a and b.



(a) (b)

Fig.5.20

2. (a) Electrolytic capacitor, (b) variable resistor, (c) two-way key, (d) transformer.

3. A transformer transforms voltages to lower or higher values. An inductor does not. An inductor is based on self-induction, a transformer on mutual induction.

4. a) thin wire; b) thick wire

5. a) The plug should be inspected for burnt wire and rewired.

   b) Sparking could be due to loose connections inside. Electrician should be called in to locate and rectify the fault.

UNIT 6 ELECTRICAL AND ELECTRONIC APPARATUS

Structure

6.1 INTRODUCTION

In Unit 5 we have introduced you to electrical circuits and the basic components used in them such as resistors, capacitors, inductors etc. In this unit, we turn our attention to electrical instruments such as the **galvanometer**, **ammeter**, **voltmeter** and **multimeter**. These instruments are used to detect current, and measure current, voltage and resistance in a circuit. In addition, the **Wheatstone bridge**, **metre bridge** and **potentiometer** are used for resistance measurements to a higher degree of accuracy. The **Post-office box** is a special kind of Wheatstone bridge used in some school laboratories. In Sec. 6.2, we discuss all these instruments.

The use of electronic devices and instruments around us is increasing day by day. For instance, we now have digital thermometers and blood pressure measuring instruments. Similarly, the use of radio, TV, and computers has become very common. Therefore, in a UG laboratory you will find many experiments on electronics. These experiments involve devices like ***p-n* junction diodes** and **transistors**, and instruments such as the **power supply**, **cathode ray oscilloscope** and **signal generator**. You will handle these devices and instruments quite regularly in the course of your work. Therefore, you should be able to identify them and know what they are used for. You should also know how to take care of them. This forms the subject matter of Sec. 6.3 and 6.4.

With this unit we end the discussion on the basic apparatus in a physics lab. In these units our emphasis has been on enabling you to identify various components, devices and instruments, and learn the precautions for using and maintaining them. With this in mind, we have briefly explained the principles underlying the working of the apparatus. You will appreciate these ideas better when you perform experiments in the laboratory.

Objectives

After studying this unit, you should be able to:

- identify galvanometers, voltmeters and ammeters of various ranges and state their uses;
- identify the wheatstone bridge arrangement, post-office box, metre bridge and a simple potentiometer and explain their functions;
- explain the functions of various controls on a multimeter and list its uses;
- identify *pn* junction diodes, *pnp* and *npn* transistors and draw their symbols;
- identify a cathode ray oscilloscope, power supply and a signal generator, and state their uses; and
- list the precautions for handling electrical and electronic apparatus and state the requirements for maintaining them.

6.2 ELECTRICAL INSTRUMENTS

In this section we discuss a variety of electrical instruments. You do not have to worry about the construction of any of these instruments, which we explain only briefly. However, you must know what each one of these is used for, how to use it and take care of it. Let us begin with the galvanometers, ammeters and voltmeters.

6.2.1 Galvanometers, Ammeters and Voltmeters

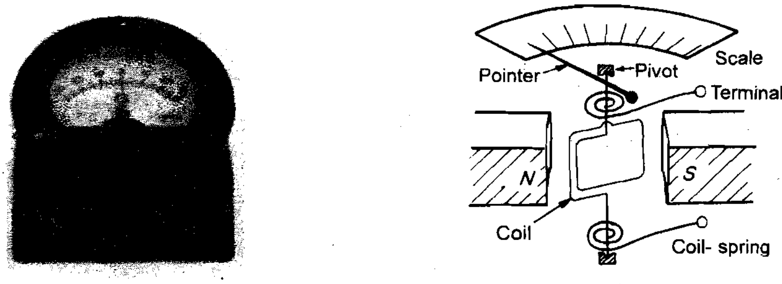
In experiments on electricity and electronics, you will almost always use an ammeter to measure current and a voltmeter to measure voltage. Both these instruments are essentially obtained by modifying a galvanometer. Therefore, in this section we discuss galvanometers first and then ammeters and voltmeters.

A. Galvanometers

A **galvanometer** is used to *detect* or *measure* small currents of the order of milliamperes or small potential differences of the order of millivolts. You will use it most commonly in experiments involving the Wheatstone bridge arrangement. A typical galvanometer used in school and undergraduate laboratories is shown in Fig.6.1a. A galvanometer is denoted by the symbol —(G)— in a circuit. It is called the **moving coil galvanometer** since it has a coil placed between the poles of a permanent magnet which moves when current flows through it (see Fig.6.1b).

There are other types of galvanometers like the ballistic galvanometer or the tangent galvanometer, which are not used much now-a-days. So we do not discuss them here.

In a moving coil galvanometer, current enters and leaves the coil through hair springs placed above and below it. You can see a pointer attached to the coil, which moves on a graduated scale for measuring current. The deflection of the pointer on the scale is proportional to the current in the coil. The zero of the galvanometer is usually in the middle of the scale. Thus, we can measure current flow in either direction. In Wheatstone bridge experiments we have to obtain a condition of zero deflection, known as **null deflection**. This means that no current flows in the circuit. The galvanometer is useful in such a situation.



(a) (b)

Fig.6.1: a) A galvanometer as it looks from outside; and b) construction of a galvanometer

From the construction of the galvanometer, it is clear that you must always take the following **safety measures** while handling it:

- **A typical galvanometer gives a full scale deflection for currents of the order of 1mA or less.** Therefore, you should not pass large currents through it as the springs and the pointer may break.

- You should prevent damage to the permanent magnet in the galvanometer. This means that you should avoid placing it in a strong magnetic field or in a high temperature environment as the magnet can be demagnetized.

- You should keep the galvanometer dust free while working. Store it in the almirah once the experiment is over.

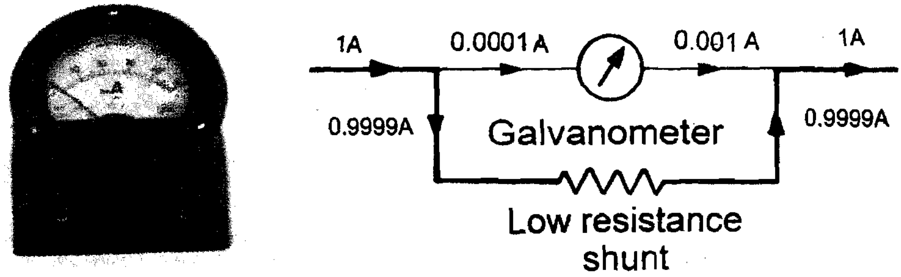
- Be careful in handling the instrument; prevent any accidental dropping as it will get damaged.

Current is one of the most important quantities measured in an electrical circuit. **Ammeters** are used to measure both direct and alternating current. Here we discuss only those ammeters which measure direct current.

B. Ammeters

In physics labs, now-a-days, you may come across both digital and analogue ammeters. An ammeter is denoted by the symbol —Ⓐ— in a circuit. Digital ammeters are electronic instruments in which the current reading appears in the form of numbers on a display panel. In analogue ammeters, we have a pointer scale arrangement as in the galvanometer described above (Fig.6.2a). Here we discuss only analogue ammeters, as they are more common.

An ammeter used for measuring direct current is essentially a galvanometer having a known **low resistance in parallel with it** known as the shunt (Fig.6.2b). The shunt takes most of the current. An ammeter is always placed in series in a circuit and has a very **low resistance**. Can you say why? If it were not so, the ammeter would change the current to be measured. In fact, an **ideal ammeter** should have **zero resistance** so that the entire current flows through it.



(a) (b)

Fig.6.2: a) An analogue ammeter; b) a galvanometer with a shunt acts as an ammeter

In practice, however, ammeters do have internal resistance. You will find a number of ammeters in different ranges having different internal resistances. For each current measurement, we need to select an appropriate ammeter. Therefore, when handling ammeters in a lab you should also know what range of the ammeter is suitable for a given current measurement.

When selecting an ammeter you should choose one that gives full-scale deflection (f.s.d.) at about one and a half to twice the maximum measurement expected. Thus if you are to measure a maximum of 50 mA current, the ammeter should have a range of 0 to 100 mA.

The following three values are usually provided either on the face of the ammeter or in its accompanying literature:

1. Full scale deflection (f.s.d.), e.g., 1mA
2. Internal or coil resistance, e.g., 65Ω
3. Accuracy, e.g., 2%.

Ammeters used for measuring alternating currents are constructed differently but the information about selection of range applies to them as well.

Suppose you have a circuit with a current of 1mA flowing in it. You connect a 1mA meter (resistance 75Ω) in the circuit. Will the ammeter register 1mA? The answer will depend on how much resistance is already connected in the circuit. For example, if you have a total resistance of 7500Ω (and therefore 7500Ω × 1mA = 7.5V emf) in the circuit, the current reading will be

$$I = \frac{V}{R} = \frac{7.5\text{V}}{(7500 + 75)\Omega} = 0.99\text{mA}$$

However, if your circuit has a resistance 75Ω (i.e., an emf 75Ω × 1mA = .075V), the current indicated by the meter will be

$$I = \frac{V}{R} = \frac{0.075}{75 + 75} = 0.5\text{mA}$$

That is, only half the current would flow through the ammeter. Obviously, we would prefer the first of these two situations if we want to measure 1mA current. Or else, **the internal resistance of the ammeter has to be very low.** Therefore, to get an accurate current reading, you have to select an ammeter of appropriate range.

Table 6.1 shows some ammeter ranges along with their internal resistances.

Table 6.1: Typical ranges of ammeters

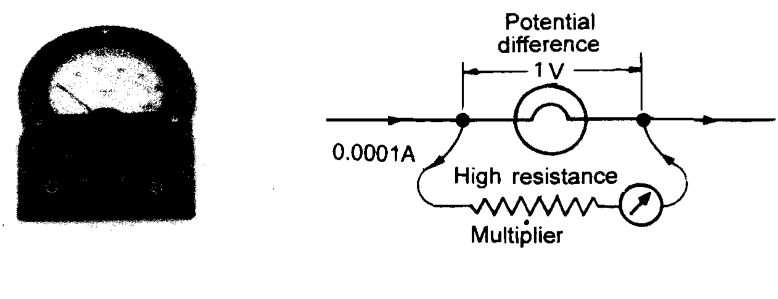
Type	Order of current measured	Internal resistance
Ammeter	Ampere (A)	Up to 0.001Ω
Milliammeter	Milliampere (10^{-3}A)	up to 1Ω
Microammeter	Microampere (10^{-6}A)	Thousands of ohms

- **In order to maintain ammeters properly, you have to take the same precautions as for galvanometers.**
- **You should take care not to connect a low resistance in parallel with the ammeter while measuring current in the circuit.** Can you explain why? This is to avoid most of the current flowing through the low resistance.
- Always connect **an ammeter in series in a circuit** in a manner that **its terminal marked (+) is connected to the positive end of the *DC* power source**. Otherwise it may get damaged.

Apart from current, we also need to measure **potential difference** across two points in a circuit using a **voltmeter**. We now discuss voltmeters. Like ammeters, there can be both digital voltmeters and analogue voltmeters in physics labs. Here we discuss only analogue voltmeters.

C. Voltmeters

Fig.6.3a shows an analogue voltmeter as it looks from outside. It is essentially a galvanometer having a known high resistance in series with it (Fig.6.3b). It is denoted by the symbol —(V)— in a circuit.



(a) (b)

Fig.6.3: a) An analogue voltmeter; b) a galvanometer with a high resistance in series with it acts as a voltmeter

Ideally, **a voltmeter should have infinite resistance so that the current through it is zero and there is no voltage drop across it**. Only then it will not affect the voltage being measured. However, in practice this is impossible and an acceptable value is around 20,000Ω per V at full-scale deflection.

Suppose we want a voltmeter capable of measuring a maximum voltage of 100V. Recall that a maximum of 1mA current can be allowed to flow through a typical galvanometer. This will be the current through the voltmeter when it is connected to measure 100V. Then using Ohm's law, we get

$$100\text{V} = (0.001\text{A})\,(R_s + 60\Omega)$$

where R_s is the internal resistance of the voltmeter. Thus

$$R_s = 99{,}940\Omega$$

You will have to select an appropriate voltmeter of a given range depending on the order of the measurement. The same rules as for ammeter apply here. For example, if the voltage measurement is in the range 0–5V, you have to select a voltmeter of range 0–10V.

- The precautions for handling a voltmeter are the same as the ones for the galvanometer.
- **Do not connect any resistance in series with the voltmeter**. It will cause a finite voltage drop across the arm containing the voltmeter and affect the voltage reading.
- Always connect a voltmeter in parallel with the part of the circuit across which the voltage is to be measured, in a manner that its terminal marked (+) is connected to the positive end of the *DC* power source.

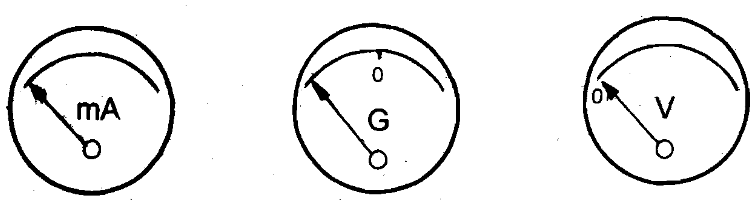
You may now like to pause for a while and reinforce these ideas with an exercise.

SAQ 1: Current and voltage measuring instruments

a) Identify the meter to be used for each of the following tasks and draw their symbols:

i) detecting 0.1mA current
ii) measuring 10V potential difference
iii) measuring 1A current
iv) detecting 0.1V voltage

b) Select from amongst the following meters, the appropriate meters for detecting 0.1mA current, measuring maximum 2mA current, measuring maximum 50V potential difference.



(i) (ii) (iii)

In a physics lab, you will also have to use a **multimeter** for a variety of purposes, e.g., to check whether different devices and components are in working order; to check continuity of wires etc. You will be doing these activities in Experiment 6. Here you will learn what a multimeter looks like and what its functions are.

6.2.2 Multimeter

As the name suggests, mulitmeter is a multipurpose instrument designed to:

- measure resistances, capacitances, *DC* and *AC* voltages and currents in several ranges,
- check continuity of a wire, and
- test capacitors, *pn* junction diodes and bipolar junction transistors.

We have both digital and analogue multimeters now-a-days (Fig.6.4). From the point of view of use there is only one difference between analogue and digital meters. In analogue meters, the reading is taken as a graduated pointer moves across a scale. In digital meters, the reading is directly displayed in the form of numbers on a window.

Refer to Fig.6.4. On the front panel of a typical multimeter there is an ON-OFF switch. There is also a dial type switch or push button type switch for range selection and markings in various ranges for

- Resistances and/or capacitances,
- Direct and alternating voltages,
- Direct and alternating currents.

There is also a socket for testing *pnp* and *npn* transistors in some multimeters.

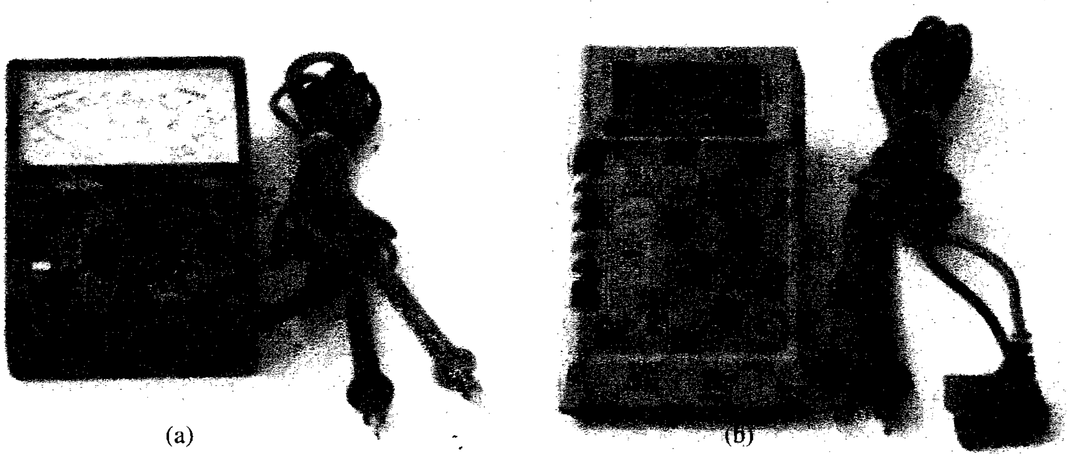


Fig.6.4: a) An analogue multimeter; and b) a digital multimeter

For resistance measurements, there is an internal source of current. This is usually a dry battery with a terminal voltage of 1.5 to 15V depending on the range of measurement. In analogue multimeters (Fig.6.4a) there is a knob for zero adjustment. It is used for adjusting the pointer on the scale of the multimeter to set the initial reading to zero. The scale of an analogue multimeter has graduated markings for resistances, alternating and direct currents and voltages.

For a given setting of the range selector switch, the maximum value in that range corresponds to full scale deflection of the pointer. For example, suppose you have set the range selector switch for resistance measurement in the range 0–1kΩ. Then the resistance reading corresponding to the full scale deflection of the pointer will be 1 kΩ. You will appreciate this idea better when you use a multimeter in Experiment 6.

In both analogue and digital multimeters, there are terminals marked VΩ and *DC* 10A for connecting the positive (red) lead and a terminal marked COM for connecting the negative (black) lead. These two leads are supplied with every multimeter. You will learn how to use a multimeter in Experiment 6. So we will not go into those details here.

While handling a multimeter, you should

- take all precautions mentioned for galvanometer, ammeter and voltmeter;
- take care not to short circuit the battery inside the multimeter;
- keep the power switch off when not taking any measurements; and
- handle a multimeter with care and store it in a cool, dry and dust free environment.

The multimeter is a sensitive and expensive instrument. So if you have any confusion about using it, consult your counsellor or read the multimeter manual available in the lab.

You may now like to attempt an SAQ to fix these ideas.

SAQ 2: Using a multimeter

a) Which one of the following tasks can only be done by a multimeter, and no other electrical instrument that you have studied so far?

   i) Measuring currents
   ii) Measuring voltages
   iii) Testing a capacitor
   iv) Detecting current in a circuit

b) Suppose you have set the range selector switch for a direct current reading in the range 0 to 1A. What is the reading when the pointer is exactly at the midpoint of the scale?

Let us now learn about some commonly used circuits for measuring resistances in a school or UG lab, namely, Wheatstone bridge, Post-office box, metre bridge and potentiometer.

6.2.3 Wheatstone Bridge, Post-office Box, Metre Bridge and Potentiometer

The Post-office box, metre bridge and potentiometer essentially work on the principle underlying the Wheatstone bridge arrangement. Therefore, we first discuss the Wheatstone bridge.

A. Wheatstone bridge

The Wheatstone bridge is an arrangement of four resistances connected as shown in Fig.6.5. The advantage of this circuit is that if we know the values of three of the four resistances connected in it, we can determine the value of the fourth resistance to a high degree of accuracy.

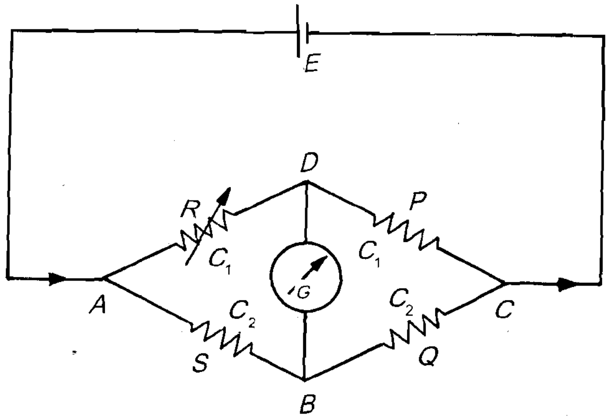


Fig.6.5: Wheatstone bridge arrangement used for resistance measurement

Refer to Fig.6.5. Suppose S is the unknown resistance that we wish to determine. Of the remaining three, R is an accurately known variable resistance and P and Q are accurately known fixed resistances. G is a sensitive galvanometer to detect current. **The idea then is to vary S until the current through G** becomes zero. This condition is called the **null condition**. In such a situation, **the Wheatstone bridge is said to be balanced**. Then we have

$$\frac{P}{Q}=\frac{R}{S} \tag{6.1}$$

or

$$S=\frac{QR}{P} \tag{6.2}$$

A Wheatstone bridge is most sensitive when the resistances in its four arms are of the same order. Therefore, while working with the Wheatstone bridge, you should take care of this aspect.

The precautions for handling and maintaining a Wheatstone bridge are the same as those for resistance boxes given in Unit 5.

The Post-office box is a special kind of Wheatstone bridge. It is called so because earlier it was used for locating faults in telephone and telegraph lines. Now-a-days it is used mostly in school laboratories and only rarely in UG laboratories.

B. Post-office box

In the Post-office box (Fig.6.6), the resistances P and Q of the Wheatstone bridge are in the form of small resistance boxes (between AB and BC) instead of fixed resistances. They have a set of resistance coils 10Ω, 100Ω and 1000Ω, respectively. The unknown resistance S is connected between the points C and D. R is the resistance between A and D and has a greater range of values from 1Ω to 10,000Ω. The resistances between A and D are so arranged that we can introduce any integral value from 1Ω to 10,000Ω in the circuit.

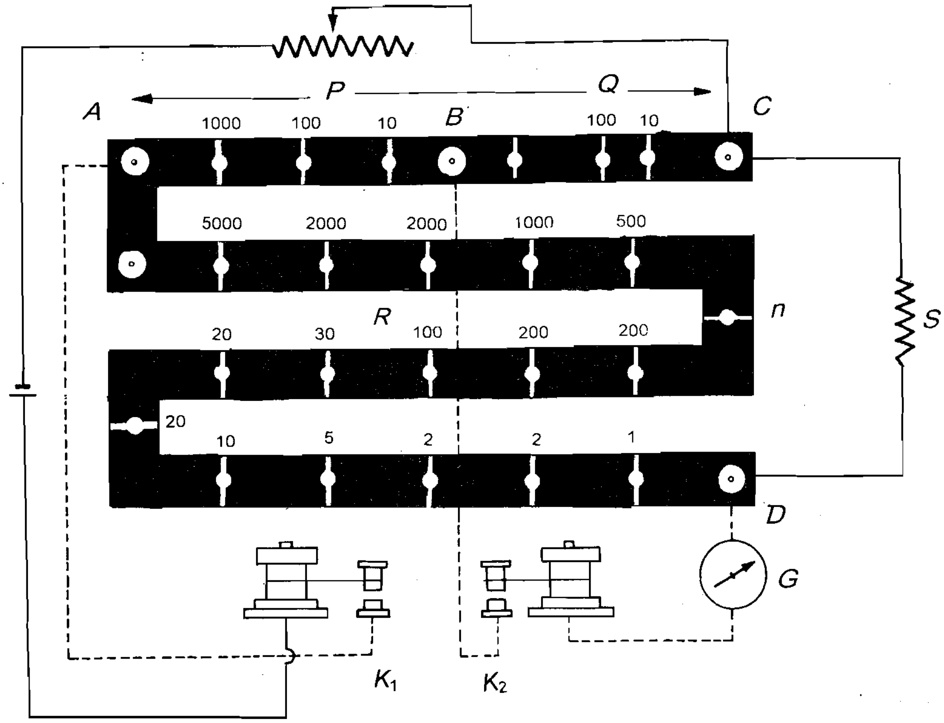


Fig.6.6: The circuit of a Post-office box for measuring resistance

How is the Post-office box connected in a circuit to measure the unknown resistance? See Fig.6.6. The battery and the rheostat are connected between the points A and C through a tapping key K_1. The galvanometer is connected between B and D through the tapping key K_2. The Post-office box functions like the Wheatstone bridge and is balanced for zero current through the galvanometer. The value of the unknown resistance is calculated using Eq. (6.2).

For maintaining a Post-office box, you have to follow the same instructions as for resistance boxes.

Let us now consider the metre bridge and the potentiometer which are also based on the same principle.

C. Metre bridge

The metre bridge (Fig.6.7) consists of a uniform resistance wire AC of length 1m. It is mounted along a scale S on a wooden board. Three thick copper strips

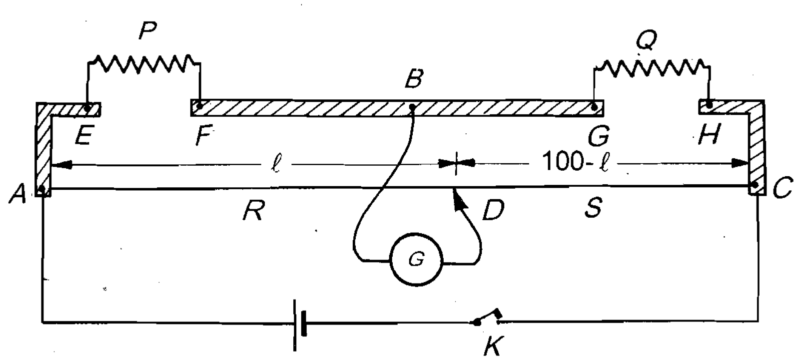


Fig.6.7: Resistance measurement by a metre bridge

AE, *FG* and *HC* are also mounted on the same board. A known fixed resistance *P* is connected across *E* and *F* and the unknown resistance *Q* is connected across *G* and *H*. The remaining two resistances *R* and *S* are obtained by dividing the wire into two parts with the help of a sliding key or jockey *D*. The galvanometer is connected across *B* and the cell across *A* and *C*. The bridge is balanced by moving *D*.

The value of the unknown resistance is obtained from the relation:

$$\frac{P}{Q} = \frac{R}{S} = \frac{\text{resistance of } AD}{\text{resistance of } DC} = \frac{L}{100 - L}$$

where *L* is the length of *AD*. Hence,

$$Q = \frac{P(100 - L)}{L} \qquad (6.3)$$

D. Potentiometer

The potentiometer commonly used in physics labs is shown in Fig.6.8. It consists of a long thin uniform wire of high resistance and length 4 or 5 m. The wire is usually made of manganin. The length of the wire is divided into a number of equal segments of 1m length. These are connected in series by thick copper strips which offer negligible resistance. The null point is obtained in a potentiometer with the help of a jockey or a sliding key. The metre scale *M* placed along the wires is used to find the length of the wire used in any measurement. The potentiometer is a very sensitive device used for measuring resistance, and measuring or comparing the emfs of two given cells.

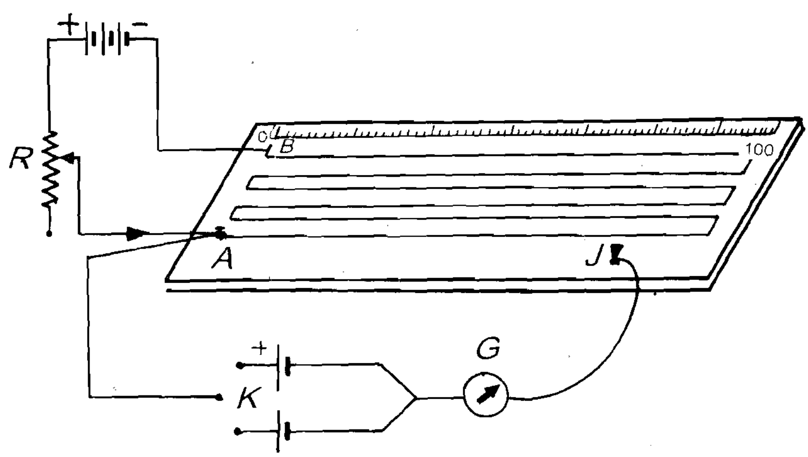


Fig.6.8: A potentiometer

While handling a potentiometer you should

- take care that the wire in it is uniform and does not develop any kinks; and
- keep all contacts in it clean and free of dust.

You should now stop for a while and revise what you have studied in this section by doing the following SAQ.

SAQ 3: Resistance measurement

a) What steps should you take in maintaining the Wheatstone bridge and Post-office box?

b) From amongst the following, select the measurements that can be made by a potentiometer:

i) direct current through a resistance
ii) emf of a cell
iii) alternating current in a circuit

c) Why should you take care that the wire in a metre bridge remains uniform?

Hint: Recall the discussion on resistances in Sec. 5.2 of Unit 5.

So far you have studied about some common electrical instruments found in every physics lab such as galvanometers, ammeters, voltmeters, multimeter, Wheatstone bridge, Post-office box, metre bridge and potentiometer. You have learnt how each one of them looks, for what purposes it is used in the lab and how to maintain it. You will also be required to handle some electronic devices and instruments in a physics lab. You should, therefore, learn about them.

6.3 ELECTRONIC DEVICES

Recall from Sec. 5.2 that each material is characterised by a parameter called **resistivity** or its inverse called **conductivity**. The conductivity is high for good conductors and low for insulators. The resistivity of a good conductor is low and that of an insulator is high. There are materials called semiconductors whose resistivity lies between the resistivities of conductors and insulators. In their pure form and at room temperatures, most of these materials do not conduct current. But under certain conditions they are not as bad conductors as insulators either. Hence they are termed **semiconductors**. The pure semiconductors are called **intrinsic semiconductors**.

Now-a-days semiconductors are used in a wide variety of electronic devices. The most common of these devices are *pn* junction diodes and *pnp* and *npn* transistors. Most of the domestic electronic appliances used today, e.g., radio receivers (commonly known as transistors), television sets, computers, ovens etc., use electronic circuits containing these devices. In laboratories, they are used in power supplies, oscillators, counters, amplifiers and many other instruments. So we will discuss them very briefly.

Let us first understand the meaning of the symbols *p* and *n*.

The conductivity of a pure semiconductor can be increased manifold by adding impurities in it. This process is called **doping**. Two types of semiconductors are obtained in this manner:

- When an intrinsic semiconductor is doped with elements that introduce excess electrons for conduction, it is called an *n*-type semiconductor.

- When an intrinsic semiconductor is doped with elements that introduce vacancies of electrons called holes, it is called a *p*-type semiconductor. Holes also act as current carriers.

If you are interested in further theoretical details, you may read the +2 NCERT textbook in physics.

In themselves, *p*-type and *n*-type semiconductors act as resistors. However, combinations of these semiconductors result in interesting devices with new properties. Here we consider two devices, namely, the *pn* junction diode and the bipolar junction (*pnp* and *npn*) transistors.

6.3.1 The *pn* Junction Diode

When impurities are introduced in a small crystal of semiconductor so that one half of it is *p*-type and the other half is *n*-type, a *pn* junction diode is formed. In Fig.6.9a we show what a *pn* junction diode looks like from outside. Its symbol is shown in Fig.6.9b. The border between *p*-type and *n*-type semiconductors is called the *pn* junction. The *p*-side acts as an anode and the *n*-side as a cathode. Let us understand the action of a *pn* junction diode when it is in forward bias and in reverse bias.

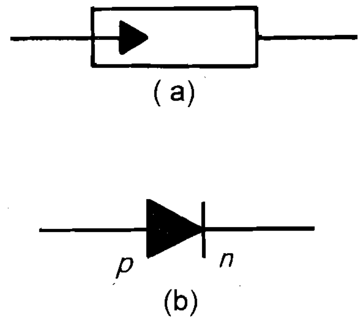


Fig.6.9: a) The *pn* junction diode; and b) its symbol. The arrow shows the direction of current flow when the diode is forward biased

A. Forward bias

In Fig.6.10, a *DC* source is connected across the diode so that its *p*-end is connected to the *positive terminal* of the battery and the *n*-end to the *negative terminal*. This connection is called the **forward bias**.

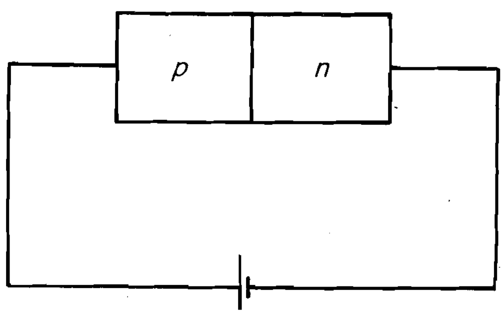


Fig.6.10: A forward biased *pn* junction diode

Current flows easily when the diode is forward biased as it offers low resistance. As the voltage across the forward biased diode is increased, the current in the circuit increases. The magnitude of the current is in the range of a few milliamperes in this case.

You may like to know what happens when the terminals of the *DC* source are reversed. Let us find out.

B. Reverse bias

In **reverse bias**, the negative terminal of the battery is connected to the *p*-side and the positive terminal to the *n*-side (Fig.6.11). What happens in this case?

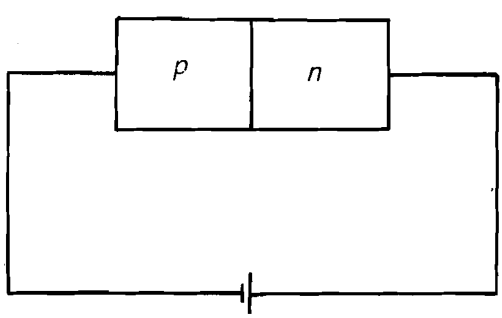


Fig.6.11: A reverse biased *pn* junction diode

A very small current of the order of microamperes flows in the circuit since the diode offers high resistance. This reverse current is called **saturation current.** Even if we increase the reverse voltage, the saturation current does not increase. Since the diode allows current to flow only in one direction, it also acts as a **rectifier**.

You may wonder why reverse saturation current is so small. This is because it arises due to the flow of minority charge carriers (electrons in the *p*-type and holes in *n*-type semiconductors) which are very small in number. You can study the details in the reference book.

Note that there is a limit to which the reverse voltage can be increased. This limit is given in the form of **maximum voltage rating** of the diode. If we increase the reverse voltage beyond this limit, the diode is destroyed. The Zener diode is a special kind of *pn* junction diode which is used in the reverse bias for voltage regulation purposes. Here we will not go into the details of why this happens. Diodes also have **maximum power ratings** which limit the maximum allowed current in a diode. Depending on the ratings, diodes are given different codes. The ratings for different diodes are either given in manuals or are available in the laboratory. You will need to confine within these ratings when using the diode.

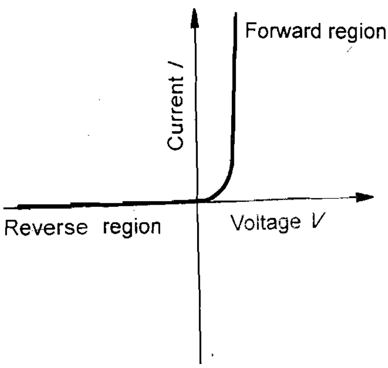


Fig.6.12: The *IV* characteristics of a *pn* junction diode

The variation of the flow of current across a *pn* junction diode is called its *IV* characteristic. It is shown in Fig.6.12. The *IV* characteristic of the diode helps us in identifying which end of the diode is *p* type and which one is *n* type. Using them we can also find out whether or not a diode is in working order. In Experiment 6, you will learn how to check a *pn* junction diode and how to identify its *p*-end and *n*-end. These are two things you will be doing often. So take care **never to exceed diode ratings**. You can find out these ratings from the counsellors in your lab.

You may now like to try an SAQ to revise these ideas.

SAQ 4: The *pn* junction diode

a) Identify the kind of biasing (unbiased, forward, reverse) of a junction diode for each of the figures given below. In which case is the current highest?

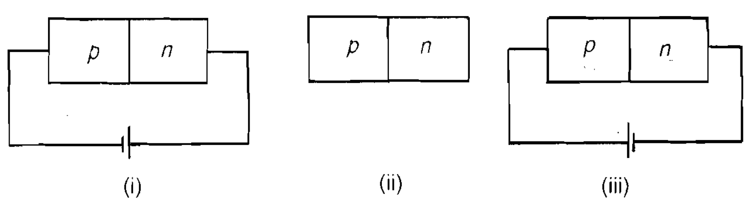


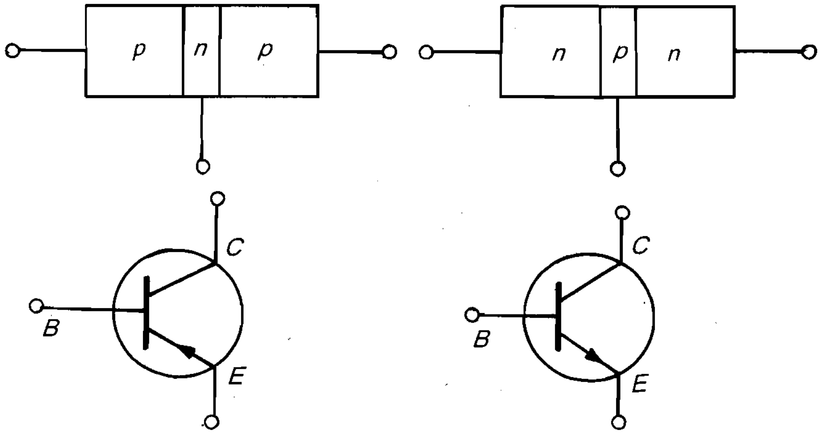
Fig.6.13

b) State the precautions you should take to prevent a *pn* junction diode from getting damaged.

We now discuss the *pnp* and *npn* transistors. These are also called the bipolar junction transistors.

6.3.2 Bipolar Junction Transistors

A bipolar junction transistor is a three terminal device (Fig.6.14a). These terminals are connected to layers which are in the *pnp* or *npn* configuration (Fig.6.14b). The first letter (in *npn* or *pnp*) designates the **emitter** (*E*), the middle letter, the **base** (*B*) and the third letter, the **collector** (*C*). The base is sandwiched between the emitter and the collector. You will note that the emitter and collector are of the same type. Does this mean that we can interchange the collector and the emitter? No, we cannot because they differ in the levels of doping. The emitter is more heavily doped in comparison with the collector. The **base** is lightly doped and thin.



(a) (b)

Fig.6.14: a) A *pnp* transistor; and b) an *npn* transistor alongwith their symbols

Note that the transistor has two *pn* junctions: one between emitter and base (called the *emitter diode*) and another between base and collector (called the *collector diode*). We will explain transistor action only briefly. See Fig.6.15. Note that the emitter diode is forward biased resulting in a high current and low resistance. The collector diode is reverse biased resulting in a high resistance. This is where the name transistor (short form of transfer resistor) comes from: it transfers a low resistance to high resistance.

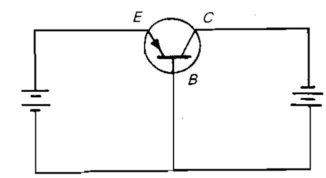


Fig.6.15: The common base configuration in which base is common to emitter and collector

Since the collector region offers higher resistance, and the current in the collector region is almost equal to that in the emitter region, the voltage at the output is higher than that at the input. This is how a transistor acts as an **amplifier**.

Transistors are used to amplify voltage and power. A variety of transistors are used in these applications. Each transistor is characterised by a specific code according to its application and ratings. In a UG physics lab transistors are used for voltage amplification. In the lab you will be usually required to identify the three terminals of the transistor. You will learn how to do this in Experiment 6.

The transistor is a delicate device and you should be cautious while handling it. You should never exceed its breakdown voltages, maximum current and maximum power ratings. You can ask about the ratings of the transistor from your counsellor in lab sessions. The most common troubles in transistors are a collector-emitter short, (i.e., zero resistance) produced by exceeding the power rating. Normally, the collector-emitter resistance is very high and the base-emitter resistance is low. You can use this information to test whether or not a transistor is in working condition. You will be doing this in Experiment 6 using a multimeter.

So far you have studied about electrical instruments and electronic devices. We now consider some common electronic instruments used in a UG laboratory.

6.4 ELECTRONIC INSTRUMENTS

Although there are many types of electronic instruments in a physics laboratory, the cathode ray oscilloscope (CRO), the power supply and the signal generator are used most commonly. A power supply is used in practically every experiment in electricity and electronics. In experiments where we have to determine the amplitudes, frequencies and wave forms of alternating voltages and currents supplied by a signal generator, we use CROs. Therefore, you should know how to work with these instruments.

A. Power supply

In almost all experiments on electricity and electronics, we need a *DC* power source. You know that the most commonly available *DC* power source is a dry cell or battery. However, it turns out to be an expensive source because it has to be replaced once it is exhausted. Therefore, it is common to use power supplies for these experiments.

A *DC* power supply converts alternating signal from the *AC* mains into a direct one and provides constant direct voltage at its output. A typical power supply used in a UG laboratory is shown in Fig.6.16. It provides a constant direct voltage between the range 0-30V at currents up to 500 mA.

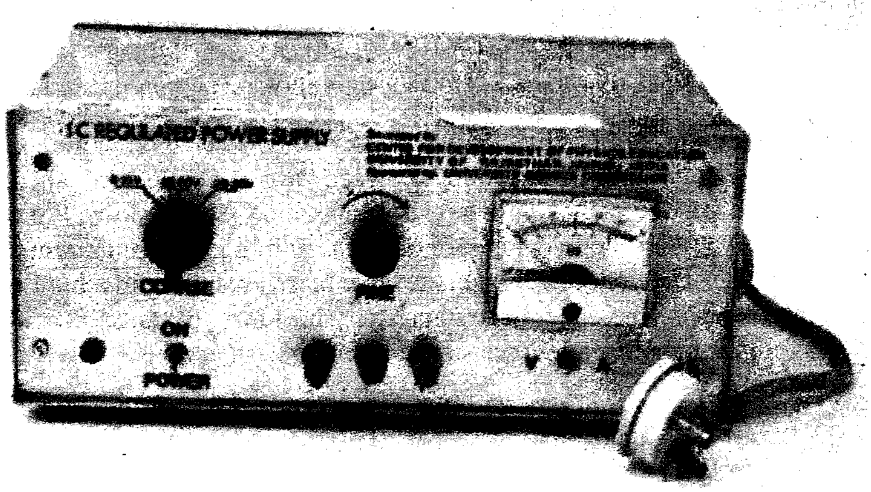


Fig.6.16: A typical power supply

On the front panel of the power supply, there is an ON-OFF switch and terminals marked *DC* output. The voltage to any circuit is supplied from these terminals. There are two knobs for varying the output voltage and current. There is usually a voltmeter and sometimes an ammeter with appropriate scale markings. Suppose you set the current control knob in the 0–50mA range, the full scale deflection will be 50mA and the least count of the ammeter will be 5mA. What would the least counts in the ranges 0–100mA, 0–250mA and 0–500mA be? These would be 10mA, 25mA and 50mA, respectively. Usually, a power supply is designed to operate at a mains voltage of 220V± 10%.

When you want to use the power supply in any circuit, always turn the output control knob to the extreme left position. Then turn the mains switch ON and only after a short warm up time, turn the power supply switch on. When you have completed the experiment, first turn off the power supply switch and then the mains switch. This precaution prevents the power supply from being damaged due to induced currents. Also keep the power supply off when it is not being used in the circuit.

In order to maintain a power supply when not in use, observe the following precautions:

- Keep it away from humidity and high temperatures.
- Keep it dust free and covered.
- The ventilators provided in the power supply help in dissipation of heat generated inside. Therefore, you should not block them by keeping anything on them.

B. Signal generator

Signal generators provide alternating voltages and currents in a wide range of frequency (typically from 50 kHz to 50 MHz). They are essentially sine-wave oscillators which produce sinusoidal signals. On the front panel of a signal generator (Fig.6.17), you will find an ON-OFF switch and controls for varying the amplitude and frequency of the *AC* signal being generated. The frequency control may be in the form of switches which generate signals of specified frequencies. Or else, it may be a dial type which generates a signal of any frequency in the given range. The output from a signal generator can be drawn from the two terminals marked OUTPUT. Some signal generators have voltmeters on their panel to read the amplitude.

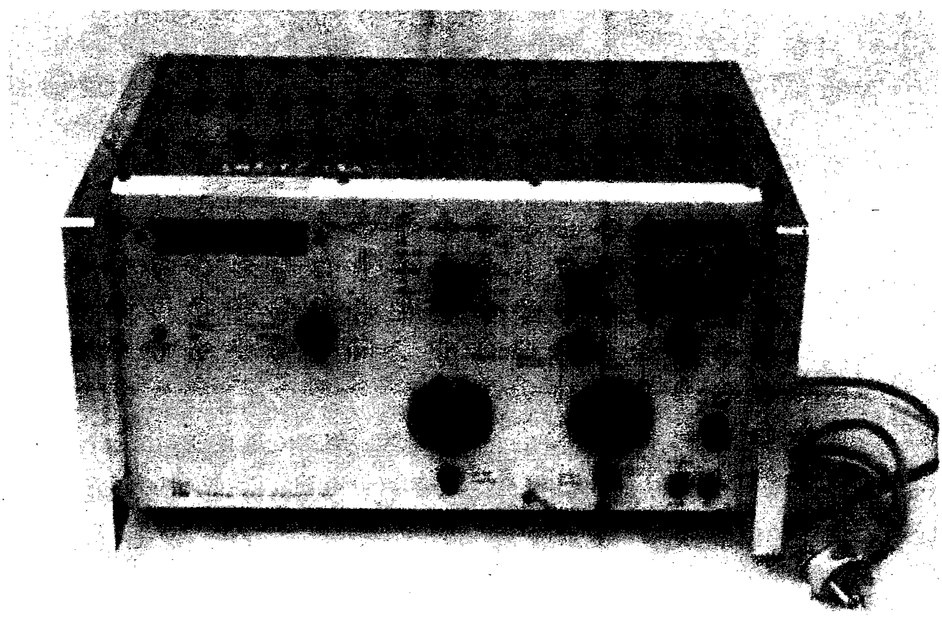


Fig.6.17: A typical signal generator

C. Cathode ray oscilloscope

Fig. 6.18 shows a typical CRO used in a UG physics laboratory. We briefly describe the controls on the display panel of the CRO in Fig.6.18. You will find similar controls on other CROs though they may be located at different positions on the panel.

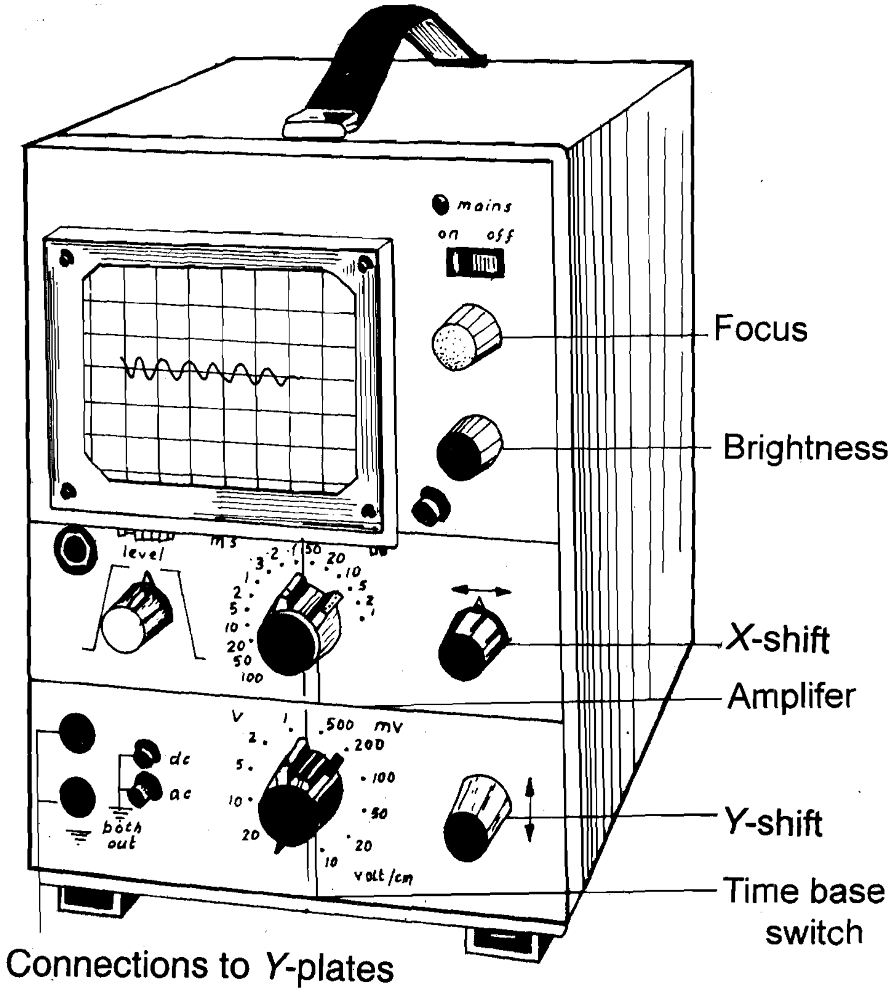


Fig.6.18: A Cathode Ray Oscilloscope with an AC voltage displayed on its screen

Notice that there is an ON-OFF switch at the top. On the left bottom of the panel, there are two input terminals. The *AC* signal is applied at these terminals. The display panel has a screen on which we can see the shape of the applied signal.

There is a control called **focus** beneath the ON-OFF switch. As its name suggests, it enables us to focus the signal and obtain its clear and sharp image.

Brightness is the knob which when adjusted increases or decreases the brightness or brilliance of the signal.

The knobs marked **x-shift** and **y-shift** are used to shift the images of the signals on the x-axis and the y-axis, respectively. By adjusting these knobs, we can bring the image of the signal to the centre of the screen.

The **time-base switch** is adjusted to obtain an appropriate setting on the time axis, i.e., the x-axis so that the time period of the applied signal can be measured easily.

The **amplifier** control is adjusted to obtain an appropriate setting on the y-axis so that the amplitude of the applied signal can be measured easily. You will learn how to use these knobs in Experiment 9.

In some CROs there is an *AC/DC* selector switch which allows them to measure both alternating and direct signals.

While handling and maintaining a CRO, you should take the following precautions.

- Set the brightness, focus, x and y-shift controls to their mid positions. Then, adjust the time base and amplifier controls to suit the input signal.
- Keep the brightness control **as low as possible**. Do not make the image excessively bright. When no current or voltage has been applied to the input you will see just a spot on the screen. Do not leave the spot stationary for a long time. In both these cases, the CRO screen may get burnt, damaging the material coated on it and shortening the life of the CRO. It is desirable to defocus the spot or adjust the time base control so that it is drawn out in a line.
- A CRO must not be stored in high temperature and high humidity for long times. When it is not to be used for a long time, you should wrap it up in a polythene sheet and put it in a cardboard carton.
- Use a simple dust cover to cover the CRO once the experiment is over.
- Do not put books, papers or any other thing on the CRO while using it as these may block its ventilation and lead to its getting heated up.
- Avoid striking the CRO screen with any hard object and exerting strong force on it, say while tracing a signal by a pencil. This may cause scratches on the screen.

Any maintenance problem relating to the working of the CRO should be handled by trained personnel. Never fiddle with it.

We now end this section with an SAQ.

SAQ 5: Electronic Instruments

List the functions of a

a) power supply,
b) signal generator, and
c) cathode ray oscilloscope.

Let us now summarise the contents of this unit.

6.5 SUMMARY

- A **galvanometer** is an instrument used to detect small currents up to 1mA and small voltages up to few mV. An **ammeter** is used for measuring current and a **voltmeter** for measuring voltage. Ammeters and voltmeters are available in different ranges in a physics lab.
- **Multimeter** is a multipurpose instrument used for measuring resistances, capacitances, currents and voltages, for testing the continuity of wire, and checking capacitors, pn junction diodes and bipolar junction transistors. It is also used to identify the p- and n-ends of a pn junction diode and the emitter, base, collector leads of a bipolar junction transistor. We can also

check whether these semiconductor devices are in working condition or not.

- The **Wheatstone bridge**, **Post-office box** and **metre bridge** are used to obtain accurate measurements of resistances. The **potentiometer** is used to measure potentials and compare emfs.

- A ***pn* junction diode** is a semiconductor device which conducts current only when it is forward biased. A **bipolar junction transistor** is a semiconductor device which amplifies alternating voltage, current and power.

- The **power supply** is a source of direct voltage and is used in almost all experiments requiring dc power source.

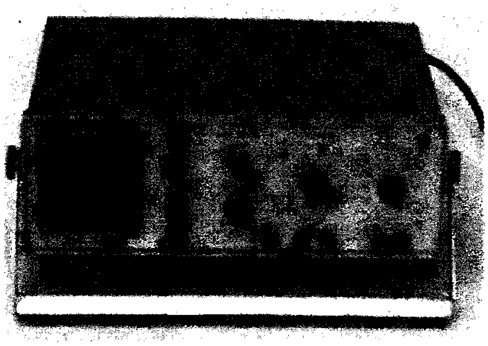
- The **signal generator** is used to provide sinusoidally varying alternating signals in electronics experiments in a wide range of frequency.

- The **cathode ray oscilloscope** is an electronic instrument used to display currents and voltages, measure their amplitudes and frequencies and trace their waveforms.

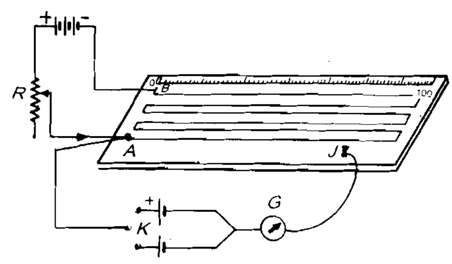
- In general, all electrical and electronic devices and instruments should be stored in cool, dry and dust free places which are well ventilated.

6.6 TERMINAL QUESTIONS

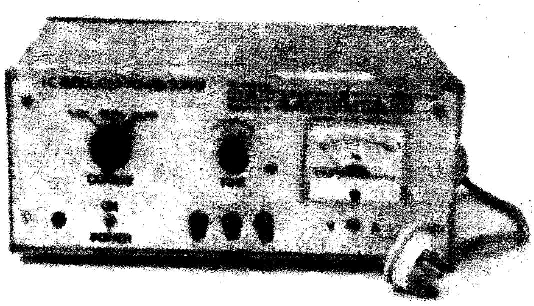
1. Identify each of the instruments shown below.



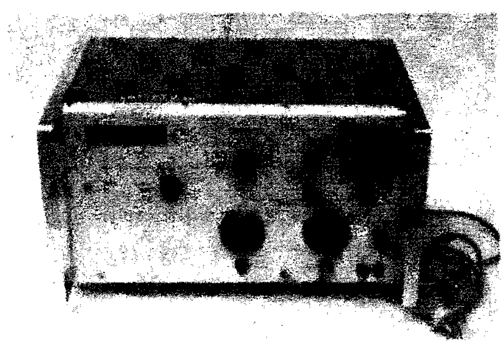
(a)



(b)



(c)



(d)

Fig.6.19: Some electrical and electronic instruments in a physics lab

2. Under what conditions can each of the following instrument get damaged and unfit for use?

   (a) Galvanometer
   (b) Cathode ray oscilloscope

3. Give a reason why you should not exceed the ratings given for a *pn* junction diode and a bipolar junction transistor.

4. Match the instruments listed in Column A with their functions listed in Column B.

Column A	Column B
1. Multimeter	(a) Determine time period and amplitude of an AC signal
2. Wheatstone bridge	(b) Provide DC power to a circuit
3. CRO	(c) Check continuity of a wire
4. Power supply	(d) Measure resistances to a high degree of accuracy
	(e) Detect the condition for zero current in a circuit

6.7 SOLUTIONS AND ANSWERS

Self-assessment Questions

1. a) i) galvanometer —(G)—
   ii) voltmeter —(V)—
   iii) ammeter —(A)—
   iv) galvanometer —(G)—

   b) (ii), (i), (iv), (iii)

2. a) (iii)
   b) 0.5A

3. a) See Sec. 5.2.1, Unit 5. Write the same precautions here.
   b) (ii)
   c) If the wire develops kinks or becomes non-uniform, its resistance will not be the same throughout its length as per Eq. (5.3).

4. a) (i) Reverse biased (ii) unbiased (iii) forward biased
   The current will be highest for (iii).

   b) The maximum forward and reverse voltage and power ratings of a diode should not be exceeded as this will damage the diode.

5. a) To provide DC signal in electrical circuits

   b) To provide AC signal of sinusoidal form in circuits

   c) To measure the amplitudes and time period of ac currents and voltages, to trace the waveforms of these signals.

Terminal Questions

1. (a) CRO, (b) potentiometer, (c) power supply, (d) signal generator.
2. a) When huge current flows through it or the magnet gets demagnetized.

   b) When operated in conditions of high humidity and high temperature; when the spot is left for a long time on its screen.
3. To prevent them from getting damaged due to overheating.
4. 1) c 2) d 3) a 4) b

EXPERIMENT 7

FABRICATION OF AN EXTENSION BOARD

Structure

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 × 15cm × 4cm), good quality 5m three-core electric wire of 20 gauge, 2 two-in-one (5A and 15A) sockets, 1 three-pin plug (15A); 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.

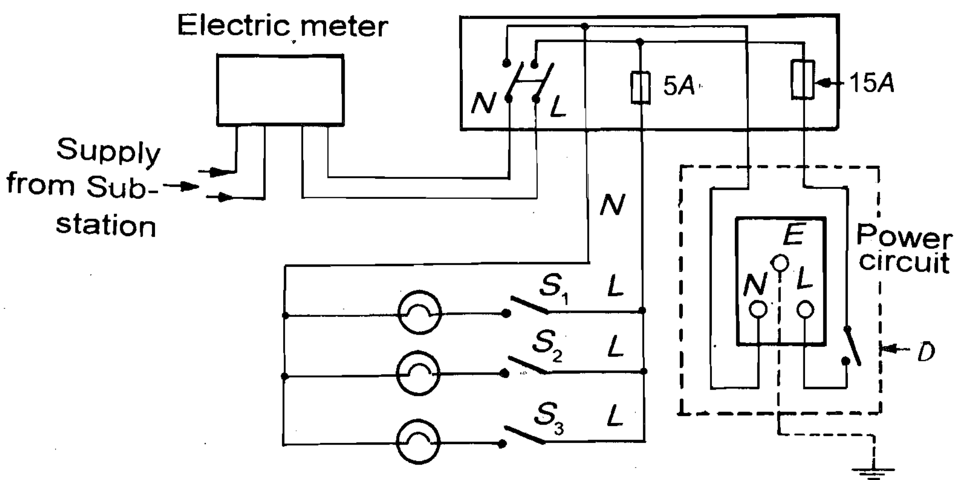


Fig.7.1: A typical laboratory wiring system

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

a) The switch such as S_1 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 margin remark on page 57). 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*.

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.

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

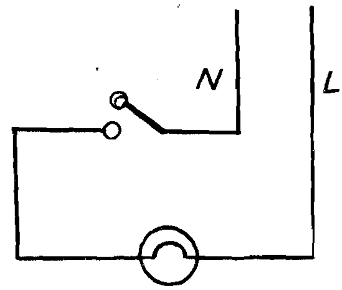


Fig.7.2: Portion of laboratory wiring

The switch for the light point has been placed along the neutral (*N*) 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.

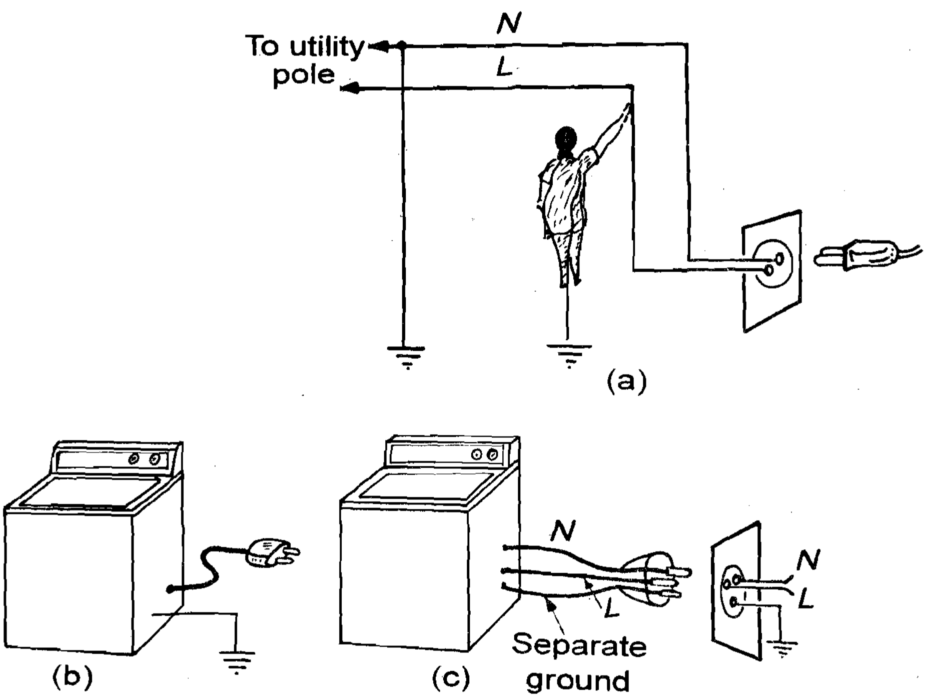


Fig.7.3: a) Human body provides low resistance path for electric current; b) and c) the two ways of earthing an electrical appliance.

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).

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 margin remark), 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.

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

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

and by a 3 kW electric heater as

$$\text{Current} = \frac{3000\,\text{W}}{220\,\text{V}} = 13.6\,\text{A}$$

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 $\frac{2000\,\text{W}}{220\,\text{V}} = 8.7\,\text{A}$ current from the mains supply.
ii) **5 A, 220 V**: This power rating straight away gives the value of the maximum current (5A) the appliance/equipment will draw from the mains supply at 220 V.

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 15A 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, 3/20 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. Now-a-days, 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 in a circuit.

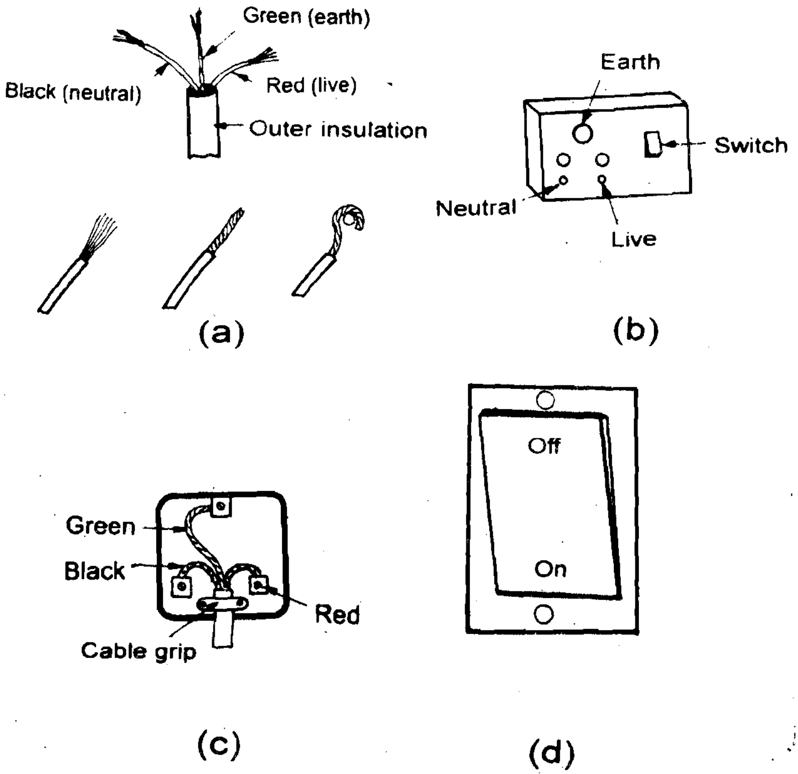


Fig.7.4: a) Three-core electric wire; b) two-in-one three-pin socket; c) three-pin plug; and d) 15A switch

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 SAQ.

SAQ 1

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 independent switches.

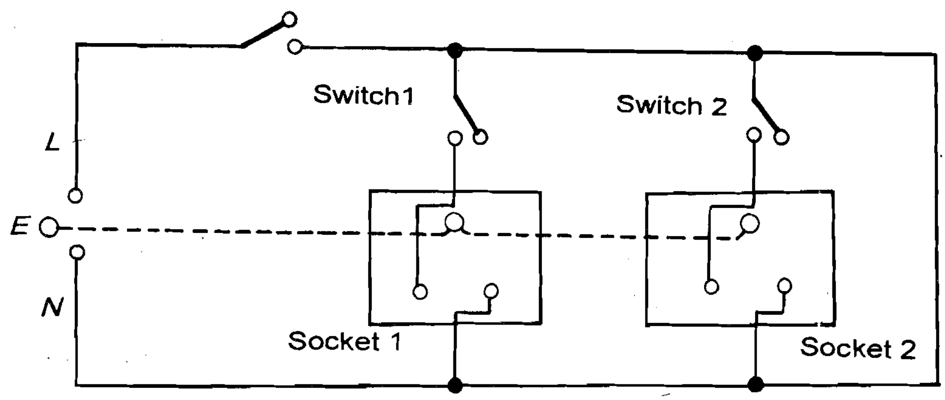


Fig.7.5: Circuit diagram of an extension board

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.

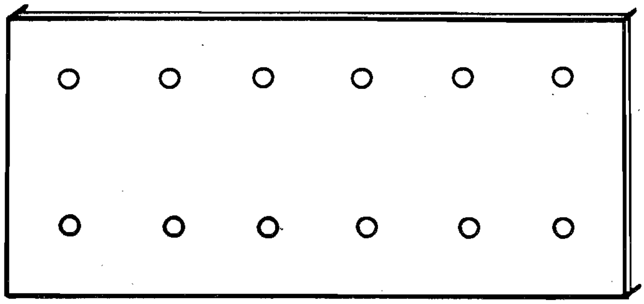


Fig.7.6: Fixing of sockets and switches on the extension board

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).

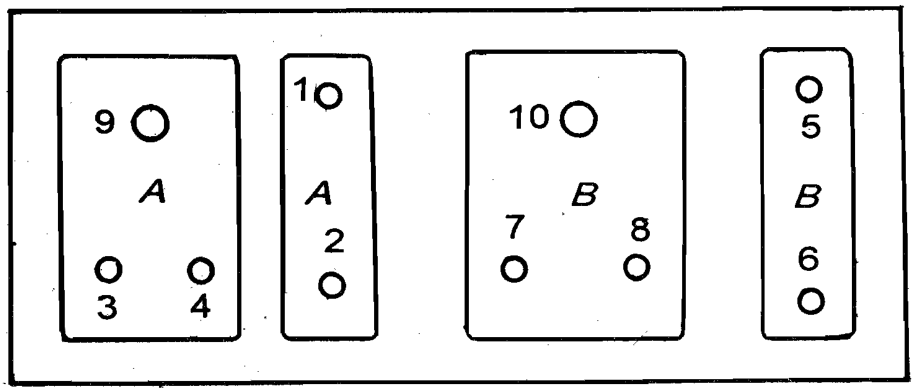


Fig.7.7: Labelled circuit diagram of the extension board

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 consellor. 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 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 upto 1mm. Similarly, if we use a more precise device like vernier callipers to measure its thickness, the measurement may be good upto 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.

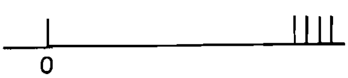


Fig.1.1: Random errors lead to a scatter of readings

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.

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

$$a_{mean} = \frac{a_1 + a_2 + a_3 + ... + a_N}{N} \qquad (1.1)$$

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

Ekta 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

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

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

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:

$$\Delta t_1 = 2.60 - 2.62 = -0.02\text{s}$$
$$\Delta t_2 = 2.59 - 2.62 = -0.03\text{s}$$
$$\Delta t_3 = 2.62 - 2.62 = \ \ 0.00\text{s}$$
$$\Delta t_4 = 2.65 - 2.62 = +0.03\text{s}$$
$$\Delta t_5 = 2.66 - 2.62 = +0.04\text{s}$$

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:

$$\Delta t_{mean} = \frac{0.02 + 0.03 + 0.00 + 0.03 + 0.04}{5}\text{s}$$
$$= \frac{0.12}{5}\text{s} = 0.02\text{s}$$

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 relative error **or percentage error**. *It is 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 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

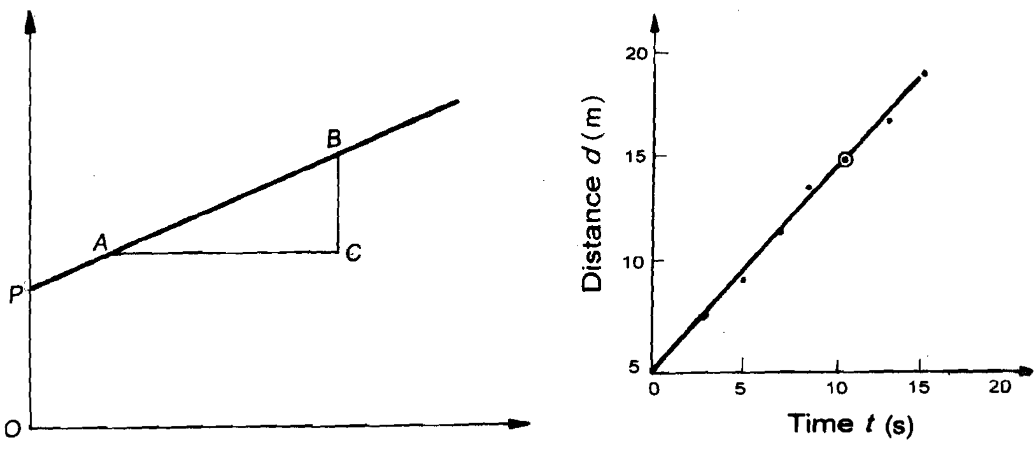
$$m = \tan\theta = \frac{BC}{AC}$$

and OP is its intercept.

If $y = A x^n$; 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 $\log A$.



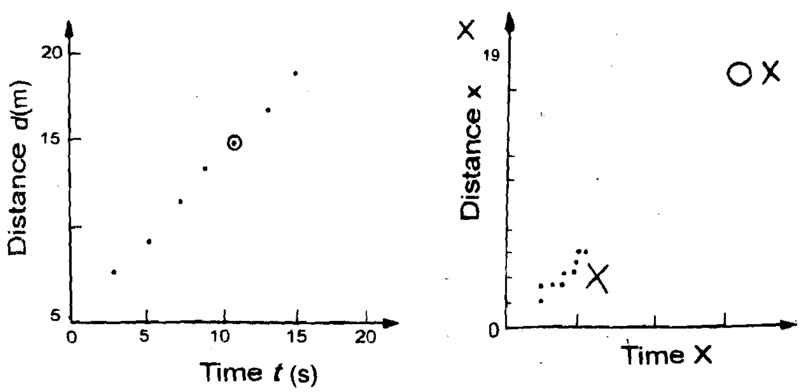
(a) (b)

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).



(a) (b)

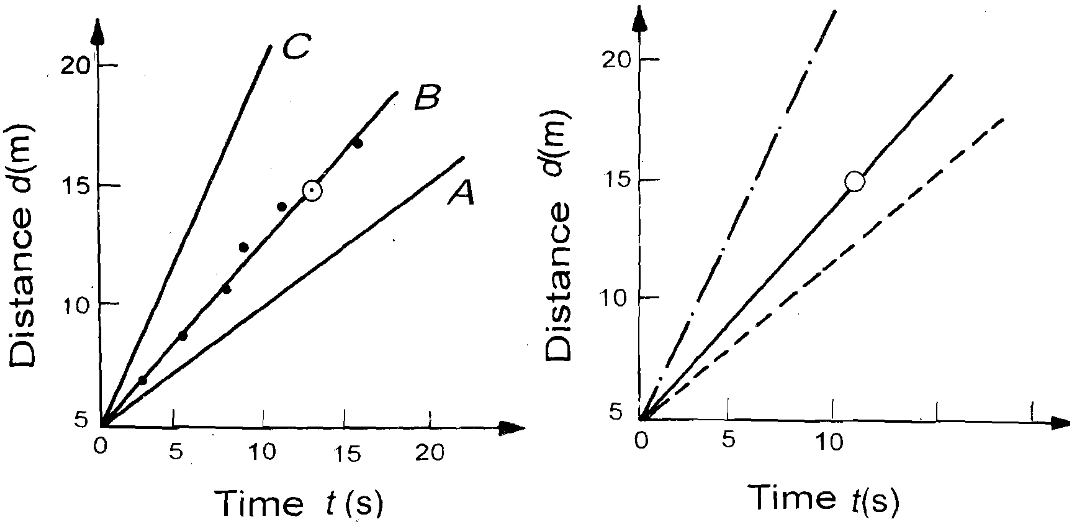
Fig.1.3: Some a) Dos and b) Don'ts to be kept in mind while drawing a graph

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, the size of this circle should exceed the size of the smallest square on the graph paper.

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).



(a) (b)

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.

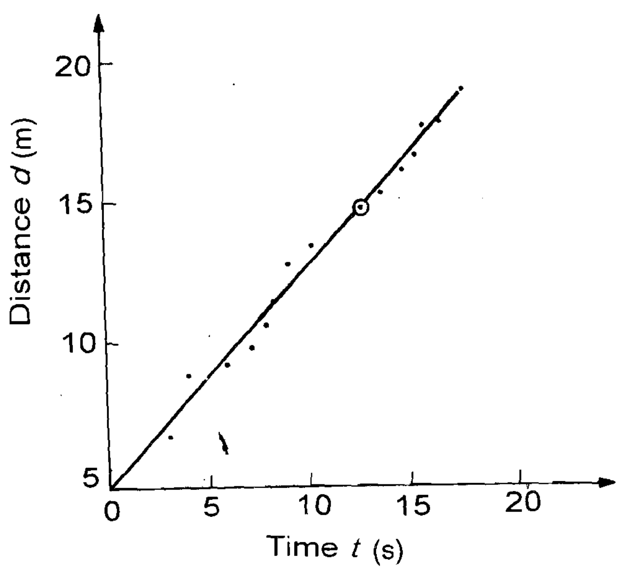


Fig.1.5: A mean fit curve

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 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.

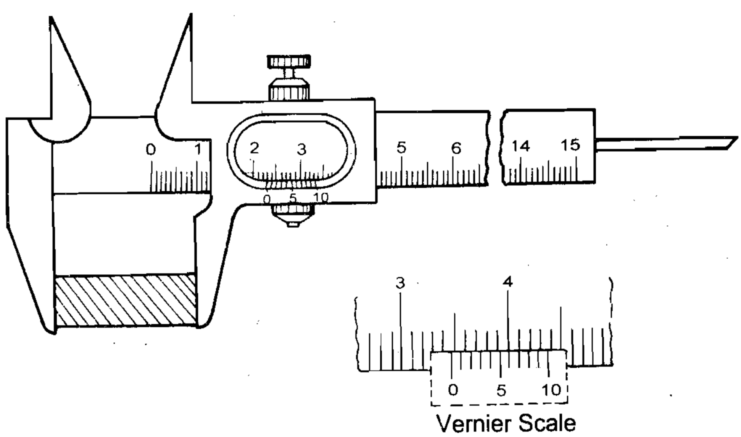


Fig.1.6: Measurement of the thickness of a block with a vernier callipers

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 × 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 × 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 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.

Observation Table 1.1: Measurement of thickness

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

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

S.No.	MS reading (cm)	Vernier reading	Thickness(cm)	
			Measured (=MS+LC×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 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

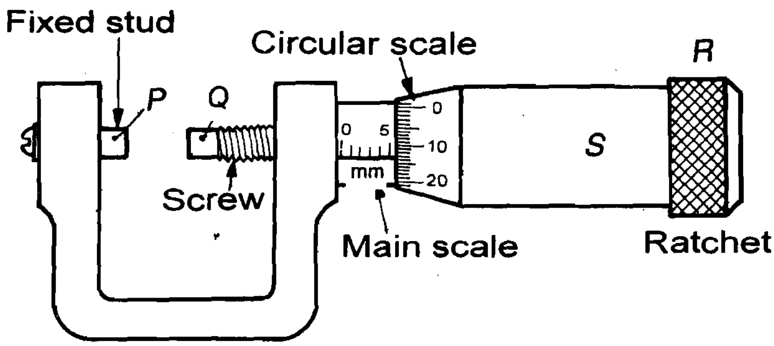


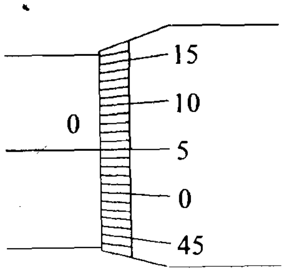
Fig.1.7: Measurement of thickness with a screw gauge

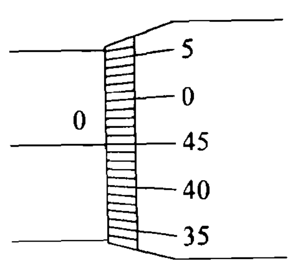
Refer to Fig.1.7, which shows a screw gauge. You will recall from Unit 3 that in a screw gauge, a screw moves in accurately cut grooves. But with constant use, there comes some wear and tear. As a result, it is also possible that there may not be forward linear motion of the screw until a certain rotation 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
- 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.)

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.





(i) ______________________, (ii) ______________________

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 (N) =
Least count of the screw gauge, $\frac{\text{Pitch}}{N}$ = mm
Zero error = ± mm

S.No.	Linear scale reading (cm)	Circular scale reading × 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 sitar, violin, ektara, veena, 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 this course 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.

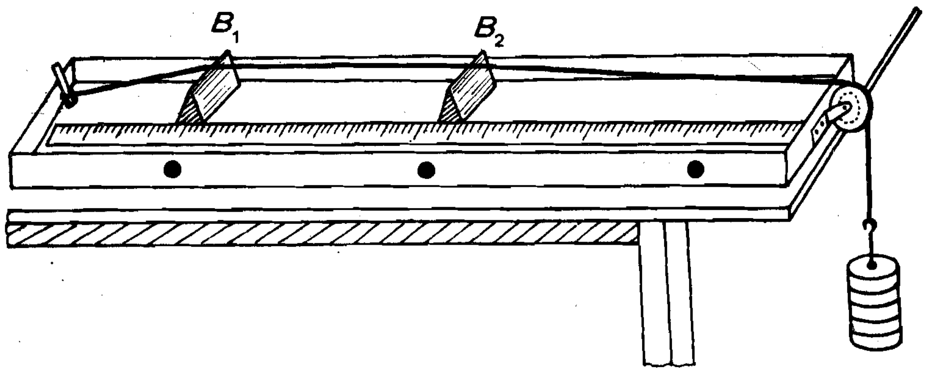


Fig.2.1: Experimental arrangement for setting up stationary waves in a sonometer wire

A kink free wire, pegged at one end passes over two wedge-shaped wooden bridges, B_1 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.

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 T 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 position 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

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

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.

Observatior 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 abovesaid 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 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

$$f_0^2 = \frac{T}{4\ell^2 m}$$

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

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

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 $\mathrm{J\,kg^{-1}\,K^{-1}}$.

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

$$\Delta Q = mc\,\Delta T \quad (3.1)$$

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 (J kg^{-1} 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

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.

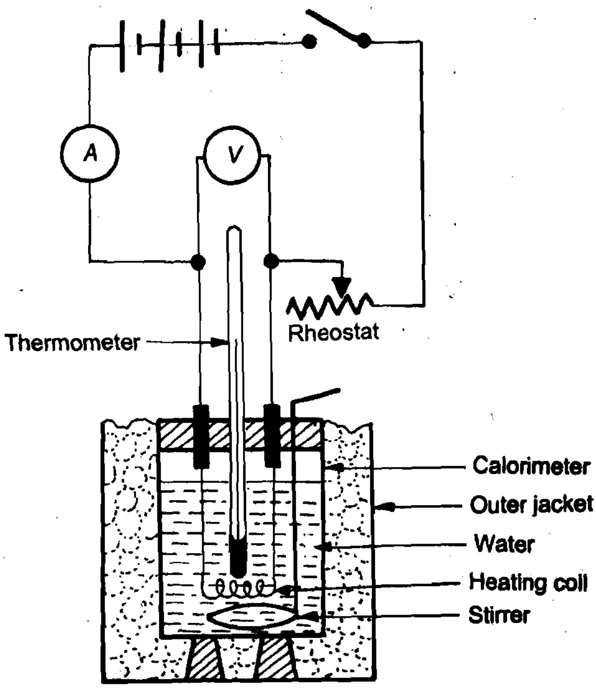


Fig.3.1: Experimental arrangement for specific heat capacity of water

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.

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 alongwith 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.

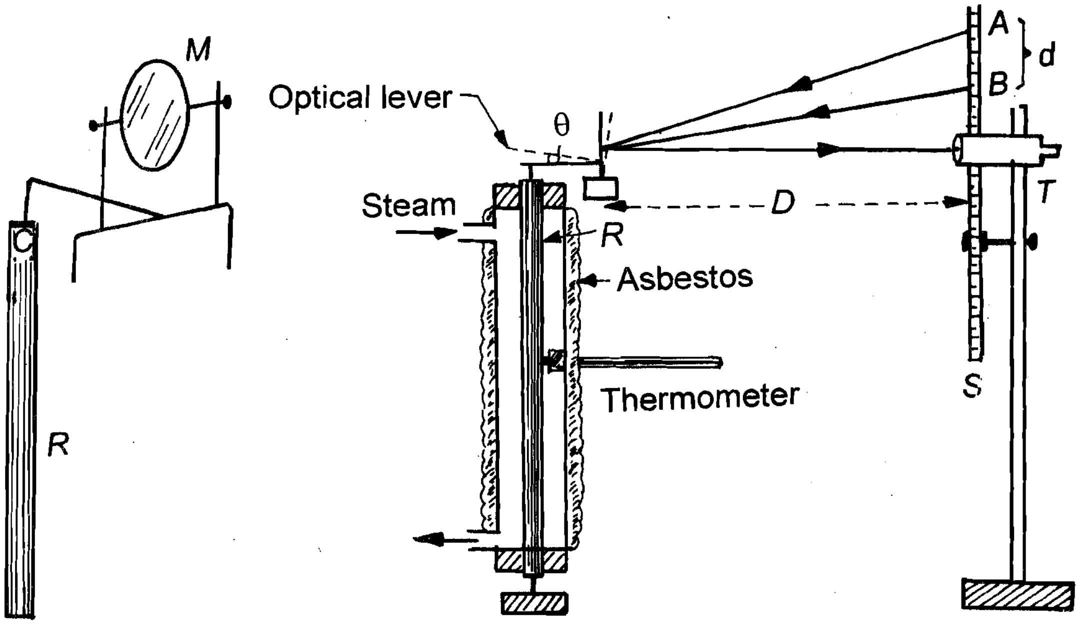


Fig.3.2: a) Optical level arrangement; b) experimental arrangement for measuring the change in length of a rod with temperature using a telescope and optical lever

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 eye-piece 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

3. Refer to Fig.3.2. Connect steam inlet opening of the linear expansion apparatus to the steam boiler using rubber tubing. Take another 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	=	°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	=	°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 legs	=	cm

12. Calculate $\Delta \ell$ from Eq. (3.9) and α_L 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 are 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**.

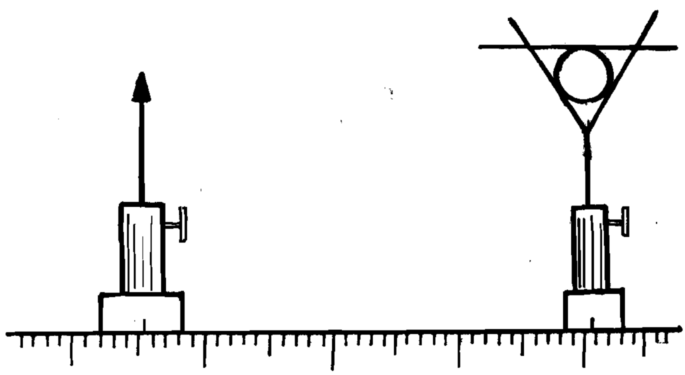


Fig.4.1: Observing index error

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.

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.

7. Use sign conventions as given in Unit 4.

B. Plot of 1/*v* versus 1/*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 *BEC* (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.

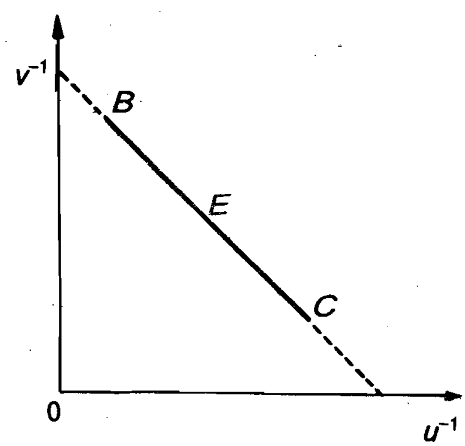


Fig.4.2: Expected plot of 1/*v* versus 1/*u*

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 $2F$. 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.

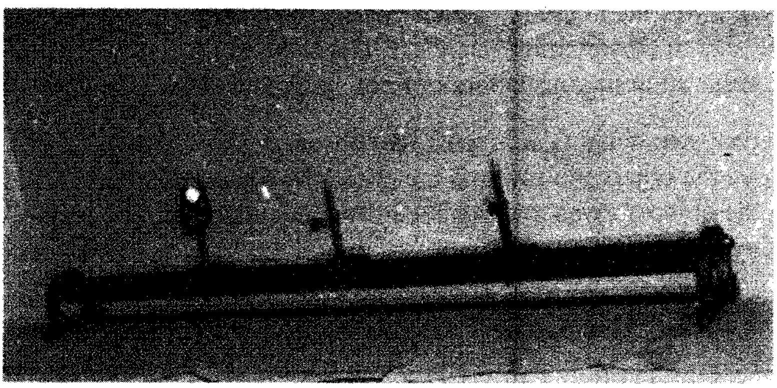


Fig.4.3: Experimental arrangement for determination of focal length of a concave mirror

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.

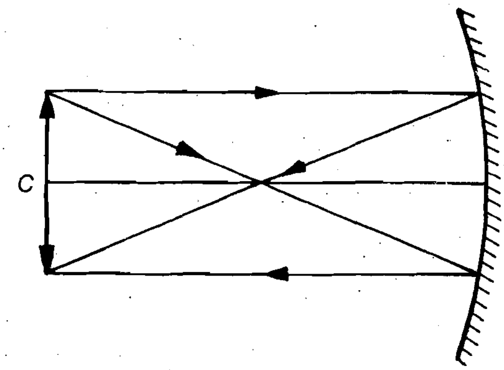


Fig.4.4: Ray diagram for image formed by a concave mirror when the object is at *C*

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 *I* 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		$\frac{1}{u}$	$\frac{1}{v}$
				u (cm)	v (cm)	u (cm)	v (cm)	(cm^{-1})	(cm^{-1})
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.

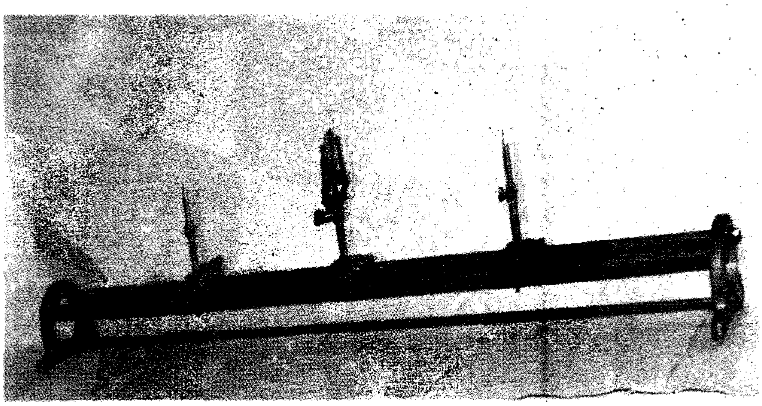


Fig.4.5: Experimental arrangement for determination of focal length of a convex lens

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.

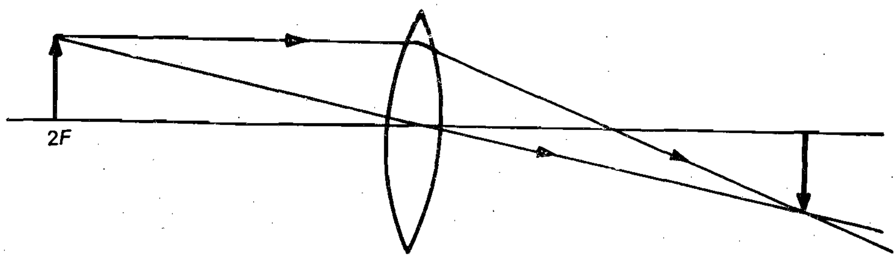


Fig.4.6: Ray diagram for a convex lens when object is placed at $2F$

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. Everytime 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 Block 1 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 f 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 ±…….. 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 Block 1, 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 focusses 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.

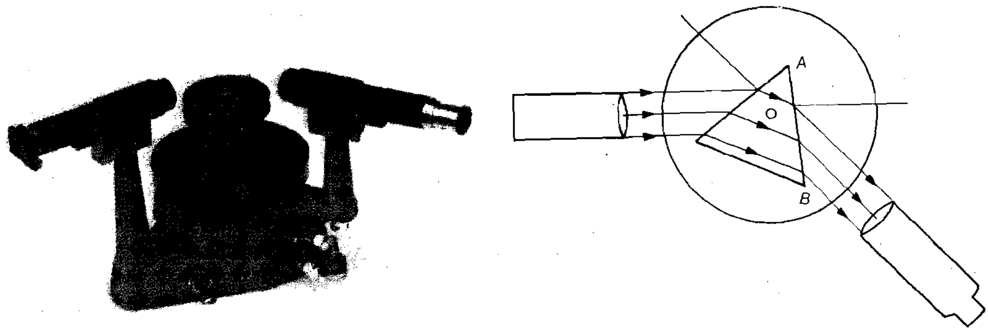
You have now adjusted the spectrometer and can proceed to observe the spectrum.

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.



(a) (b)

Fig.5.1: Observing spectrum

3. From Unit 4, Block 1, 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 $5890\,\text{Å}$ and $5896\,\text{Å}$. This pair is usually referred to as sodium doublet. With a mercury lamp you will observe sharp spectral lines of different colours of wavelengths:

   $R_1 = 6908\,\text{Å},\ R_2 = 6234\,\text{Å},\ Y_1 = 5790\,\text{Å},\ G = 5461\,\text{Å},\ BG = 4961\,\text{Å},$

   $B = 4358\,\text{Å},\ V_1 = 4078\,\text{Å},\ V_2 = 4047\,\text{Å}.$

   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.

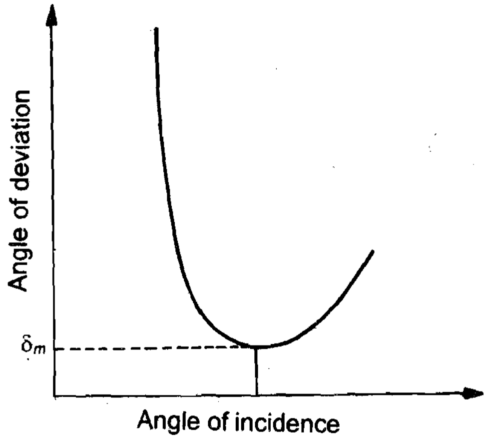


Fig.5.2: Variation of angle of deviation with angle of incidence

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 $= \frac{1}{2}^{\circ}$ or 30′

Least count = 1 m.s.d. − 1 v.s.d.

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

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

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 *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.

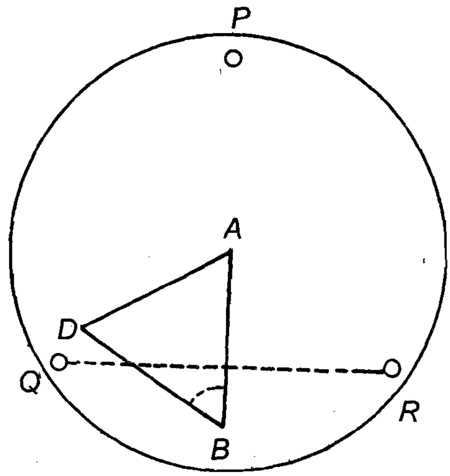


Fig.5.3: Mounting the prism for measurement of its angle

2. 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).

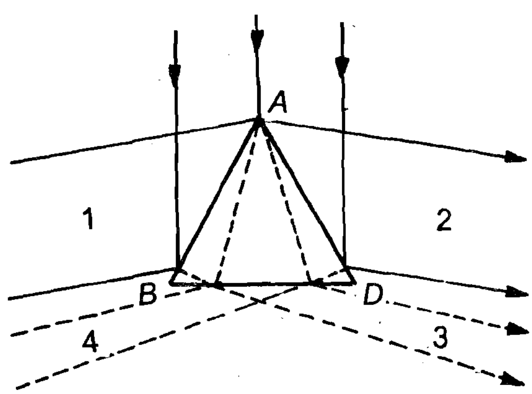


Fig.5.4: Determination of the angle of the prism

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.

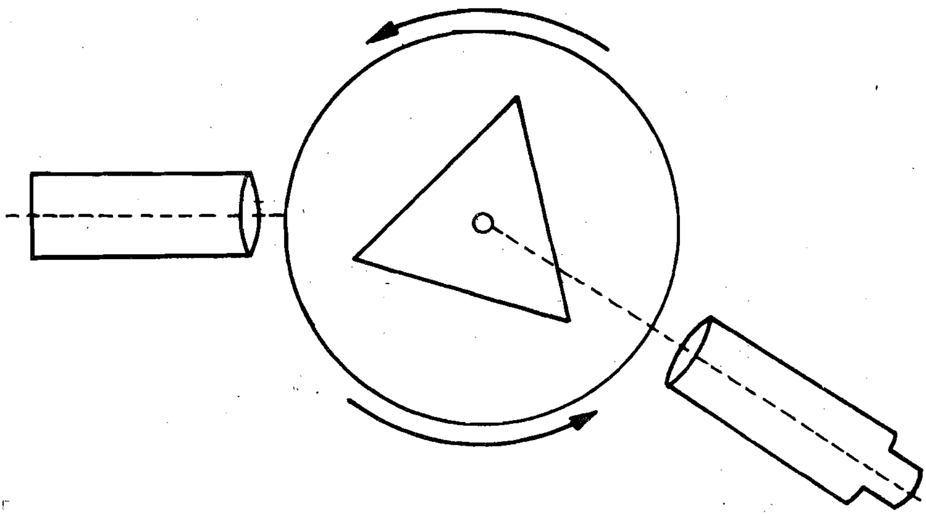


Fig.5.5: Locating the reflected image

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 (2*A*). 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 (2*A*) = ...

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 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 *pn* 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 Ω scale in the highest range;
2. Insert black lead in 'COM' input terminal and red lead in VΩ 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.

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.

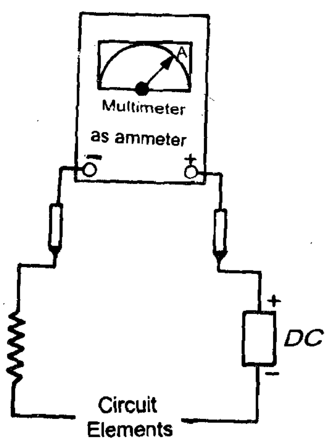


Fig.6.1: Direct current measurement in a circuit

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 VΩ 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 kΩ.

The range of 10 kΩ 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 to *p*-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).

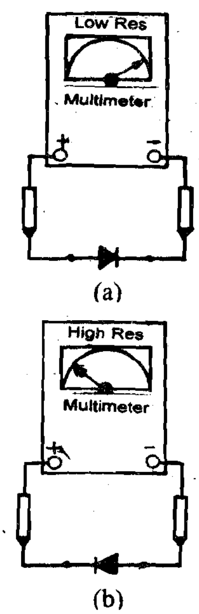


Fig.6.2: Testing of a *pn* Junction diode

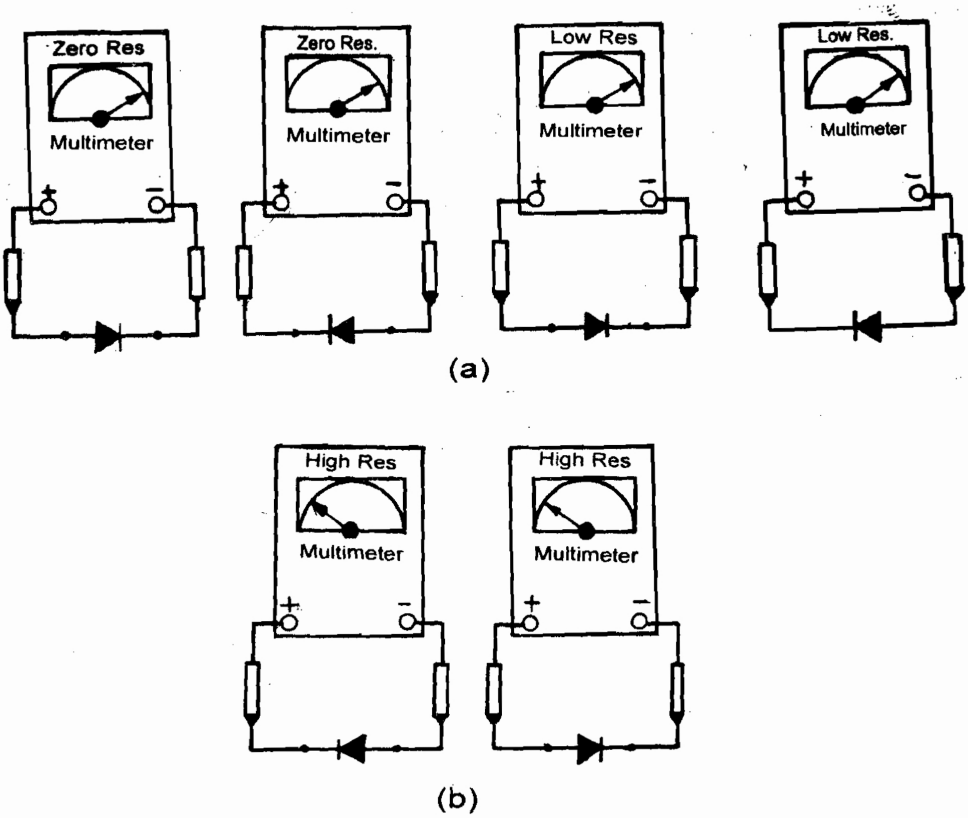


Fig.6.3: Behaviour of a defective *pn* junction

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

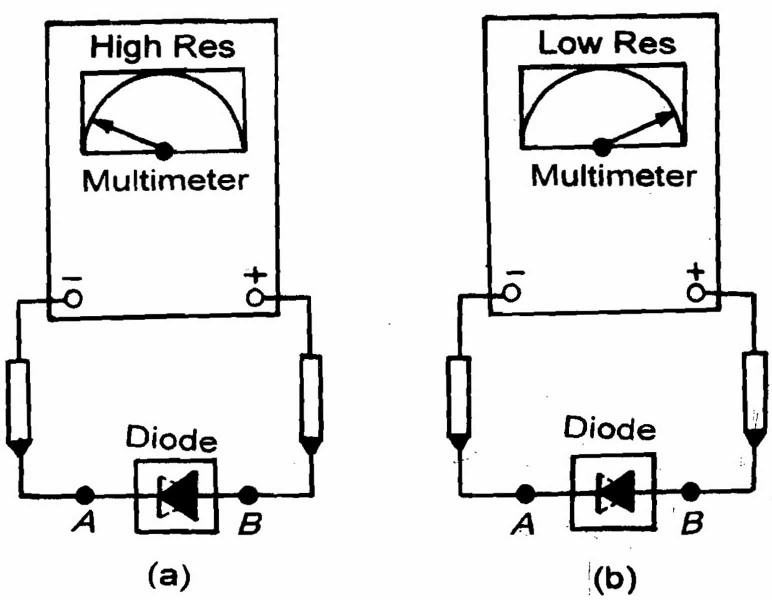


Fig.6.4: Identification of *p*-end and *n*-end in a *pn* junction diode

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*).

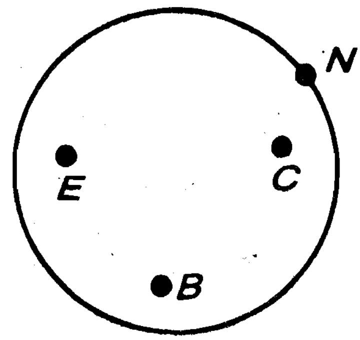


Fig.6.5: Identifying emitter, collector and base terminals of a transistor

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 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 8
CURRENT AND VOLTAGE MEASUREMENTS

Structure

8.1 INTRODUCTION

Electricity is now an integral part of our life. Our reliance on it is too much. From Unit 6 of Block 1 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 a *pn* junction diode; and
- maintain the ammeters and voltmeters in good working condition.

The apparatus required for this experiment is listed below.

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

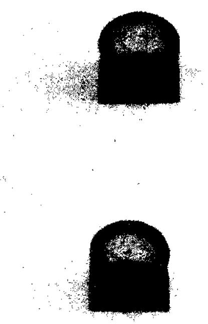


Fig.8.1: Analogue ammeters and voltmeters in a physics laboratory

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.8.1). 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 0.1A in an experiment involving *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

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.

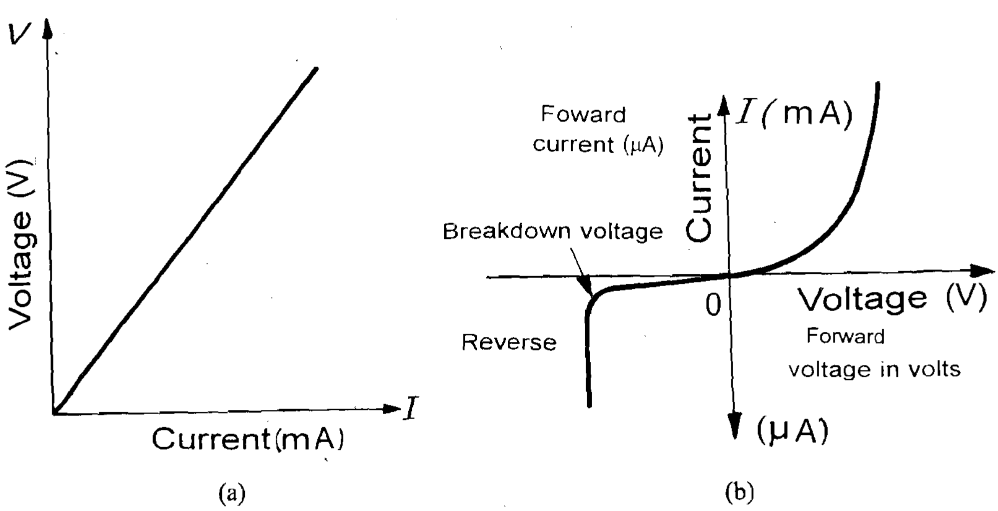


Fig.8.2: ***IV* characteristics of a) a resistor; and b) a *pn* junction diode**

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

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.

$$V = IR$$

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.

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 oonnections 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.

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

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

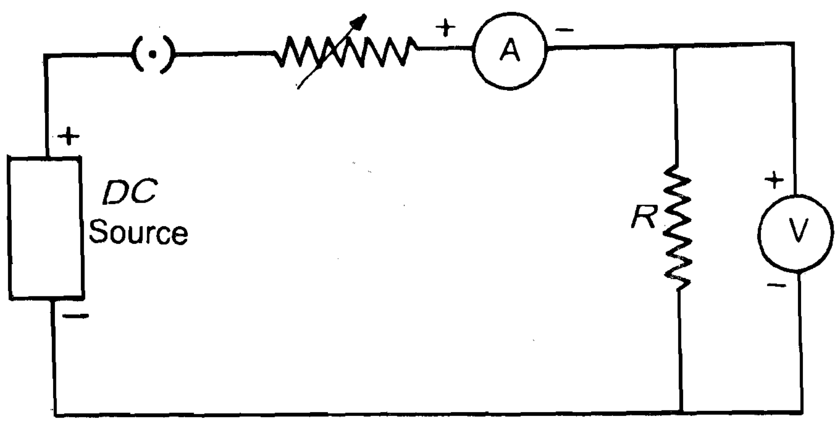


Fig.8.3: Circuit diagram for drawing *IV* characteristics of a resistor

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 $R = 1{,}000\Omega$, current will range from 0 to $\frac{5\text{V}}{1000\Omega} = 0.005\text{A} = 5\text{mA}$.

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 0A. 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* (Ω)
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
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:

$$R = \text{Slope of the } VI \text{ graph}$$

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

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 semi-conducting 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 I = ...

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 *p*-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.

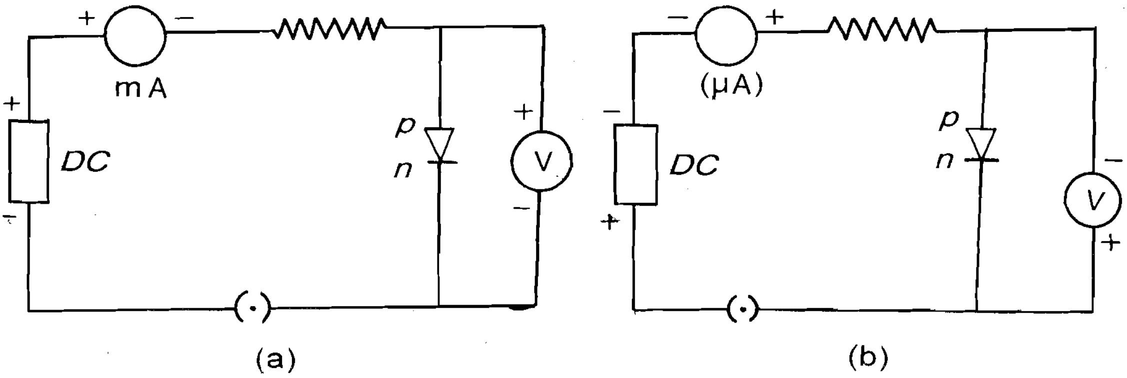


Fig.8.4: Circuit diagram for the *IV* characteristics of a *pn* junction diode in a) forward bias; and b) reverse bias.

3. Set the value of the resistance in the circuit at about 1000Ω 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 100Ω 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.

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 8.4: 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.		
⋮		

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

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

Plot the current (in mA) along the y-axis and voltage (in V) along x-axis for forward bias. For reverse bias, current will be in μA 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.

Course Name:	**Laboratory Techniques in Physics**
Course Code:	**LT- 04**
Credits:	**02 Credits**

Experiment 1: Measurements in Physics

Experiment 2: Stationary Waves in Stretched Strings

Experiment 3: Measurement of Thermal Properties

Experiment 4: Investigations with Mirrors and Lenses

Experiment 5: Working with a Spectrometer

Experiment 6: Handling and Maintaining a Multimeter

Experiment 7: Fabrication of an Extension Board

Experiment 8: Simple Current and Voltage Measurements

Experiment 9: Using an Oscilloscope

Lab Requirements for LT- 04

1. Vernier callipers
2. Screw gauge
3. Bob of pendulum or wooden block
4. Metallic wire/needle
5. Sonometer
6. ½ kg hanger
7. ½ kg slotted weights
8. Tuning fork of unknown frequency
9. Rubber pad
10. Physical balance
11. Weight box
12. Calorimeter wit heating coil
13. A sensitive thermometer
14. Stirring rod
15. DC power supply
16. Stop watch
17. Ammeter (0-5A)
18. Voltmeter (0-5V)
19. Rheostat
20. Capacitor
21. Coefficient of linear expansion apparatus
22. Metre scale
23. Steam boiler
24. Tripod stand
25. Rubber tubing for steam delivery
26. Burner
27. Beaker
28. A metallic rod
29. Telescope
30. Optical lever
31. Lamp and scale arrangement
32. Optical bench
33. Concave mirror (f = 15-20 cm)
34. Convex lens (f = 15-20 cm)
35. Pins
36. Index needle
37. Spectrometer
38. Prism
39. Light source such as sodium or mercury lamp
40. Spirit level
41. Reading lens
42. Reading lamp
43. Multimeter
44. Resistors
45. Electrolytic capacitors
46. *pn* junction diode
47. *pnp* and *npn* transistors
48. Signal generator
49. Wooden or plastic box (30 cm × 15 cm × 4 cm)
50. Good quality 5m three-core electric wire of 20 gauge
51. 2 two-in-one (5 A and 15 A) sockets
52. 1 three-pin plug (15 A)
53. 2 switches (15 A)
54. Ammeters and voltmeters of differen ranges
55. Resistance boxes
56. One way key
57. Oscilloscope
58. Tracing paper