Secondary

# Physics

New Syllabus

Students' Book Two

Fifth Edition



KENYA LITERATURE BUREAU

Approved by the Ministry of Education

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# PHYSICS

## Student's Book Two

*(Fifth Edition)*

KENYA LITERATURE BUREAU
NAIROBI

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# Prologue

This book is primarily meant to cover exhaustively the Form One Physics syllabus as per the new 8-4-4 curriculum. It is by design also a versatile companion for those students taking related courses in technical colleges and other institutions.

The book has been made more elaborate and in-depth theorical coverage boosted with numerous experiments to enhance a better understanding of concepts under study.

Any student making full use of the title, and by extension the KLB Secondary Physics series, will certainly acquire scientific knowledge and skills useful in answering to the challenges of daily life.

I am grateful to the panel of writers and everybody who took part in the preparation and production of this edition.

**THE MANAGING DIRECTOR**

*Kenya Literature Bureau*

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# Chapter 1

# Magnetism

A naturally occurring material known as lodestone, a form of iron ore, attracts some materials when they are brought near it. When a bar of lodestone is suspended freely, it settles in the north-south direction. This property of lodestone has been used to make the present-day magnets.

Magnets attract certain materials known as magnetic materials, examples of which are iron, nickel, cobalt and their alloys. Magnets are made from these magnetic materials.

## Properties of Magnets

Magnets have a number of properties some of which include:

### 1. Magnetic Poles

**Experiment 1.1: To determine the poles of a magnet**

*Apparatus*

Bar magnet, iron filings.

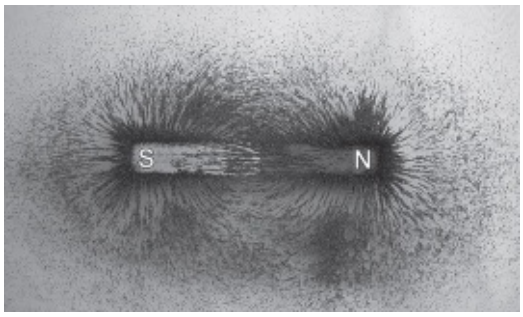



*Fig. 1.1 (a): Bar magnet in iron filings*

*Procedure*

- Dip the bar magnet into iron filings. Note where the iron filings cling most.
- Repeat the experiment using a horseshoe magnet.



*Fig. 1.1 (b): A horse-shore magnet in iron filings*

*Observation*

The iron filings cling mainly around the ends of the bar magnet, see figure 1.1 (a) and (b). This shows that magnetic attraction is strongest at the ends of the bar magnet.

The ends of a magnet where the power of attraction is greatest are called the poles of the magnet or magnetic poles.

## 2. Directional Property

**Experiment 1.2: To investigate the directional property of a magnet**

*Apparatus*

Bar magnet, cotton thread, and wooden stand.

*Procedure*

- Suspend a bar magnet with a cotton thread from a wooden stand, so that the magnet swings freely in the horizontal plane. Give it time and observe the direction in which it comes to rest.
- From the rest position, turn the magnet through about 90° and release it. Note again the direction in which it comes to rest.
- From the rest position, now turn the magnet through about 180°. Release it and note the direction in which it comes to rest.

*Observation*

The suspended magnet always comes to rest with one end pointing roughly to the north direction and the other to the southern direction of the earth, see figure 1.2.

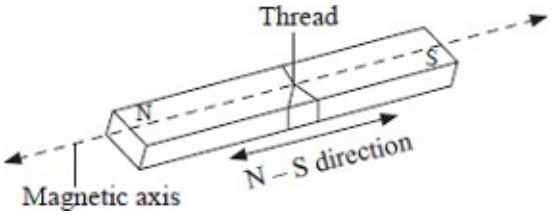



*Fig. 1.2: Suspended magnet at final resting position*

*Conclusion*

Magnets have two poles. The pole which points towards the north is called the North-seeking or the north (N) pole;the other one is the south-seeking or south (S) pole.

A magnet can be, therefore, used as a compass.

Note that this experiment can be used to identify poles of a magnet.

## 3. Effect on Magnetic and Nonmagnetic Materials

**Experiment 1.3: To classify objects into magnetic and non-magnetic materials**

*Apparatus*

Rods of different materials, wooden stand, cotton thread, bar magnet.

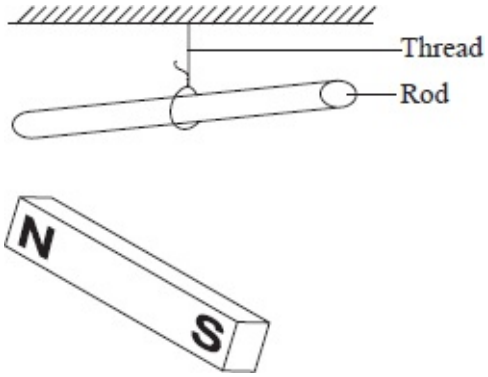



*Fig. 1.3: Effect of magnet on a material*

*Procedure*

- Suspend a rod with a thread as shown in figure 1.3.
- Bring the north pole of a magnet towards one end of the rod and observe what happens.
- Repeat the experiment using the south pole of the magnet.
- Now repeat the experiment using different materials shown in Table 1.1. Note

your observations.

*Table 1.1*

| *Object* | *Observations* | |
|---|---|---|
| | *North Pole* | *South Pole* |
| Steel needle | Attracted | Attracted |
| Piece of chalk | | |
| Steel pin | | |
| Aluminium strip | | |
| Carbon rod | | |
| Copper wire | | |
| Match stick | | |
| Glass | | |

*Observation*

It is observed that some objects are attracted by both the north and south poles of the magnet, while others are not attracted.

*Conclusion*

An object which is attracted by a magnet is a **magnetic material**. An object which is not attracted by a magnet is a **nonmagnetic** material. Metals such as cobalt, iron and nickel together with their alloys which are strongly attracted by a magnet are called **ferromagnetic materials**.

Some examples of non-magnetic materials are copper, brass, aluminium, wood and glass.

## 4. Attraction and Repulsion

**Experiment 1.4 : To establish the law of magnetism**

*Apparatus*

Two bar magnets, cotton thread, wooden stand, iron rod.

*Procedure*

- Suspend a bar magnet as shown in figure 1.4.

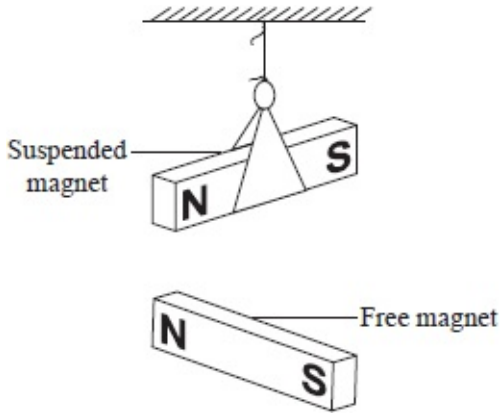



*Fig. 1.4: Attraction and repulsion of magnetic poles*

- Bring the north pole of another magnet towards the north pole of the suspended magnet. Observe what happens.
- Bring the same pole towards the south pole of the suspended magnet.
- Repeat the experiment using the south pole of the free magnet.
- Now repeat the experiment using a piece of unmagnetised iron instead of the suspended bar magnet. Tabulate your results as shown in Table 1.2.

*Table 1.2*

| | *North pole of suspended magnet* | *South pole of suspended magnet* |
|---|---|---|
| North pole of the free magnet | Repulsion | Attraction |
| South pole of the free magnet | | |
| One end of iron bar | | |
| The other end of iron bar | | |

*Observation*

A north pole attracts a south pole and repels a north pole, while a south pole repels a south pole. This can be summarized as **like poles repel, unlike poles attract**. This is the basic law of magnetism.

The polarity of a magnet can be tested by bringing both its poles, in turn, adjacent to the known poles of a suspended magnet. Repulsion only occurs between the like poles of a magnet. However, attraction can occur between two unlike poles or between a pole and a piece of an unmagnetised magnetic

material.

Thus, the only sure test for polarity of a magnet is repulsion.

## 5. Breaking a Magnet

When a bar magnet is broken into two or more pieces, the pieces retain their magnetism, each having a north pole and a south pole at its ends, see figure 1.5.

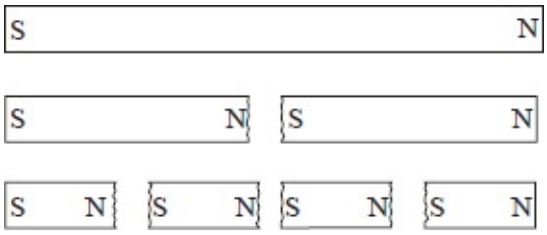



*Fig. 1.5*

## 6. Magnetic Field Patterns

When a magnetic material is placed near one pole of a magnet, it is attracted. This suggests that there is a magnetic effect in the space around a magnet. The region or space where the magnetic influence is felt is called the **magnetic field**. The field is stronger near the poles of the magnet and is weaker farther away from the poles.

**Experiment 1.5 To Investigate magnetic field patterns of a magnet using Iron filings**

*Apparatus*

Bar magnet, horse-shoe magnet, smooth stiff cardboard, iron filings.

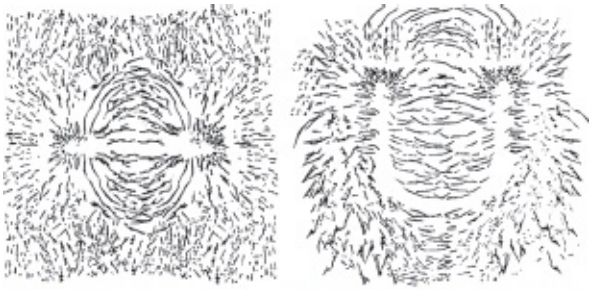



*Fig. 1.6: Field patterns*

*Procedure*

- Place the bar magnet on a table and put a stiff cardboard over it.
- Sprinkle a thin layer of iron filings on the board and tap the cardboard gently.

Note the observations.

- Repeat the experiment with the horse-shoe magnet under the board.

*Observation*

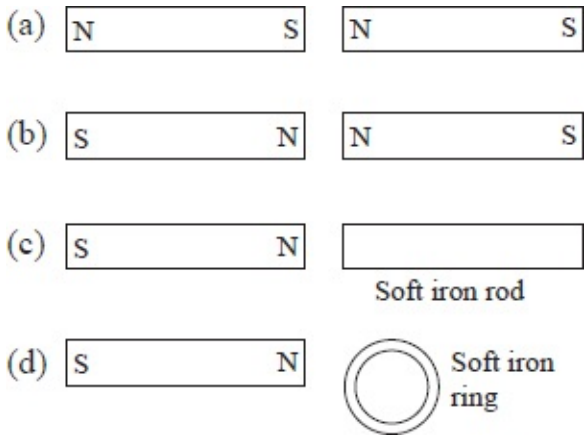
The iron filings form patterns which seem to originate from one pole and end the other, see figure 1.6 (a) and (b).

*Conclusion*

The magnetic field around a given magnet or arrangement of magnets is a definite pattern.

### *Class Activity*

Using the procedure of Experiment 1.5, determine the field patterns for the combination below:




## Direction of Magnetic Field

**Experiment 1.6: To investigate the direction of magnetic field using a magnetic needle**

*Apparatus*

Magnet bar, magnetic needle fixed on a cork, glass trough.

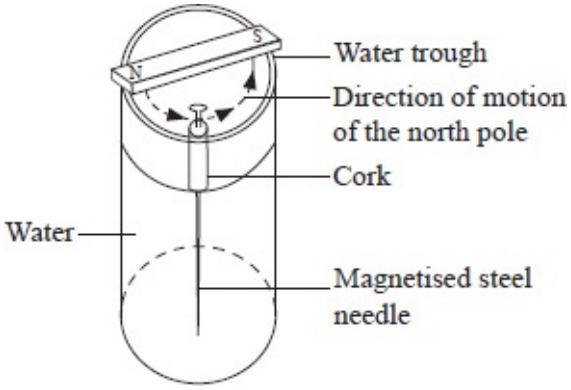



*Fig. 1.7: Direction of magnetic field*

*Procedure*

- Pour water into the trough up to three-quarters its volume.
- Float a magnetised needle with its north pole uppermost, as shown in figure 1.7.
- Place a strong magnet so that it rests on the edge of the trough.
- Adjust the level of the water so that the north pole of the needle is at the same level with the plane of the magnet.
- Hold the needle near the north pole of the magnet and then release it. Observe its movement.
- Repeat the experiment with the south pole of the needle uppermost and placed near the south pole of the magnet. Note its movement.

*Observation*

When the needle is held with its north pole near the north pole of the magnet and released, the needle is repelled and moves towards the south pole along a curve, as shown in figure 1.7.

If the south pole of the needle is placed near south pole of the magnet and the needle released, the direction of motion is reversed. The direction of the motion of the needle is determined by the pole of the needle which is adjacent to the magnet.

Therefore, in deciding the direction of the field, one of these directions has to be chosen as a standard direction. By convetion, the direction of motion of the north pole is chosen.

**The direction of the magnetic field at a point is the direction which a free north pole would move if placed at that point in the field.**

Thus, a magnetic line of force can be defined as the path along which a north pole would move if free to do so.

**Experiment 1.7 : To investigate magnetic field patterns by use of a plotting compass**

*Apparatus*

Bar magnet, plotting compass, white sheet of paper, drawing board.

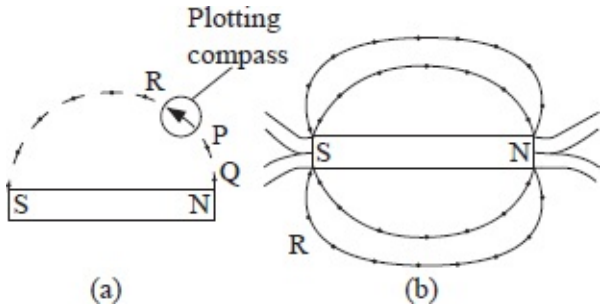



*Fig. 1.8: Plotting a magnetic field.*

*Procedure*

- Place the bar magnet on the sheet of paper fixed on a drawing board.
- Mark its outline and indicate the polarity of the magnet on the paper.
- Place a plotting compass near the north pole of the magnet.
- Starting from one pole of the magnet, mark in the paper the north and south ends of the compass needle with pencil dots at P and Q as shown on figure 1.8 (a).
- Move the compass until the south pole of the needle is at P mark the new position of the north pole at R.
- Repeat the procedure so that a series of dots is obtained. Join these dots using smooth curves, as in figure 1.8 (b).
- Repeat the above procedure starting from different points near the magnet. Join each set of dots using a smooth curve as shown in the figure.

*Observation and Conclusion*

Smooth parallel curves that start from one pole and end at the other pole are obtained, see figure 1.8 (b). These curves represent the magnetic field lines.

Magnetic field lines have the following properties:

(i) They originate from north pole and end at the south pole.

(ii) They repel each other and form closed paths never intersecting other lines of forces.

(iii) They are closer together where the field is strongest.

In figure 1.9 (b), the left end X has a higher field strength than right end Y.

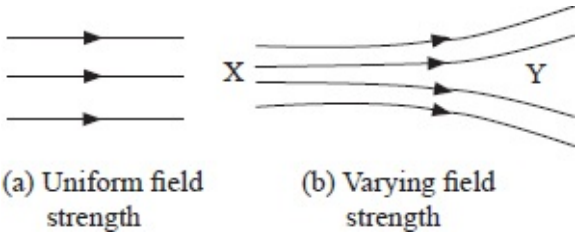



*Fig. 1.9: Magnetic field strength*

## Magnetic Field Patterns

### Magnetic Pattern around a Bar Magnet

The field lines are shown in figure 1.10. The magnetic field for a magnet lines of force originate from the north pole and end at the south pole.

The magnetic field lines around a bar magnet originate from North Pole and end at the South Pole.

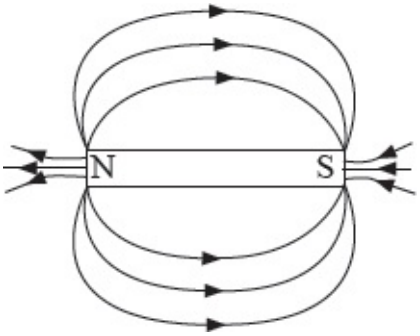



*Fig. 1.10: Field pattern around a bar magnet*

### Field Patterns between Unlike Poles

Each magnet has its own magnetic field. The two fields combine to produce a single magnetic field, as shown in figure 1.11.

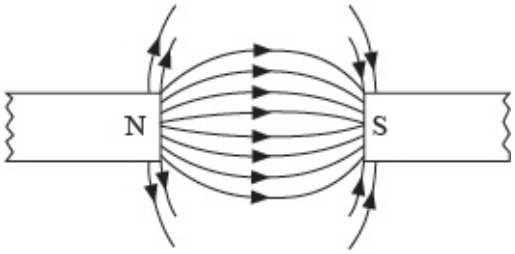



*Fig 1.11. Field patterns between unlike poles*

For a horse-shoe magnet, the north pole to the south pole, the field lines between the poles are more concentrated.

For a horse- shoe magnet, the tied lines between the poles are highly concentrated at the region between the poles.

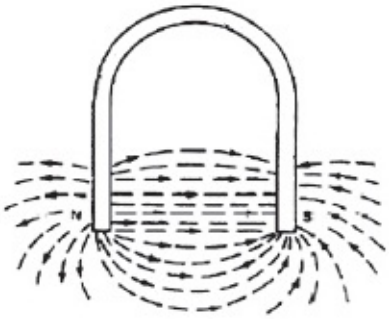


*Fig. 1.12: Field pattern of a horse-shoe magnet*

## Field Patterns between Like Poles

When like poles are placed adjacent to each other magnetic field from the poles repel each other resulting in a neutral point X as shown in figure 1.13.

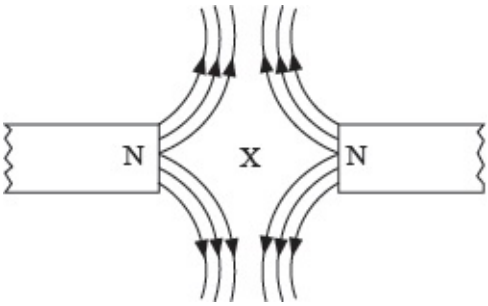



*Fig. 1.13: Field pattern between two like poles*

There is no magnetic field at point X, which is called a neutral point. A neutral point can thus be defined as that point where the effect of two magnetic fields totally cancel each other.

## Effect of Soft Iron Rod and Ring

Lines of force the magnet get concentrated along the soft iron rod, as shown in figure 1.14. The lines emerge on the far end of the rod, thus preventing them from reaching certain regions.

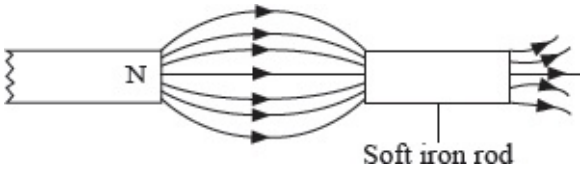



*Fig. 1.14: Effects of soft iron rod*

A soft iron ring concentrates the magnetic lines of force, as shown in figure 1.15. This prevents lines from entering region P. Region P is thus said to be **magnetically shielded** by the ring from magnetic fields.

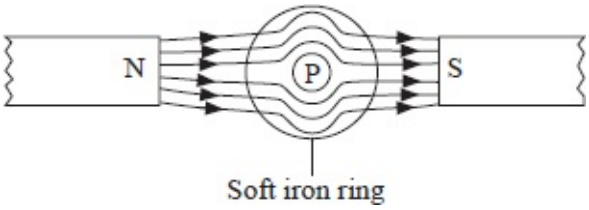



*Fig. 1.15: Magnetic shielding*

Therefore, both the iron rod and ring can be used in magnetic shielding or screening. Some electrical measuring instruments and watches are shielded this way from stray magnetic fields using alloys of high magnetic permeability (the property of certain materials to concentrate a magnetic field, hence leaving some areas totally free from magnetic influence).

## The Earth's Magnetic Field

The fact that a suspended bar magnet aligns itself such that its north pole points roughly to the geographical north of the earth, suggests that the inner core of the earth behaves as if it were a magnet. Using the basic law of magnetism, it can be visualised that the magnetic is embedded in the earth's magnet is embedded in the earth's crust with its south pole near the geographical north and its south pole near the geographical south poles see figure 1.16.

The origin of the earth's magnetism is believed to be in part associated to the spinning liquid metallic core of iron and nickel.

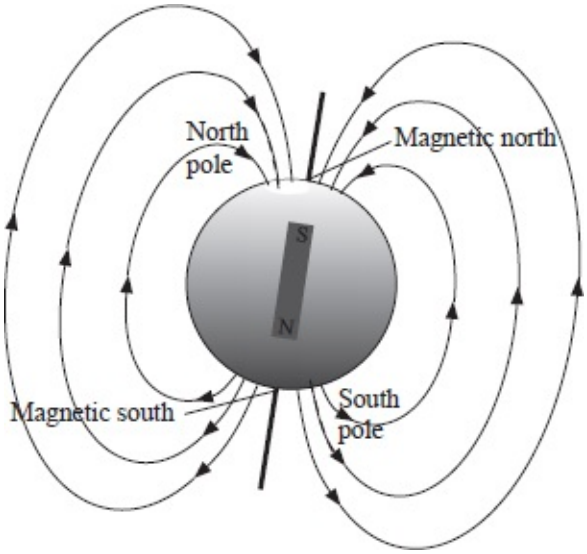



*Fig. 1.16: Earth's magnetic field.*

### Experiment 1.8: To plot the earth's magnetic field

*Apparatus*

Drawing board, plain white paper, four pins, plotting compass.

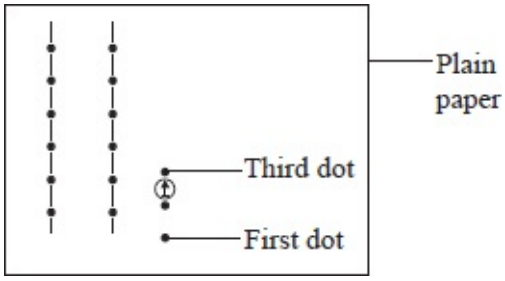



*Fig. 1.17: Plotting the earth's magnetic field*

*Procedure*

- Fix a plain paper on a drawing board placed on a table.
- Mark a dot at one end of the paper.
- Place a plotting compass such that the south pole of the needle is at the first dot. Mark the position of the north pole with a second dot.
- Move the compass so that the south pole of the needle is at the second dot. Mark the position of the north pole with a third dot, see figure 1.17.
- Repeat the procedure until a series of dots is obtained.
- Join the dots.
- Repeat the procedure to obtain more lines.
- Indicate with an arrow the direction the north pole of the needle points when placed on the line.

*Observation*

A series of parallel lines are obtained. These lines represent the direction of the earth's field, from magnetic south to magnetic north, see figure 1.18.

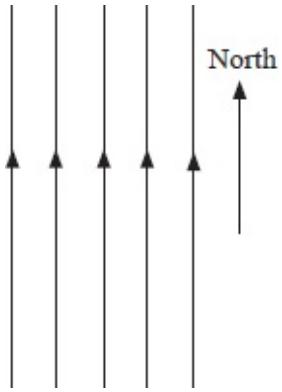
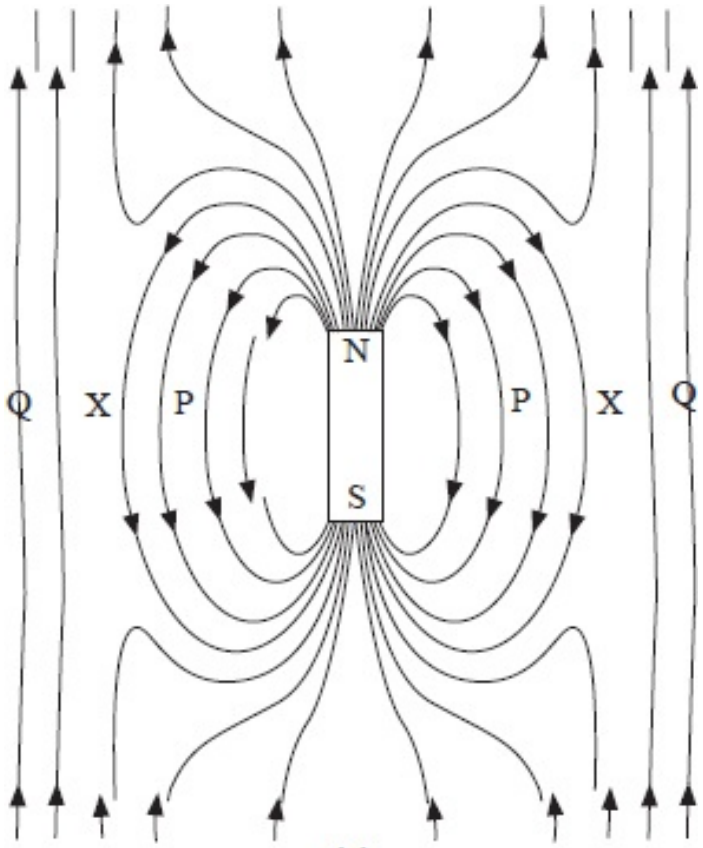



*Fig. 1.18: Earth's magnetic field.*

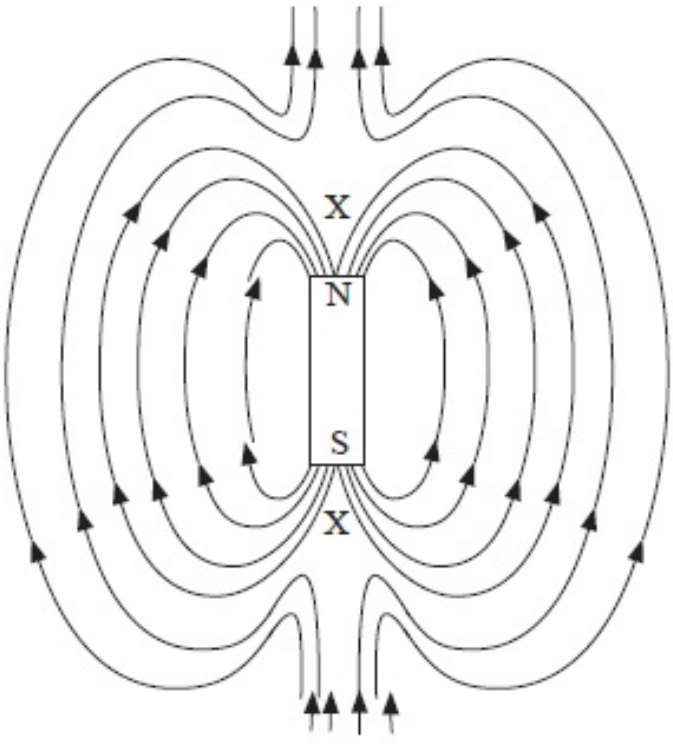
The earth’s field is an example of uniform field.

A bar Magnet placed anywhere near the earth’s surface will have its magnetic field combining with the field of the earth, see figure 1.19 (a).

At points marked X, the magnetic field of the earth and that due to the magnet are equal and opposite. The resultant magnetic field is therefore zero at these points, which are called neutral points, see figure 1.19 (a) and (b).




(a)




(b)

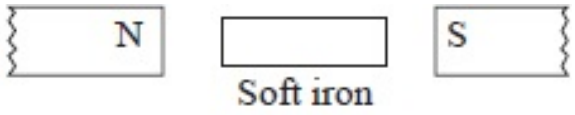
*Fig 1.19: Bar magnet in the earth's magnetic field*

At P, the field of the magnet is stronger than that of the earth, while it is weaker at Q.

## Exercise 1.1

1. Sketch the magnetic field patterns for the arrangements below:

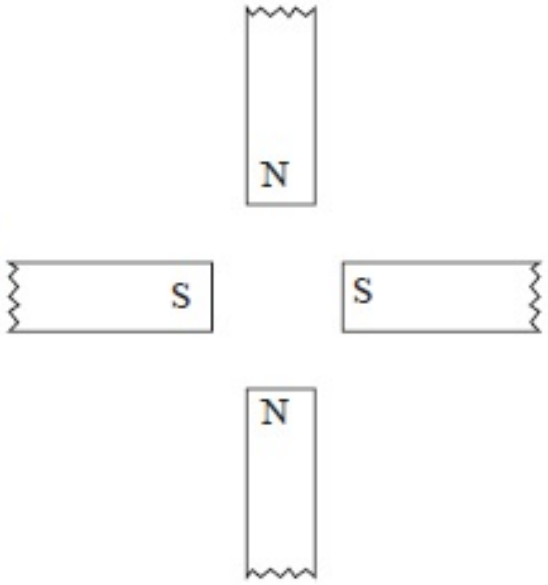
(a)




(b)




(c)



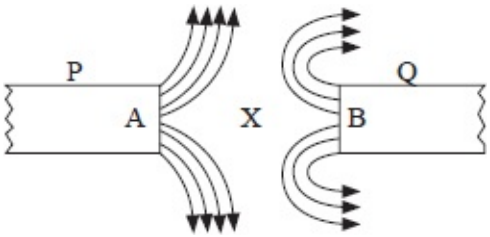

(d)




(e)



2. The diagram below shows the magnetic field pattern between two magnets P and Q:




(a) Identify poles A and B.
(b) State which of the two magnets P and Q is stronger. Explain.

## The Domain Theory

Magnetic materials contains small magnetic regions referred to as magnetic domains. A domain comprises small atomic magnets called dipoles.

A dipole has a north and south pole. The dipoles in a particular domain align themselves in a common direction giving the domain an overall north pole and a south pole. A line can thus be drawn (magnetic axis) joining the poles, see figure 1.20.

The total field outside a magnetic material is the sum of individual domain fields.

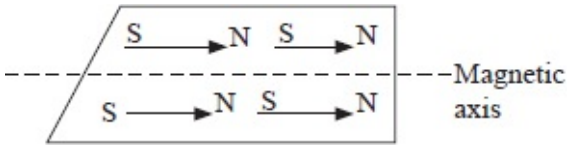



*Fig. 1.20: Dipoles in a domain*

In the un-magnetised condition, the dipoles in neighbouring domains arrange themselves in closed loops, see figure 1.19

The domains however align in different direction giving no resultant field outside the material.

When a magnetising field is applied to the material, there is adjustment of domain boundaries causing some of the domains to increase in size and others to shrink. In the process, the domain, align themselves with their magnetic axis pointing in the same direction. The net external field increases and the material is said to be magnetised.

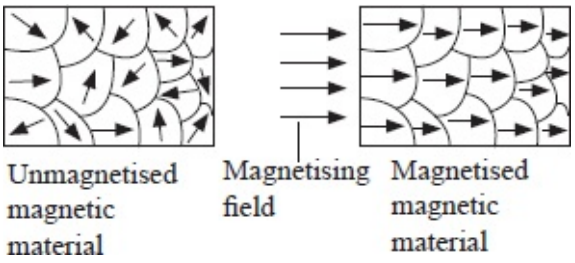



*Fig. 1.12*

When all dipoles align themselves in one direction, the material is said to be magnetically saturated. No further magnetisation can take place beyond this point

When the magnetising field is removed, domains of hard magnetic (materials which are hard to magnetise) maintain their new orientation, while those of soft magnetic materials (materials which are easy to magnetise) have their domains reverting to their original arrangement.

## Magnetisation of a Magnetic Material

The process of making a magnet from a magnetic material is called magnetisation. The common methods used in magnetisation are:

(i) Induction.

(ii) Stroking.

(iii) Hammering.

(iv) Electrical method.

## Induction Method

**Experiment 1.9. To make a magnet by induction method**

*Apparatus*

Two bar magnets, office pins

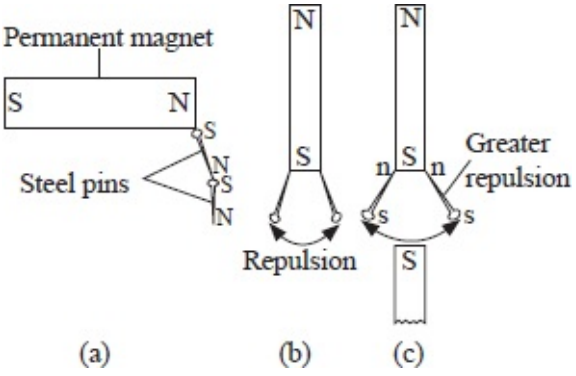



*Fig. 1.22: Induced magnetism.*

*Procedure*

- Hold a bar magnet vertically.
- Move the lower pole towards one end of a pin.
- Move the lower end of that pin to the ends of the other pins, one by one. Note what happens
- Detach the top pin from the magnet. What do you observe?

*Observation*

The first pin gets attracted to the magnet. The other pins get attracted to the first pin and form a chain, see figure 1.22 (a).

When the first pin is detached from the magnet, the lower pins fall off after a short time.

*Explanation*

The ends of the pins attracted to the magnet acquire a polarity that is opposite to that pole of the magnet. The lower end of the pin acquires a polarity similar to the pole used, see figure 1.22 (c).

The pins become magnetised and the dipoles in them get aligned along the magnetic axis of the magnetising magnet.

The pins in the experiment get magnetised by induction method.

## Stroking Method

When a steel needle is stroked using one end of a strong magnet repeatedly, the needle becomes magnetised.

**Experiment 1.10: To make a magnet by stroking method**

### *Single Stroke Method*

Apparatus

A bar magnet, cotton thread, steel bar.

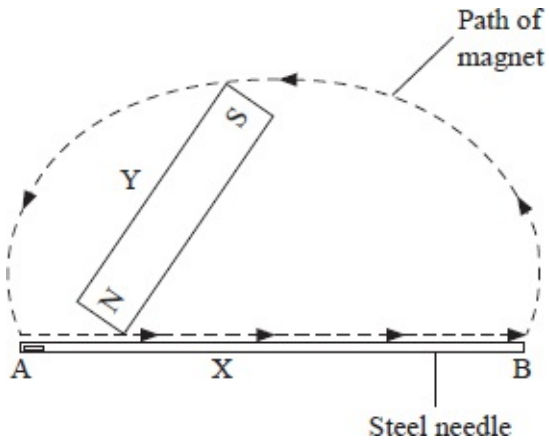



*Fig. 1.23. Single stroke method*

*Procedure*

- Place the steel bar X on a table.
- Stroke the bar with one pole of the magnet from A to B, lifting it away as shown in figure 1.23
- Repeat the procedure several times, keeping the inclination of the roughly the same.
- Test for the polarity of the bar by suspending it freely. Note what happens.

*Observation*

The suspended bar aligns itself with the magnetic axis of the earth. One of its ends is repelled by the plotting compass.

*Conclusion*

The bar is magnetised by stroking method. The end of the bar where the magnet Y finishes stroking acquires an opposite polarity to that of the stroking end of the magnet. Since the stroking pole of the magnet in the figure is north, the and **B** of the bar becomes the south pole.

The disadvantage of this method is that it produces magnets in which one pole is nearer the end of the magnetised material than the other.

This can be avoided by use of the double stroke method.

## *Double Stroke Method*

*Apparatus*

Steel bar, two bar magnets, cotton thread, plotting compass.

*Procedure*

- Stroke the steel bar Z from the centre repeatedly in opposite directions, using

opposite polarities of two bar magnets P and Q, see figure 1.24.

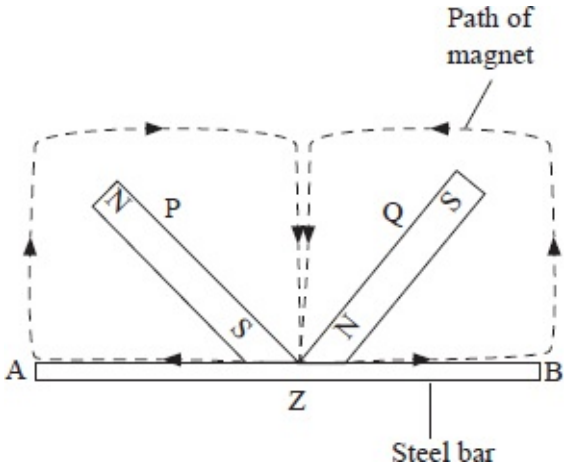



*Fig. 1.24 Magnetisation by double stroke method*

- Test for the polarity of the steel bar.

*Observation*

The end A of the bar acquires a north pole while end B acquires a south pole.

*Conclusion*

The steel bar has been magnetised by double stroking.

If a steel bar is magnetised by the double stroke method using north poles of two magnets, the bar acquires a south pole at each end and a double north pole at the centre, see figure 1.25

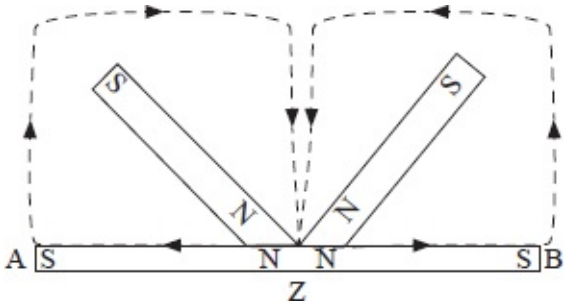



*Fig. 1.25: Making a magnet with consequent poles at the centre*

## Hammering Method

This method makes use of the influence of earth's magnetic field. A steel bar to be magnetised is placed inclined to the horizontal in a north–south direction at an angle θ and the upper end hammered several times.

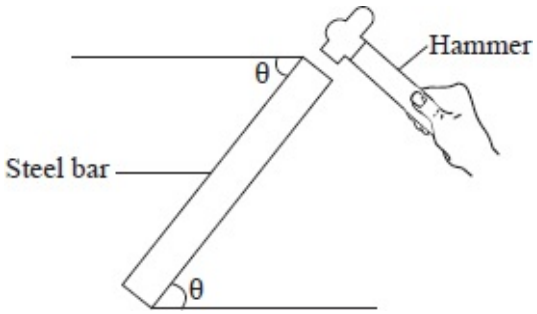



*Fig. 1.26 Hammering in the earth's field*

***Note:***

θ is referred to as the angle of dip. It varies according to position on the earth.

The process results into the formation of a weak magnet.

## Electrical Method

This is the best and quickest method of making a magnet. It utilises the magnetic effect of an electric current. The method is used widely in industrial production of magnets.

A coil with many turns of insulated copper wire, called a solenoid, is used. A direct current (d.c.) is passed through the solenoid.

**Experiment 1.11: To magnetise a steel bar by electrical method**

*Apparatus*

Steel bar, a solenoid, battery, ammeter, switch, connecting wires, cotton thread and plotting compass.

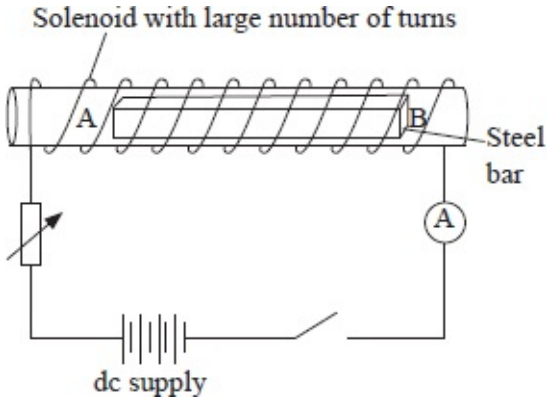



*Fig. 1.27: Magnetising by electrical method*

*Procedure*

- Place a steel bar AB inside the solenoid connected in series with the battery.

- Switch on the current for sometime, then switch off.
- Test for the polarity of the steel bar.

*Observation*

The bar is magnetised. The polarity of the magnet depends on the direction of the electric current.

The poles A and B can be identified using the **clock rule**, which states that **if , on viewing one end of the bar, the current flows in clockwise direction, then that end is a south pole. If anticlockwise, then it is a north pole**, see figure 1.28.

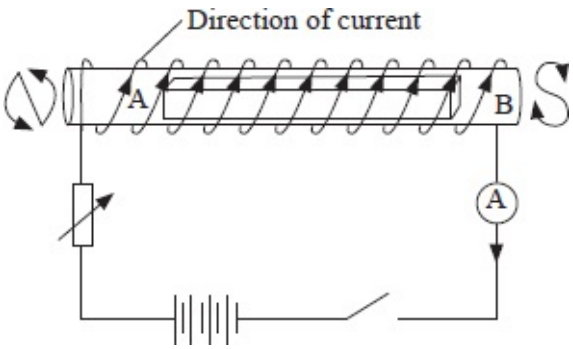



*Fig. 1.28: The clock rule*

The poles A and B can also be identified using the right-hand grip rule for a current-carrying coil, see figure 1.29.

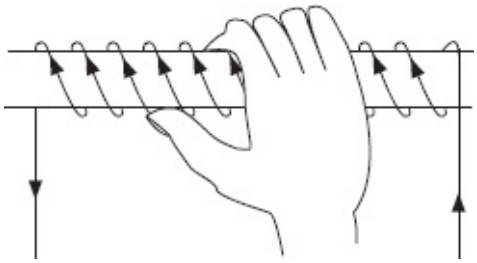


*Fig. 1.29: Right-hand grip rule*

The right-hand grip rule states that **if a coil carrying a current is grasped in the right hand such that the fingers point in the direction of the current in the coil, then the thumb points in the direction of north pole**.

Allowing the current to flow for a long time does not increase the extend of magnetic saturation. It only causes overheating of the solenoid, which adversely affects magnetism.

## Demagnetisation

The magnetic properties of a magnet can be destroyed by hammering in the east-west direction, heating or using electricity.

## Hammering and Heating

A magnet is demagnetised by heating or hammering it when placed in east-west direction.

The magnetism is lost because hammering or heating disorients magnetic dipoles.

## Electrical Method

This is the most effective method of demagnetisation

An a.c voltage is connected in series with a solenoid which is placed with its axis pointing east-west, as shown in figure 1.30. The bar magnet to be demagnetised is placed inside the solenoid and the alternating current switched on. After a few minutes, it is withdrawn slowly from the solenoid.

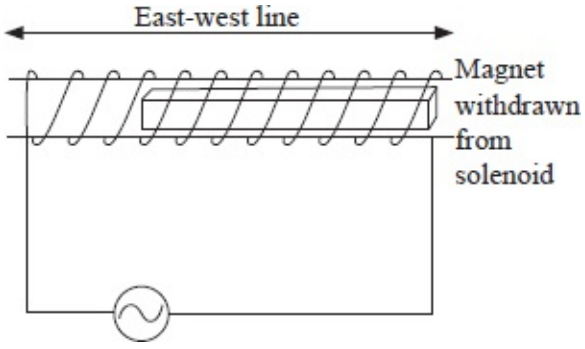



*Fig. 1.30: Demagnetising using electric current*

When suspended freely, it does not settle in any particular direction.

This shows that it has lost magnetism.

The magnet loses its power because alternating current reverses many times per second, disorienting the magnetic dipoles.

***Note***:

In the above methods, the magnets are placed in the east-west direction so that they don't retain some magnetism due to the earth's magnetic field.

## Hard and Soft Magnetic Materials

When a bar of soft iron is placed inside a solenoid and a current switched on, it becomes a strong magnet. When the current is switched off, it loses magnetism.

Magnetic materials such as soft iron which are magnetised easily but do not retain their magnetism are said to be **soft magnetic materials**.

An alloy of nickel and iron is another example of a soft magnetic material. It can be magnetised by very weak fields, such as the earth's magnetic field. These magnetic materials are used in making electromagnets, transformer cores and for magnetic shielding.

On the other hand, steel is difficult to magnetise, but once magnetised, it retains the magnetism for a long time. Magnetic materials such as steel are said to be **hard magnetic materials**. Hard magnetic materials are used in making permanent magnets.

## Storing Magnets

A bar magnet tends to become weaker with time due to self-demagnetisation. This is caused by the poles at the end which tend to upset the alignment of the domains inside it. To prevent this, magnets are stored in pairs with small soft iron bars, called keepers, placed across their ends. Unlike poles of the magnets are placed adjacent to on another as in figure1.31.

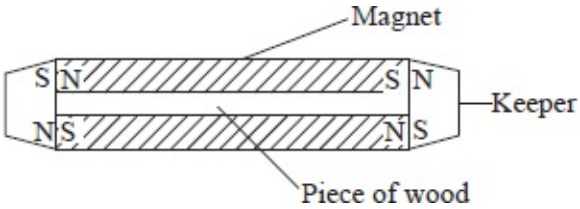



*Fig. 1.31: Magnetic keepers*

The keepers acquire polarities as shown in the figure so that the dipoles in the magnet and the keepers form complete loops.

The dipoles thus retain their orientation and magnetism is maintained.

## Application of Magnets

Magnets have a wide range of uses some of which are elaborated below:

### *(i) Loudspeaker/Microphones*

Loudspeakers convert electrical signals into sound. Magnet in the speaker provides a magnetic field which interacts with the field of varying electrical current fed into the speaker and results in a vibration of the coil of the speaker.



*Fig 1.32: Speakers*

In microphones sound waves are converted into electrical signals with a magnet playing a significant role.



*Fig.1.33: Microphone*

### *(ii) Computer Hard Disk/Recording and reading Head/Video Tapes.*

The head of hard disk of a computer records data on magnetic tapes or stripes in the disk. This is done through magnetisation of magnetic materials in those stripes corresponding to the data input. The reading head together with encoding system in the computer on command by the user reproduce this information for manipulation.



*Fig. 1.34: Computer hard disk*

### *(iii) In Medicine*

Hospitals are employing the use of magnets from the simple extraction of metallic objects from patients, body (e.g., eye) to Magnetic Resonance Imaging (MRI). Figure 1.35 shows an example of M. R. I machine which uses powerful magnet whose fields enable doctors to take pictures of internal parts of human body. This produces photographs with more details than when X- rays are used.

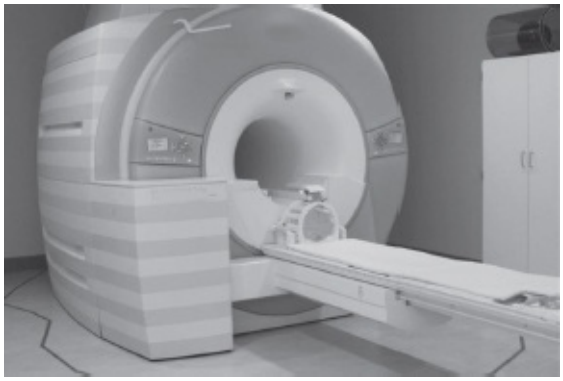


*Fig 1.35: An MRI machine*

Magnets are also used in what is referred to as magnetic therapy where special magnets are used to relief pain and relax the body.

### *(iv) Sorting/Separating*

Magnets are used to sort or separate magnetic materials as in quarries where metal is separated from ore. Very strong magnets are used to recover metallic objects from ocean bed.

### *(v) Magnetic Screw Drivers*

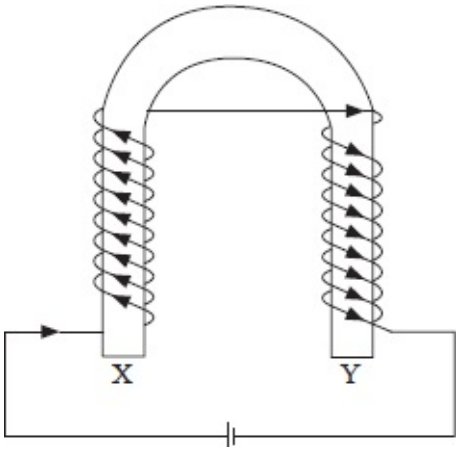
In lifting small screws or putting them in place during repair work, technicians make use of magnetic screw drivers.
See figure 1.36 below.



*Fig. 1.36: Magnetic screw driver*

## Revision Exercise 1

1. Describe two methods of magnetising a steel rod.
2. Compare magnetic properties of steel and iron.
3. Explain why a magnetic material is attracted by a magnet.
4. Explain why iron filings are not suitable for plotting lines of force of a weak magnetic field.
5. Explain why soft iron cannot be used to make permanent magnets.
6. Describe how you would verify the basic law of magnetism.
7. Explain the meaning of the following:
   (a) Magnetic field.
   (b) Magnetic lines of force.
8. Describe how you would shield a magnetic material from a magnetic field. State one application of magnetic shielding.
9. Describe three methods of demagnetising a permanent magnet.
10. Use domain theory to explain the difference between magnetic and non-magnetic materials.
11. A coil of insulated wire is wound around a U-shaped soft iron core XY and connected to a battery as shown in the figure below.




State the polarities of ends X and Y.

12. Explain, with the help of a diagram, what a neutral point of a magnetic field is.
13. (a) With the aid of diagrams, explain how you would magnetise a steel bar so as to obtain a south pole at a marked end of the bar by:
    (i) Using a permanent magnet.

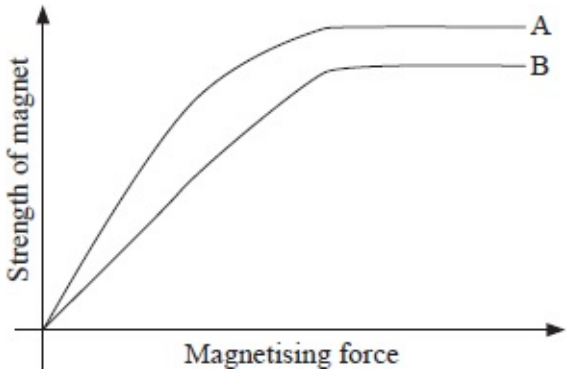
(ii) Using an electric current.

(b) State which of the above methods produces the stronger magnet.

Give a reason.

14. You are given three steel bars. One is magnetised with opposite poles at its ends. Another is magnetised with consequent poles. The third is not magnetised. Describe an experiment which you would perform to identify each.

15. The graphs below are for two magnetic materials:




State:

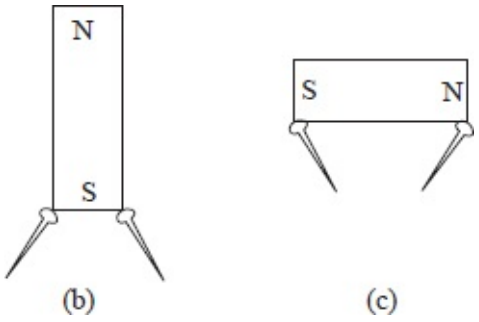
(a) which material is easier to magnetise.

(b) which material forms a stronger magnet.

(c) one application of each.

16. Briefly describe how you can construct a simple plotting compass.

17. In diagrams (a) and (b) below, two pins are attached to magnets as shown:




Explain the behaviour of the pins in each case.

18. Describe four properties of magnets.

19. State five uses of magnets.

# Chapter 2

# Measurement II

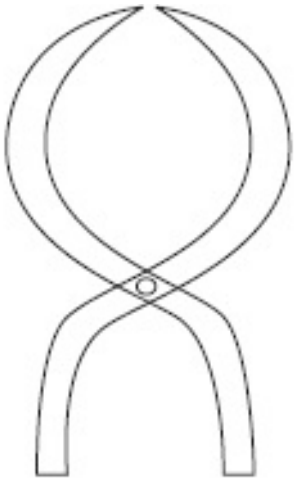
In Measurement I, the basic instrument for measuring length was the meter rule. In this chapter, measurements of lengths such as diameter of a wire and that of a test- tube, which cannot be obtained directly using an ordinary ruler, are done using calipers and micrometer screw gauge. The two types of callipers used are engineer's calipers and vernier calipers.

## Engineer's Callipers

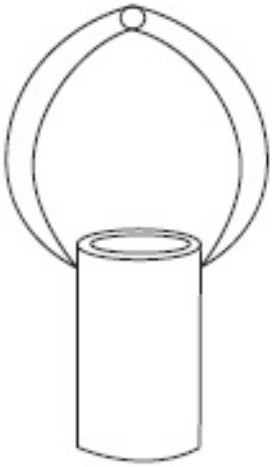
Figure 2.1 (a) shows a pair of engineer's callipers used for measuring lengths on solid objects where an ordinary metre rule cannot be used directly. It consists of pair of hinged steel jaws which are closed until they touch the object at the desired position.

Diameters of round objects can be measured using outside and inside calipers shown in figure 2.1 (b) and (c) respectively.

One kind is changed to the other by turning the jaws round.



(a) Engineer's callipers



(b) Outside callipers



(c) Inside callipers

*Fig. 2.1: Engineer's callipers*

When using the callipers, the jaws are opened just to slip past the cylinder or the widest part of the sphere. The distance between the jaws is then transferred and read on an ordinary millimetre scale, as shown in figure 2.2.

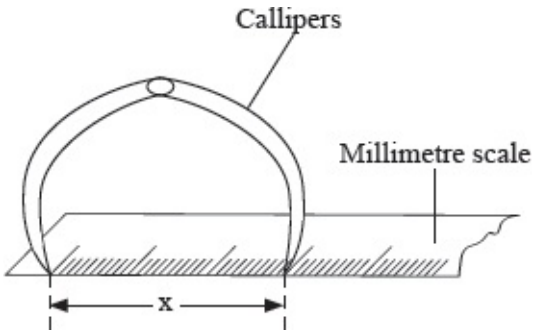



*Fig. 2.2: Measuring length between the jaws of callipers*

## Vernier Callipers

A vernier callipers consists of a steel frame with a fixed jaw and a sliding jaw, as shown in figure 2.3. The steel frame carries the main scale which is graduated in centimetres but also has milimetre divisions.

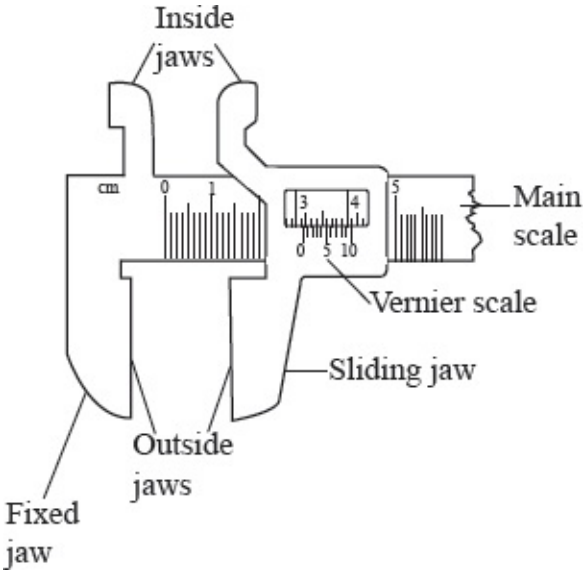



*Fig. 2.3: Vernier calipers*

The sliding jaw carries the vernier scale, which has ten equal divisions.

The length of the vernier scale is 0.9 cm., each division of the vernier scale is 0.09 cm. The difference in length between the main scale division and the vernier scale division is known as the least count.

Least count = (0.1 – 0.09) cm

= 0.01 cm

Most vernier callipers have both inside and outside jaws. The outside jaws are used to measure external diameters while the inside jaws are for measuring the internal diameters.

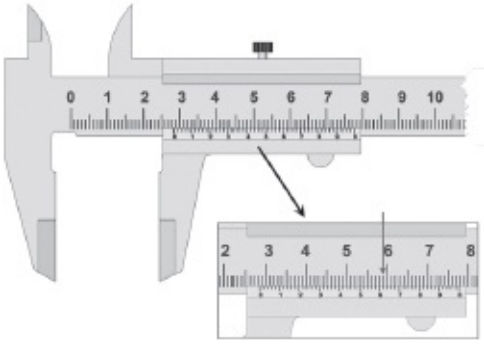



*Fig. 2.4 (a):*

Vernier callipers have small steel metal protruding at the back for measuring depths (depth probe) see figure 2.4 (a) above.

Digital vernier callipers are available in the market, see figure 2.2 (b) below.




*Fig. 2.4 (b): Digital vernier callipers*

## *Using Vernier Callipers*

- Place the object whose diameter is to be measured between the outside jaws. Close the jaws till they just grip the object, see figure 2.5.

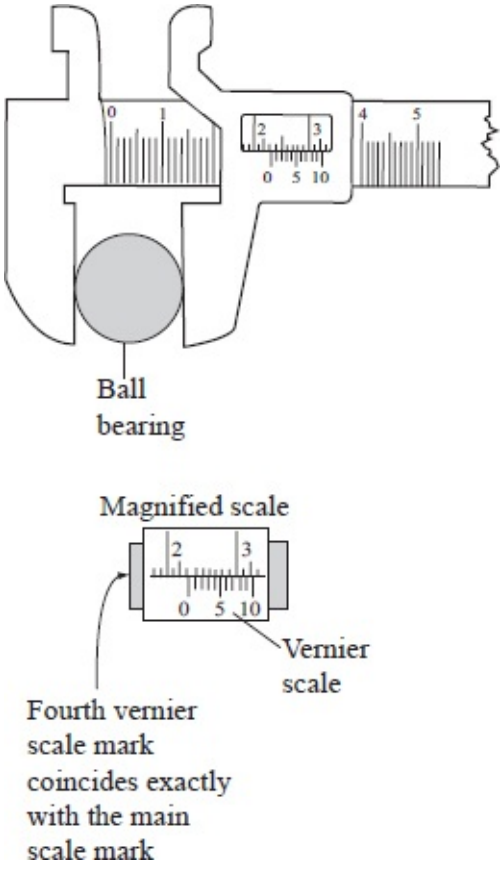



*Fig. 2.5 Using vernier callipers*

- Record the reading on the main scale, opposite and to the left of the zero mark of the vernier scale. From figure 2.5, it is 2.3 cm.
- Read the vernier scale mark that coincides exactly with a main scale mark. The fourth mark of the vernier scale coincides exactly with a main scale mark. This gives a reading of the least count

  = 4 × 0.01

  = 0.04 cm

  The sum of the vernier scale reading and the main scale reading gives the diameter of the ball bearing.

  Therefore, the diameter of ball bearing

  = (2.3 + 0.04 ) cm

  = 2.34 cm

When the readings are taken in centimetres, the reading from the vernier scale gives the second decimal place.

***Example 1***

What is the diameter of the circular disc in the figure below?

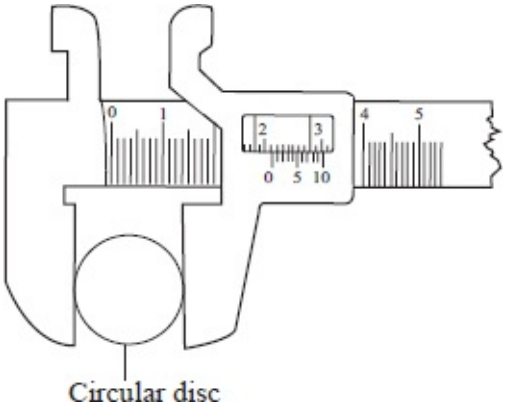



*Fig. 2.6*

*Solution*

Main scale reading = 2.1 cm

The vernier scale mark that coincides with main scale mark is the fourth one.

So,

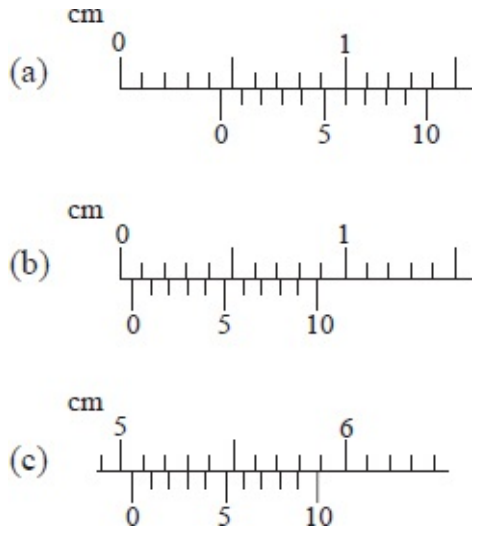
vernier scale reading = 0.02 cm

Diameter of the disc = (2.1 + 0.02) cm

= 2.12 cm

## Exercise 2.1

1. Describe how you would measure the internal diameter of 100 $cm^3$ beaker using vernier callipers.
2. Write down the vernier callipers readings in diagram (a), (b) and (c) below (diagrams not drawn to scale)




3. List down some objects both small and big, whose diameters cannot be measured using vernier callipers.

## *Class Activity*

*Model of a Vernier Callipers*

- Using manila paper, make your own vernier callipers. The main scale should run from 0 cm to 8 cm.
- Measure diameters of different objects using your vernier callipers.
- Repeat the procedure using vernier callipers from the laboratory and compare your results.

## *Zero Error*

When the jaws of the vernier callipers are closed without an object between them, the zero mark of the main scale should coincide with the zero mark of the vernier scale, as shown in figure 2.7.

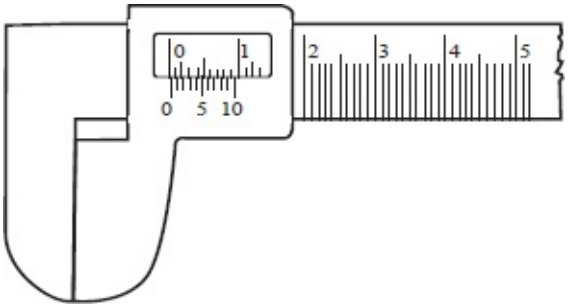



*Fig. 2.7: Vernier callipers with jaws closed*

However, sometimes this may not be the case, as illustrated in figures 2.8 and 2.9.

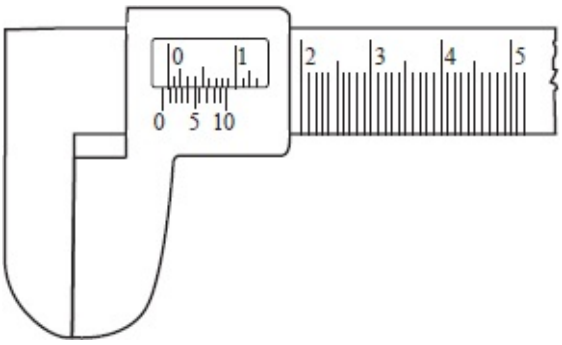



*Fig. 2.8: Vernier callipers with negative zero error*

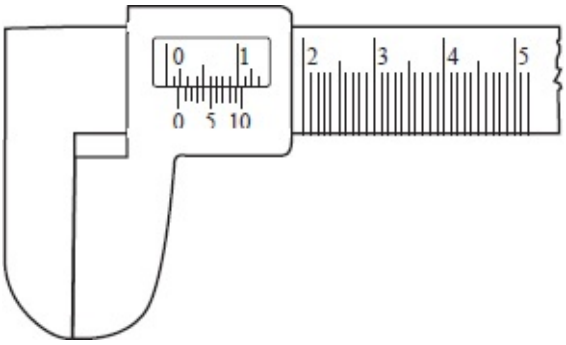



*Fig. 2.9: Vernier callipers with positive zero error*

The vernier calipers are then said to have a zero error. The zero error in figure 2.8 is not the same as the one in figure 2.9.

In figure 2.8, the zero mark of the main scale is to the right of the zero mark of the vernier scale. In this case, the zero error is negative, hence the measured diameter is less than the actual diameter. This is corrected by adding the zero error to the reading.

In figure 2.9, the Zero error is positive. Therefore, the zero error is subtracted from the measured diameter to get the correct value of the diameter.

Measurements taken with such callipers are normally corrected by either adding or subtracting the zero error.

## Exercise 2.2

1. What are the zero errors of the vernier callipers in figures 2.8 and 2.9.
2. If the correct diameter of an object is 3.65 cm, what would be the readings of both callipers for this diameter.
3. The callipers in figure 2.8 was used to measure the diameter of a cylindrical object of height 10 cm and recorded 3.05 cm while the one in figure 2.9 was used to measure the diameter of a spherical object and recorded 3.25 cm. Calculate the correct volumes of these objects in $m^3$. (Take $\pi = 3.142$)

## Micrometer Screw Gauge

The micrometer screw gauge is used to measure small diameters such as the diameter of a thin wire.

A micrometer screw gauge consists of a U-frame carrying an anvil at one end a thimble which carries a circular rotating scale known as the thimble scale and a spindle which can move forward and backwards when the thimble is rotated.

The sleeve has a linear scale in millimetres and the thimble has a circular scale of 50 equal divisions.

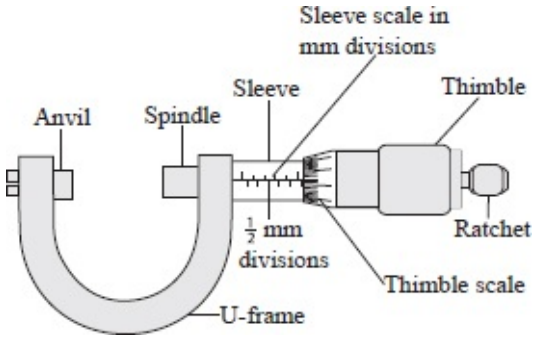



*Fig. 2.10: Micrometer screw gauge*

The ratchet at the end of the thimble prevents the user from exerting undue pressure on an object when the micrometer screw gauge is in use. The linear scale has half-millimetre marks.

This distance moved by the spindle in one complete rotation of the thimble is known as the **pitch** of the micrometer.

In figure 2.10, since the spindle advances or retreats by 0.5 mm per complete rotation of the thimble, the pitch of micrometer is 0.5 mm.

Thus, each division represents a spindle travel of $\frac{0.5}{50}$ mm = 0.01mm.

Hence, if the thimble rotates throught 1 division, the spindle advances by 0.01 mm or 0.001 cm. Some micrometer screw gauges have a pitch of 1.0 mm and 100 divisions on the thimble.

Digital micrometer screw gauge are available in the market, see figure 2.11.




*Fig. 2.11: Digital micrometer screw gauge*

## *Using a Micrometer Screw Gauge*

The object whose diameter is to be found is held between the anvil and spindle (jaws). The micrometer is closed using the ratchet until the object is held gently between the anvil and the spindle. The ratchet will slip when the object is gripped firmly enough to give an accurate reading.

In figure 2.12 the sleeve reading is 10.5, mm and the thimble scale reading is : $\frac{24}{100}$ mm = 0.24 mm.

Thus, the diameter of the marble

= sleeve reading + thimble reading

= 10.5 mm + 0.24 mm

= 10.74 mm

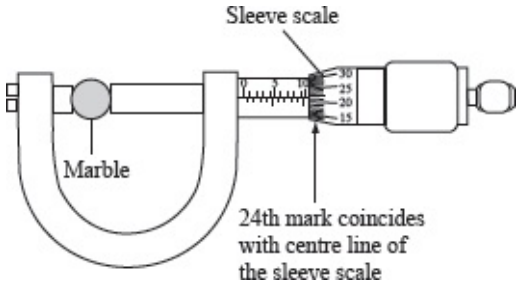
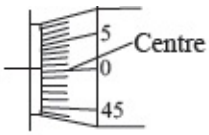



*Fig. 2.12: Using a micrometer screw gauge to measure the diameter of a marble*

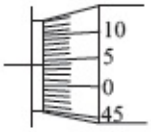
## *Zero Error*

As in the case of vernier callipers, there occurs zero error in the micrometer screw gauge. It arises when the zero mark of the thimble scale does not coincide exactly with the centre line of the sleeve scale when the micrometer is closed. The anvil is usually used for the adjustment of the zero, so that the micrometer has no zero error.

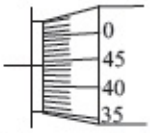
The micrometer in figure 2.13 (a) has no zero error while those in figures 2.13 (b) and (c) have zero errors. Note the position of the zero mark in each case.




(a) Zero mark of thimble scale coincides with the centre line of the sleeve scale




(b) Zero mark of thimble scale does not coincide with the centre line of the sleeve scale. Negative zero error add error to reading




(c) Zero mark of thimble scale does not coincide with the centre line of the sleeve scale. positive zero error subtract zero error from reading

*Fig. 2.13: Zero error in micrometer screw gauge*

***Example 2***

What is the reading of the micrometer screw gauge in figure 2.14?

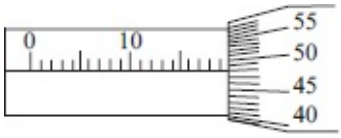



*Fig 2.14*

*Solution*

Sleeve scale reading = 19 mm

Thimble scale reading = 0.48 mm

Hence, micrometer reading = (19 + 0.48) mm

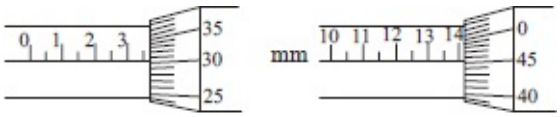
= 19.48 mm

There are other measuring instruments which may also be used to measure

smaller diameters, for example, the bore of a capillary tube. One such instrument is the travelling microscope. This is a microscope mounted on a heavy metallic base with a scale along which the microscope moves up, down and sideways.

## Exercise 2.3

1. What is the reading of a micrometer screw gauge in the figures below:




(a) (b)

2. Compare and contrast the thimble scales of two micrometer screw gauges with pitches of 0.5 mm and 1.0 mm respectively.
3. State the two limitations of the micrometer screw gauge?
4. List down the advantages and disadvantages of the micrometer screw gauge over the vernier callipers.
5. Sketch a micrometer screw gauge scale reading:
   (a) 0.23 mm
   (b) 5.05 mm

## Significant Figures

In measurements, some computations give answers with many digits, for example, 9403.435662. It is advisable to express such a number in simpler form.

The digits 1 and 9 are significant when they appear in a number. The first digit from the left of the number is the first significant figure. In example, 9 is the first significant figure. The number of significant figures is determined by counting the number of the digits from the first significant figure on the left.

Zero is sometimes significant and at times it is merely used as a place holder. When a zero occurs at the left end of a number, it is not significant. For example, the zeros in 0.2 cm, 0.002 m are just place holders. Thus, in number 0.005734, the first significant figure is 5.

If zero occurs between non-zero digits, e.g, as in 7005, it is considered significant. Also, if zero occurs at the right hand end after the decimal point, it is always significant, e.g, 1.0 cm, 1.00 cm, 1.000cm.

If a zero occurs at the right hand end of an integer, it may or may not be significant. For example, the number 750000 could be correct to 2,3,4,5 or 6 significant figures. When the number is expressed to 2 significant figures, none of the zeros is significant. Conversely, to 6 significant figures all the zeros are

significant. On the other hand, the number 995 can be written as 1000 to one significant figure or 1000 to 2 significant figures. None of the zeros in the first case is significant while in the second case, the first zero is significant but the last two are not.

***Example 3***

Find the area of a rectangle that measures 4.26 cm by 2.77 cm and write your answer correct to:

(a) Four significant figures.

(b) Two significant figures.

*Solution*

$$\begin{aligned} \text{Area} &= 4.26 \times 2.77 \text{ cm}^2 \\ &= 11.8002 \text{ cm}^2 \\ &= 11.80 \text{ cm}^2 \text{ to four s.f.} \\ &= 12 \text{ cm}^2 \text{ to two s.f.} \end{aligned}$$

## Standard Form

The range of lengths in the universe is extremely large, from the diameter of your hair to the estimated size of the universe. Writing down these very small and very large lengths in metres is clumsy. This problem can be solved by writing such lengths in standard form.

A positive number is said to be in standard form when written as $A \times 10^n$ where A is such that $1 \leq A < 10$ and index n is an integer.

For example, the number 9327 when written in standard form would be $9.327 \times 10^3$.

Note that in this case, A is equivalent to 9.327 and the index n = 3 is positive because the decimal point after the last digit has been moved to the left.

However if the number lies between 0 and 1, then the index n becomes negative. For example, 0.009327 in standard form is $9.327 \times 10^{-3}$.

***Example 4***

Express each of the following numbers in standard form:

(a) 201

(b) 2670

(c) 0.087

(d) 0.0000009047

Solution

(a) $201 = 2.01 \times 10^2$

(b) $2670 = 2.670 \times 10^3$

(c) $0.087 = 8.7 \times 10^{-2}$

(d) $0.0000009047 = 9.047 \times 10^{-7}$

The use of standard form in expressing length, mass and time is a convenient means of writing large and small quantities. For example, the distance of the sun from the earth is estimated as $1.5 \times 10^8$ km and the mass of an electron is given as 9.1 × 10-31 kg.

## The Oil Drop Experiment

This is an experiment to estimate the size of a molecule in an ordinary laboratory.

### *Theory*

When an oil drop is carefully put in contact with the surface of water, it spreads out to form a very thin layer, which is almost circular. This is because the oil breaks the surface tension of the water, whose particles pull away from the oil. The thin layer can be approximated to be one molecule thick.

### *Estimating the Volume of an Oil Drop*

***Method 1***

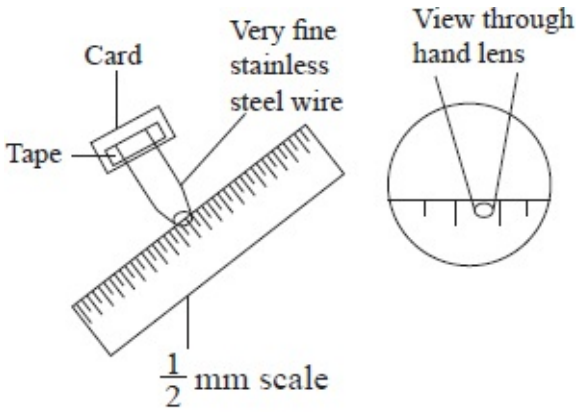
- Fill a $1cm^3$ graduated burette with oil.
- Count the number of drops as they are squeezed out of the pipette. Let the number be y.
- If the number of drops is y, then the average volume occupied by the one drop is $\frac{1}{y}$ $cm^3$.

***Method 2***

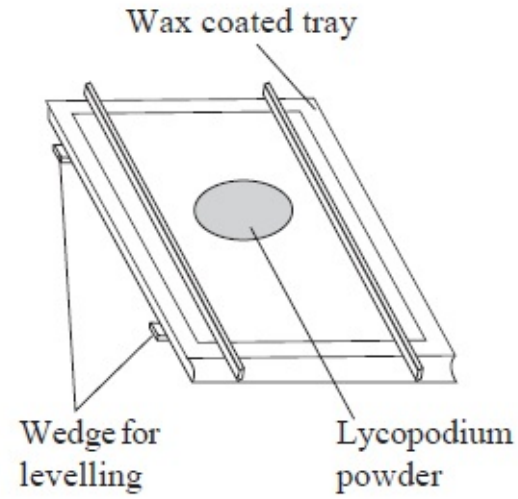
- Hold a drop of the oil in front of a fine millimetre scale using a fine wire and view it through a magnifying glass. See figure 2.15 (a)
- Read off the diameter of the oil drop.
- Assuming that it is spherical, its volume is given by $V = \frac{4}{3}\pi\left(\frac{d}{2}\right)^3$

*To obtain a Mono Layer of Oil Patch*

- Fill a level tray with water until it overflows.
- Clean the surface of water by moving a wax-coated rod across it.
- Place two waxed beams at the centre of the tray and slide them towards the edges of the tray. They will be used to estimate the diameter of the spread.
- Sprinkle lycopodium powder lightly on the water surface.
- Touch the surface of the water with the drop until it spreads on the surface. The area covered by the oil is seen as a clear circular patch of oil left as the water particles pull away from it, see figure 2.15 (b).
- Adjust the rods and use a metre rule to estimate the diameter of the patch, say $d_1$. Repeat the same steps three or four times and get the average diameter.




(a) Estimating the volume of drop




(b) Obtaining monolayer of oil

*Fig. 2.15 Estimating the volume of an oil drop*

*Data Analysis*

Average diameter of the patch,

$$d_{av} = \frac{d_1 + d_2 + d_3}{3}$$

Area of the patch = $\pi r^2$

$$= \pi\left(\frac{d_{av}}{2}\right)^2$$

Volume of the oil drop = area of the patch (A) × thickness of the patch (h)

Thus, $V = \pi\left(\frac{d_{av}}{2}\right)^2 \times h$

Therefore, $h = \frac{4V}{\pi (d_{av})^2}$

The oil drop experiment can be used to determine the extent of environmental damage caused by oil spillage from ships.

***Example 5***

In an experiment to estimate the size of a molecule of olive oil, a drop of oil volume 0.12 $mm^3$ was placed on a clean water surface. The oil spread into a patch of area $6.0 \times 10^4$ $mm^2$. Estimate the size of a molecule of olive oil.

*Solution*

Volume of the drop = 0.12 $mm^3$

Area of the patch = $6.0 \times 10^4$ $mm^2$

$$\text{Thickness, t, of patch} = \frac{V}{A}$$

$$= 0.12$$

$$= \frac{0.12}{6.0 \times 10^4}$$

$$= 2.0 \times 10^{-6} \text{ mm}$$

Thus, thickness, $t = 2.0 \times 10^{-9}$ m

This is the thickness of an oil molecule in a mono layer of olive oil.

## Prefixes used with SI Units

Table 2.1 shows the mutiples and sub-mutiples used with SI units, their prefixes and symbols for these prefixes.

*Table 2.1: Prefixes Used with SI Units*

| | | |
|---|---|---|

| *Sub-multiple/multiple* | *Prefix* | *Symbol for prefix* |
|---|---|---|
| $10^{-1}$ | deci | d |
| $10^{-2}$ | centi | c |
| $10^{-3}$ | milli | m |
| $10^{-6}$ | micro | μ |
| $10^{-9}$ | nano | n |
| $10^{-12}$ | pico | p |
| $10^{-15}$ | femto | *f* |
| $10^{-18}$ | atto | a |
| $10^{1}$ | deca | da |
| $10^{2}$ | hecto | h |
| $10^{3}$ | kilo | k |
| $10^{6}$ | mega | M |
| $10^{9}$ | giga | G |
| $10^{12}$ | tera | T |
| $10^{15}$ | peta | P |
| $10^{18}$ | exa | E |

1 μs= $10^{-6}$ s

1 s =$10^{6}$ μs

5kg =5 × $10^{3}$ g

## Exercise 2.4

1. Write the following correct to:
   (a) Two significant figures.
   (b) Three significant figures.
      (i) 7321 769
      (ii) 657.65
      (iii) 27.002
      (iv) 0.001895
      (v) 0.0008996

2. The dimensions of a cuboid are 6.35 cm × 4.75 cm × 0.74. Find its volume correct to:
   (a) Five significant figures.
   (b) Four significant figures.
   (c) Three significant figures.
   (d) Two significant figures.
3. Express the following numbers in standard form:
   (a) 0.00123
   (b) 0.000000001
   (c) 1.5
   (d) 15
   (e) 1595
4. Express the following numbers in an ordinary form:
   (a) $6.6 \times 10^{-5}$
   (b) $1.257 \times 10^{-2}$
   (c) $7.126 \times 10^{3}$
   (d) $9.99 \times 10^{4}$
   (e) $8.1234 \times 10^{1}$
5. Express each of the following in $cm^2$, giving your answer in standard form:
   (a) 8.4 $m^2$
   (b) 40.2 $m^2$
   (c) 0.08 $m^2$
6. Express each of the following in $m^2$, giving your answer in standard form:
   (a) 7.5000 $cm^2$
   (b) 0.07 $cm^2$
7. Express each of the following volumes in $cm^3$, giving your answer in standard form:
   (a) 14 $mm^3$
   (b) 0.002 $mm^3$
8. Express each of the following volumes in $m^3$, giving your answer in standard form:
   (a) 3000 $cm^3$
   (b) 0.00039 $cm^3$

## Decimal Places

The number of digits to the right of the decimal point determine the accuracy of

the number given. For example, if the number is given as 6.0234, it is said to be accurate to four decimal places. The same number could be written as:

6.023 to 3 decimal places.

6.02 to 2 decimal places.

6.0 to 1 decimal place.

6 to the nearest whole number.

The number 6.0234 represents the highest degree of accuracy, followed by 6.023. If written as 6, it has the least degree of accuracy.

Similarly, $\pi = 3.1415926$. This is accurate to 7 decimal places. When expressed as 3.142, it is correct (to 3 decimal places). For working purposes $\pi$ is given as 3.142 correct to 3 decimal places. While using a millimetre scale, a reading of 5.4 cm would be accurately measured. However, a reading of 5.47 cm can only be given by making an estimate of the second decimal. Therefore, the reading given by an ordinary ruler is only accurate to the first decimal place (d.p).

***Example 6***

Find the area of the rectangle measuring 3.93 cm by 5.35 cm. Express your answer correct to 2 d.p.

*Solution*

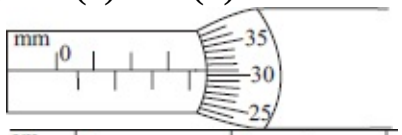
$$\begin{aligned} \text{Area} &= 3.93 \times 5.35 \text{ cm}^2 \\ &= 21.0255 \text{ cm}^2 \\ &= 21.03 \text{ cm}^2 \end{aligned}$$

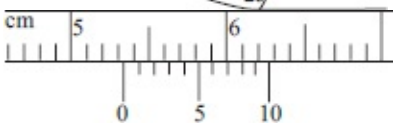
## Revision Exercise 2

1. Express each of the following in millimetres, giving the answer in standard form:
   (a) 3.7 m
   (b) 0.94 m
   (c) 7.0 km
2. Express the following in grams, giving the answer in standard form;
   (a) 25 kg
   (b) 0.89 kg
   (c) 3.0 tones
3. Write down the number of significant figures in each of the following:

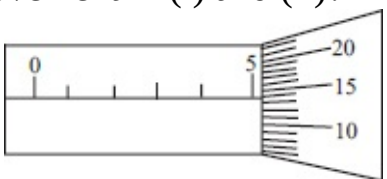
(a) 60000
(b) 523.7
(c) 805
(d) 0.000030
(e) 0.0037
(f) 0.0207

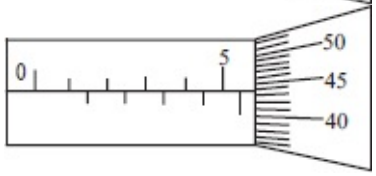
4. Write each of the following numbers in standard form:
   (a) 308 000 000
   (b) 0.000457
   (c) 0.000002394
5. Write down each of the following in standard form to 2 significant figures.
   (a) 1000 kg
   (b) 1 000 000 m
   (c) 0.0000037 kg
   (d) 693
   (e) 569 000 000
   (f) 32 067
6. Determine are the readings on the micrometer and vernier scales shown in figures (a) and (b) below.

(a)



(b)


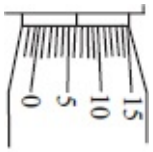

7. (a) Write down the micrometer screw gauge readings shown in figures (i) and (ii) below.
   (b) How many complete revolutions of the thimble correspond to 1mm movement in (i) and (ii)?

(i)


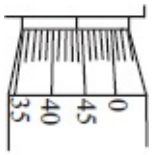

(ii)



8. What are the zero errors of the micrometer screw gauges in figures (a) and (b) below? (the micrometers are closed). If the micrometers were used to

measure the diameter of a wire whose diameter is 1.00 mm, what would be the reading on each?

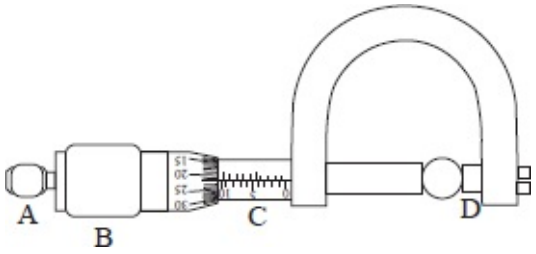



(a) –ve

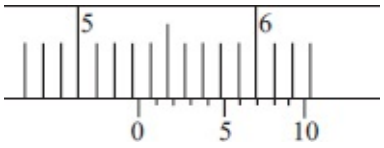



(b) +ve

9. In the figure of the micrometer screw gauge below:
   (a) Label the parts marked A, B, C and D.
   (b) State the readings shown by the scale.




10. State the readings on the vernier scale below:




11. If an oil drop of diameter 0.5 mm spreads on the surface of water to form an oil patch of diameter 0.2 m, estimate the thickness of the oil molecule and express your answer to two significant figures.

# Chapter 3

# Turning Effect of a Force

## Moment of a Force

One of the effects of a force is that it can make a stationary body move. This topic dwells on cases when a force applied on an object makes the object turn about a given point known as the pivot or fulcrum. This turning effect of a force is called the moment of force. Example of activities in which a force produces a turning effect are closing opening a door, steering a car, turning off a water tap, cycling or riding on a see-saw, tightening a nut using a spanner and opening a soda bottle.

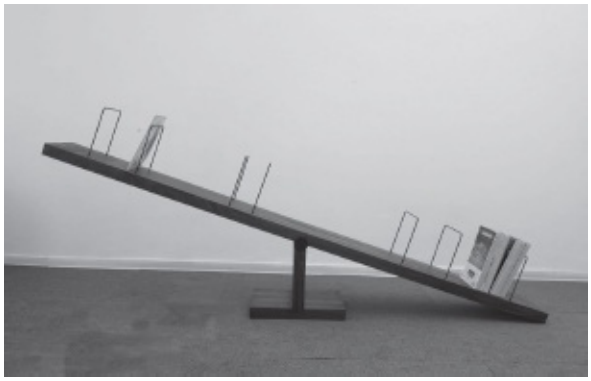


*Fig. 3.1: See-saw*

### Experiment 3.1: To investigate the turning effect of a force

*Apparatus*

Half-metre rule, three 50 g masses, two 200 g masses, string.

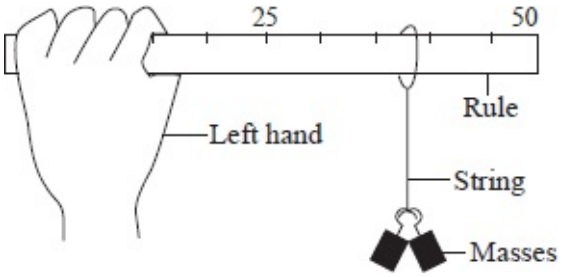



*Fig. 3.2: Turning effect of a force*

*Procedure*

- Tie two masses of 200 g each to the string and suspend them from a half-metre rule.
- Hold the rule horizontally, as shown in figure 3.2.
- Vary the position of the masses. Note the variation of the turning effect on your hand.
- Repeat the experiment by hanging the two masses at a particular point and then add three more masses of 50g one at a time.

*Observation*

The turning effect on the hand feels greater as the masses are moved farther. The twisting effect of your hand feels is the turning effect (or moment) of a force. The moment of a force about a point depends on the magnitude of the force and the distance of the force from the point of support. The maximum turning effect at any point is obtained when the distance from the point of support is perpendicular to the line of action. At point A in figure 3.3, the maximum turning effect is obtained when the fore F is applied perpendicularly to the distance from the point of support as in (ii)

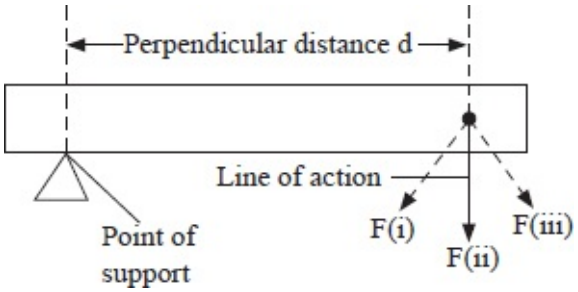



*Fig. 3.3: Maximum moment of a force*

The moment a force is its turning effect on ability to make an object to turn about a given point. It is the product of the force (F) and the perpendicular distance between the point of support and the line of action of the force.

Thus, moment of a force

= force perpendicular distance

$= F \times d$

The moment of a force is increased when the perpendicular distance from the line of action of the force to the pivot is increased. Thus, it is easier to loosen or tighten a nut using a spanner with a long handle than one with a short handle.

The SI unit of moment of a force is Newton-metre (Nm).

***Example 1***

Find the moment of the force about O in the following figures:

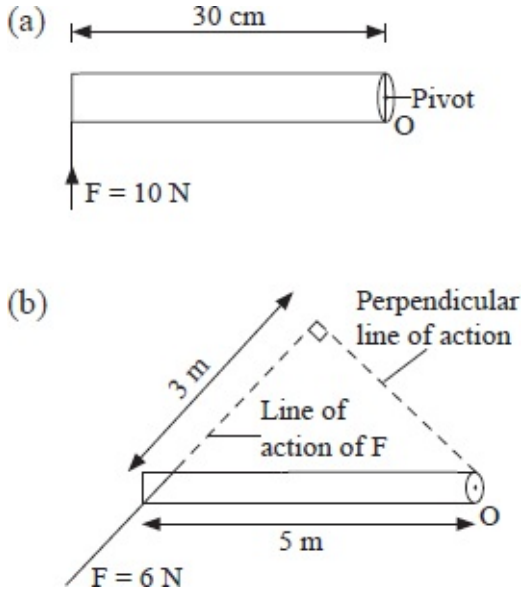



*Fig. 3.4*

*Solution*

(a) Moment of a force = force × perpendicular distance from the pivot.
Therefore moment of force about O
= 10 N × 0.3 m
= 3 Nm

(b) Note that the perpendicular distance between the line of action of force and the turning point, d, is not given.
Since if forms a right angle with the line of action, then, using Pythagoras theorem,
$5^2 = 3^2 + d^2$
$d^2 = 25\text{-}9$
$d^2 = 16$
d = 4 m
Therefore, moment of force about O
= 6 N × 4 m
= 24 Nm

## The Principle of Moments

**Experiment 3.2: To verify the principle of moments**

*Apparatus*

Metre rule, known weights.

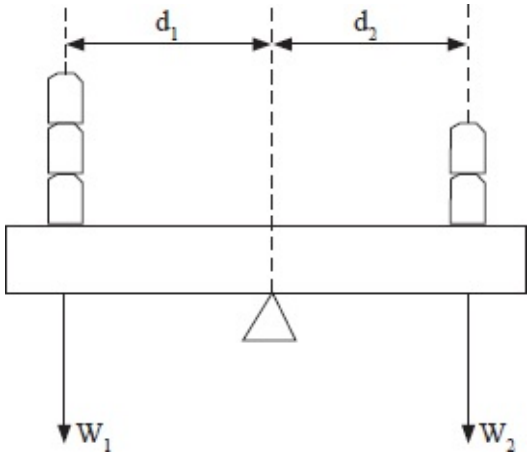



*Fig. 3.5*

*Procedure*

- Balance a metre rule (or any other uniform rod) on a pivot at its centre, a known distance d.
- Place a known weight $W_1$ on one side of the pivot and balance it with a different known weight, $W_2$ on the other side, see figure 3.5.
- Record the values $W_1$ $d_1$, $W_2$ at a known distance $d_1$ and $d_2$ in Table 3.1.
- Repeat using different values of $W_1$, $d_1$, and $W_2$
- Complete $W_1 \times d_1$ and $W_2 \times d_2$ for each set of figures and fill in table 3.1 $W_1$, $d_1$, $W_2$.

*Table 3.1*

| $W_1$ (N) | $d_1$ (m) | $W_1d_1$ (Nm) | $W_2$ (N) | $d_2$ (m) | $W_2d_2$ (Nm) |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

- Compare $W_1 \times d_1$ with $W_2 \times d_2$ for each setting.

*Observation and Conclusion*

The force $W_1$ in figure 3.5 tends to make the rule turn in an anticlockwise direction. The moment due to $W_1$ is therefore referred to as an anticlockwise

moment. Similarly, the force $W_2$ tends to make the rule turn in a clockwise direction. It's moment about the pivot is a clockwise moment.

Clockwise moment = $W_2 \times d_2$

$= W_2d_2$

Anticlockwise moment = $W_1 \times d_1$

$= W_1d_1$

At equilibrium, $w_1d_1 = W_2d_2$

**The principle of moments states that for a system in equilibrium, the sum of clockwise moments about a point must be equal to the sum of anticlockwise moments about the same point.**

***Example 2***

A uniform metre rule pivoted at its centre is balanced by a force of 4.8 N at 20 cm mark and some other two forces. F and 2.0 N at the 66 cm and 90cm marks respectively. Calculate the force F.

*Solution*

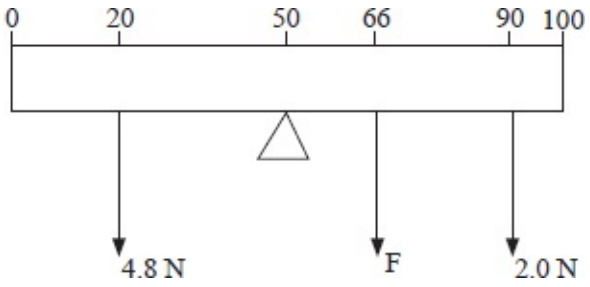



*Fig. 3.6*

Distance of 4.8 N from the pivot

= 50 – 20

= 30 cm

= 0.3 m

Distance of F from pivot

= 66 – 50

= 16 cm

= 0.16 m

Distance 2.0 N from pivot

= (90 – 50) cm

= 0.4 m

Sum of clock wise moments

= (F × 0.16) + (2.0 × 0.4)

= 0.16 F + 0.8

Sum of anticlockwise moments

= 4.8 × 0.3

= 1.44

At equilibrium;

Sum of clockwise moments = sum of anticlockwise moments

Therefore, 0.16 F + 0.8 =1.44

$0.16\ F = 0.64$

$$F = \frac{0.64}{0.16}$$

$F = 4.0\ N$

## Moment Due to Weight of an Object

Consider a uniform metre rule suspended at its 50 cm mark by a loop of cotton thread from spring balance. The reading of the spring balance gives the weight W, of the metre rule. This weight acts at the midpoint since the rule balances horizontally, as in figure 3.8.

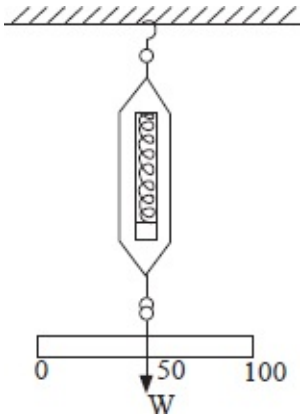



*Fig. 3.8*

If the pivot is not placed at the midpoint of the metre rule, the weight of the metre rule acting at the midpoint will be considered alongside the other forces in the system. The weight of the metre rule then has a moment about the fulcrum.

Now consider a uniform metre rule balanced by a weight of 1N with the pivot placed at the 40 cm mark as shown in figure 3.9

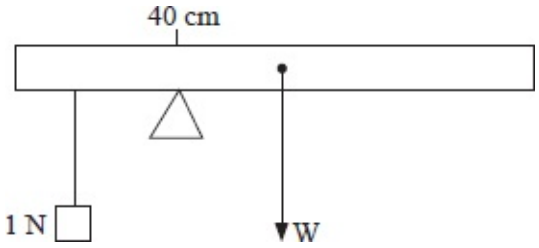



*Fig. 3.9: To determine the weight of a uniform metre rule*

Since the weight W of the metre rule acts at its midpoint, the weight, W, is determined as below:

Clockwise moments = anticlockwise moments

W (50 – 40) = 1(40 – P)

1 × W = 40 – P

For a system of parallel forces in equilibrium, the sum of forces in either direction are equal.

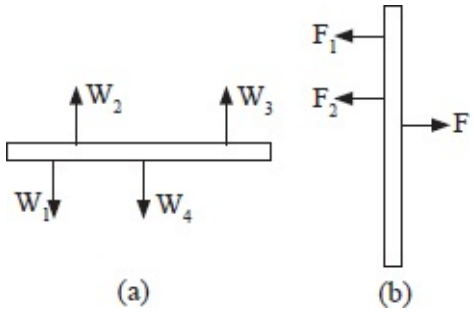



*Fig 3.10: Parallel forces*

Thus, in figure 3.10 (a)

$W_2 + W_3 = W + W_1$

And in figure 3.10 (b) $F_1 + F_2 = F$

**Experiment 3.3: To study parallel forces**

*Apparatus*

Two spring balances, known weights, metre rule.

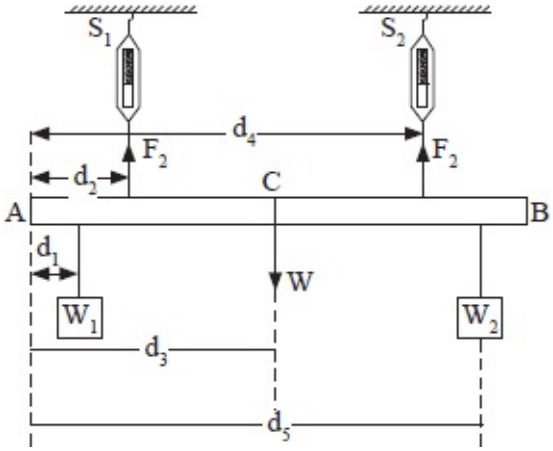



*Fig. 3.11: Balancing forces.*

*Procedure*

- Suspend the metre rule horizontally from two spring balances $S_1$ and $S_2$, as shown in figure 3.11.
- Suspend two known weights $W_1$ and $W_2$ and adjust their positions until the metre rule is horizontal and the spring balances vertical.
- Observe the readings on $S_1$ and $S_2$, note that the forces $F_1$ and $F_2$ (on $S_1$ and $S_2$ respectively) are acting vertically upwards while $W_1$, $W_2$ and W are acting vertically downwards.
- Measure the distances of $W_1$, W, $W_2$, $S_1$ and $S_2$ from any fixed point. Say A.
- Repeat the experiment by altering the weights $W_1$ and $W_2$.
- Record your observations in a table as shown below.

*Table 3.1*

| *Downward forces (in Newtons)* | | | | *Upward forces (in Newtons)* | | |
|---|---|---|---|---|---|---|
| $W_1$ | $W_2$ | W | $W_1 + W_2 + W$ | $F_1$ | $F_2$ | $F_1 + F_2$ |
| | | | | | | |

*Observation*

The sum of the vertically upward forces is equal to the sum of the vertically downwards forces. Thus, if we take forces in one direction to be positive and those in the opposite direction negative, then the algebraic sum of parallel forces is zero.

## Moments of Parallel Forces

In figure 3.10, the moments of $F_1$ and $F_2$ about the point A are $F_1$ and $d_2$ and $F_2$ and $d_4$ respectively. Forces $F_1$ and $F_2$ produce anticlockwise moments about point A and their sum $F_1d_1 + F_2d_4$

Forces $W_1$, W and $W_2$ produce clockwise moments about A. Their sum is: $W_1d_1 + Wd_3 + W_2d_5$

It can be shown that;

The sum of clockwise moments = the sum of anticlockwise moments, i.e., the algebraic sum of the moments of the parallel forces is zero.

***Example 3***

Figure 3.12 shows a uniform metre rule of weight 1.6 N supported by spring balance at the 32 cm mark. The metre rule is balanced horizontally by a 1.2 N weight suspended as shown. Find:

(a) The point where the 1.2 N is suspended.

(b) The reading on the spring balance.

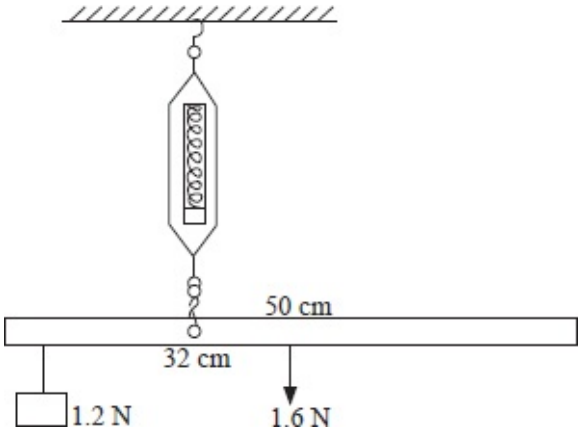



*Fig. 3.12*

*Solution*

(a) Since the metre rule is uniform, its weight acts through its centre, i.e, the 50 cm mark. Taking moments about the 32 cm mark and letting the 1.2 N weight be d m from the 32 cm mark:

Anticlockwise moments = clockwise moments

$1.2 \times d = 1.6 \times (0.50 - 0.32)$

$1.2d = 1.6 \times 0.18$

$$d = \frac{1.6 \times 0.18}{1.2}$$

$D = 0.24$ m

Therefore, the 1.2 N should be suspended at the (32 – 24) cm mark, i.e. the 8 cm mark.

(b) Since the rule is balanced, upward forces =downward forces. Hence, reading on the spring balance
= 1.6 +1.2
= 2.8 N

## Equal Parallel Forces in Opposite Directions

When a cyclist makes a turn, one hand applies an inward force while the other applies an outward force on the handlebars. These two forces assist each other in turning the bar.

Such pair of forces that are equal, parallel and acting in opposite directions are referred to as anti-parallel forces or a couple. Other examples are:

(i) Forces applied on a wheel spanner tightening or untightening a nut.

(ii) Forces applied when opening a water tap.

(iii) Forces applied on a steering wheel of a car when going round a bend.

In all the examples above, a pair of anti-parallel forces produces a turning effect.

Figure 3.13 shows two equal, parallel and opposite forces acting on a metre rule. If the forces are d metres apart, then the turning effect is calculated as follows:

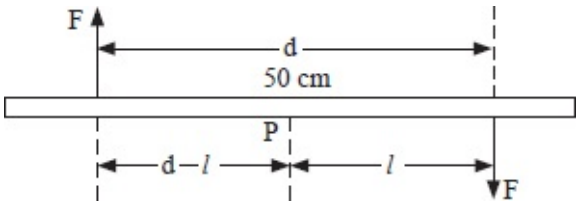



*Fig. 3.13: Anti-parallel forces acting on a metre rule*

Taking moments about a point p, l m from one of the forces, moment due to one force = F × *l*

Moments due to the other force

= F × (d – *l*)

Total moments = F × *l* + F × (d – *l*)

= F*l* + Fd – F*l*

= Fd

The expression shows that the **moment of anti-parallel forces is the product of one of the forces and the perpendicular distance between them.**

***Example 5***

Two vertical, equal and opposite forces act on a metre rule at the 12 cm and 80 cm marks respectively. If each of the forces has a magnitude of 3.6 N, calculate their moment on the metre rule about 28 cm mark.

*Solution*

Moment due to the upward force

= 3.6 (0.28 – 0.12)

= 3.6 × 0.16

= 0.576 Nm

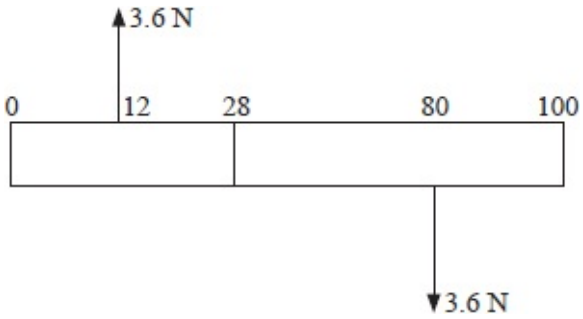



*Fig. 3.14*

Moment due to the downward force

= 3.6 × (0.80 – 0.28)

= 3.6 × 0.52

= 1.872 Nm

Total moment = 0.576 +1.872

= 2.448 Nm

*Alternatively*,

Total moment = one of the forces × perpendicular distance between them.

=3.6 × (0.80 – 0.12)

= 3.6 × 0.68

= 2.448 Nm

***Example 6***

Figure 3.15 shows two parallel forces $F_1$ and $F_2$ acting in opposite directions along the sides AD and CB of a rectangular horizontal plate ABCD.

Two equal and opposite forces of 3 N act along the sides CD and AB.

The plate measures 0.8 m by 0.6 m. Calculate $F_1$ and $F_2$, given that the plate does not rotate.

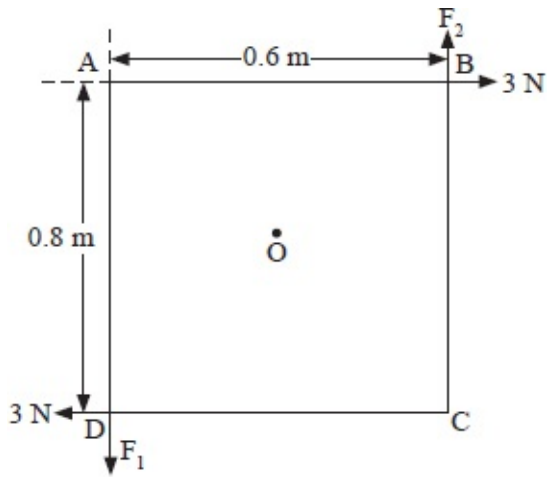



*Fig. 3.15*

*Solution*

Since the plate does not rotate, the moments of the forces must be equal and opposite.

Taking moments about A;

$3 \times 0.8 = F_2 \times 0.6$

$$F_2 = \frac{2.4}{0.6}$$

$= 4.0$ N

Also taking moments about C;

$F_1 \times 0.6 = 3 \times 0.8$

$$F_1 = \frac{2.4}{0.6}$$

$$F_1 = 4 \text{ N}$$

Therefore, $F_1 = F_2$

## *Class Activity*

$F_1$ and $F_2$ by taking moments about B, D and O. Explain what happens.

***Example 7***

For the hammer in figure 3.16, how large is the force applied to the nail when the force on the handle is 320 N? Assume the force applied to the nail is vertical. Take the lengths x = 0.8 cm and y =10 cm.

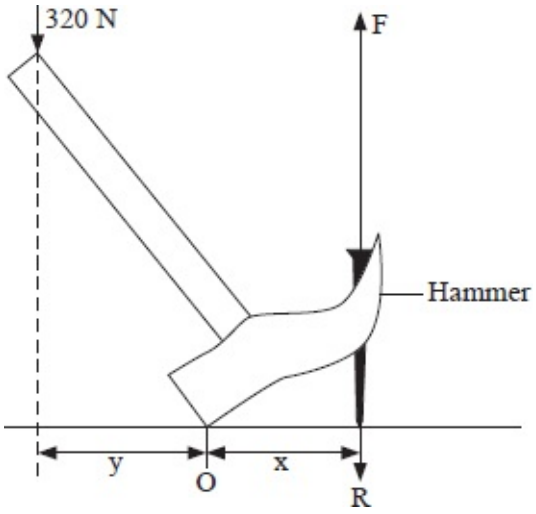



*Fig. 3.16*

Assumption: The force (F) applied to the nail = The resistance (R) the nail offers to being pulled out.

*Solution*

$$R \times \frac{0.8}{100} = 320 \times \frac{10}{100}$$

$$R \times 0.008 = 320 \times 0.1$$

$$R = \frac{32}{0.008}$$

$$R = F = 4000 \text{ N}$$

## Applications of Anti-parallel Forces

### *Steering wheel*

Cars are made to turn round corners by exerting two equal and opposite forces, F, acting tangentially to the steering wheel as shown in figure 3.17.

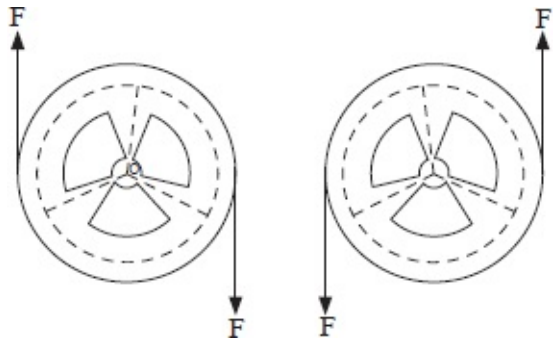



*Fig. 3.17: Anti-parallel forces on a steering wheel*

The wheel is pivoted at its centre O, and rotates about O in a clockwise or

anticlockwise direction. The two forces form a moment of anti-parallel forces about O.

If the diameter of a wheel is D, the the turning effect of the two forces is given by the product of one force and the diameter, i.e moment of the anti-parallel forces = F × D Nm.

Heavy commercial vehicles have larger steering wheels to enhance the turning effect of the vehicle.

### *Water tap*

A water tap is opened or closed by applying two equal and opposite forces as shown in figure 3.18 (a) and (b). The two forces produce a moment about the axis of rotation O.

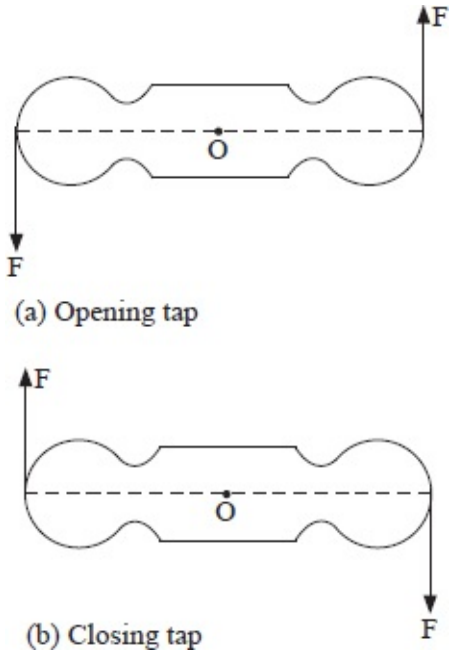



*Fig. 3.18: Anti-parallel forces on a water tap.*

In figure 3.18 (a), the forces produce an anticlockwise turning effect, hence opening the tap. In figure 3.18 (b), the clockwise turning effect of the two forces closes the tap.

### *Bicycle Handle-bars*

When a bicycle is turned round a bend with both hands on the handlebars, two equal and opposite forces are applied, see figure 3.19.

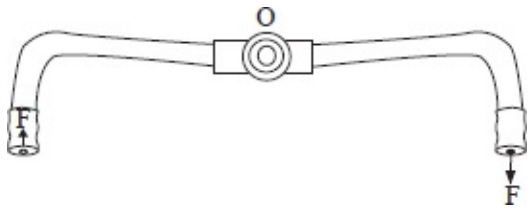



*Fig. 3.19: Anti-parallel forces on bicycle handle-bars*

These forces constitute anti-parallel forces which produce a moment about the axis of rotation, O.

Anti-parallel forces and their moments are also applied in water sprinklers and wheel spanners, see figure 3.20.

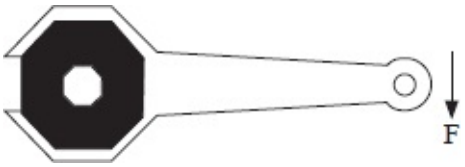
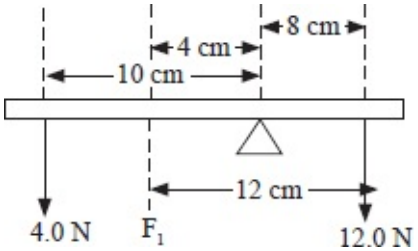


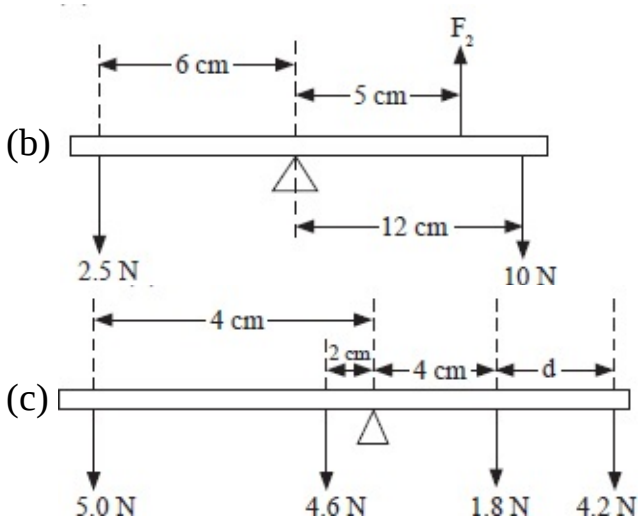

*Fig. 3.20: Wheel spanner*

## Revision exercise 3

1. A boy of mass 40 kg sits at point of 2.0 m from the pivot of a see-saw. Find the weight of a girl who can balance the see-saw by sitting at a distance of 3.2 m from the pivot. (Take g = 10 $Nkg^{-1}$)
2. Explain why :
   (a) It is easier to loosen a tight nut using a spanner with a long handle than one with a short handle.
   (b) The handle of a door is usually placed as far as possible from the hinges.
3. The diagram centres below shows uniform bars balanced about their canters by different forces. Calculate the unknown distance and forces marked in each case.

(a)






4. (a) State the principle of moments.
   (b) A uniform metre rule of mass 120 g is pivoted at the 60 cm mark. At what point on the meter rule should a mass of 50 g be suspended for it to balance horizontally?
5. A uniform metal rod of length 80 cm and mass 3.2 kg is supported horizontally by the two vertical springs balances C and D. Balance C is 20 cm from one end while balance D is 30 cm from the other end. Find the reading on each balance.
6. A uniform metre rod of length 5.0 m is suspended horizontally from two vertical string P and Q is attached at 0.8 m from one end while Q is attached at 2.0 m from the other end. Given that the weight of the metal rod is 110 n; calculate the tension in each of the strings.
7. A uniform metre rule of mass 150 g is pivoted freely at the 0 cm mark. What force applied vertically upwards at the 60 cm mark is needed to maintain the rule horizontally?
8. A uniform metre rule is balanced at the 30 cm mark when a mass of 50 g is hanging from its zero cm mark. Calculate the weight of the rule.
9. A metre rule is balanced by masses of 24 g and 16 g suspended from its ends. Find the position of its pivot.
10. A metre rule is pivoted at its centre. A glass block is hanged from one end and the rule is balanced horizontally by hanging masses of 100 g and 50 g at 60 cm and 80 cm marks respectively. Calculate the mass of the glass block.

# Chapter 4

# Equilibrium and Centre of Gravity

A metre rule suspended with a string as shown in figure 4.1 is found to balance when the point of suspension is at a particular position on the ruler.

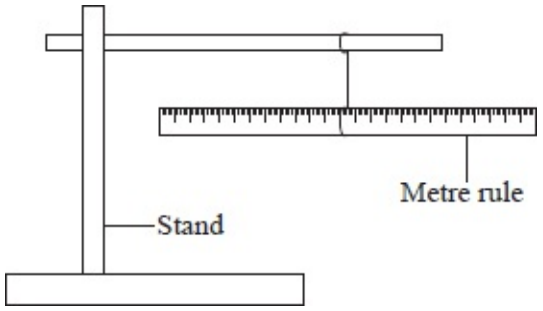



*Fig. 4.1*

The metre rule can be thought of as being made up of numerous tiny particles of wood, each having a small gravitational force acting on it, see figure 4.2.

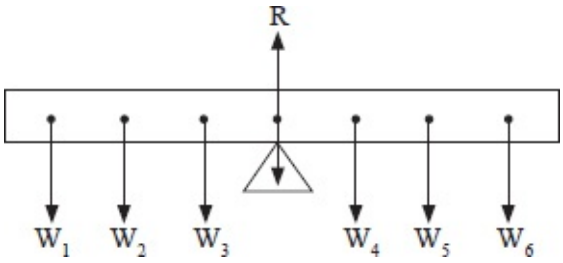



*Fig. 4.2: Weights of particles in wood*

The rule will only balance at a particular point where the turning effects of the gravitational forces acting on the tiny particles cancel out, see figure 4.3 The rule is then said to be in a state of balance or in equilibrium. The gravitational forces on the particles of wood can be represented by a single downward force which acts at the point shown in figure 4.3. The resultant force is the weight (W = mg) of the rule. The point is called the **centre of gravity**.

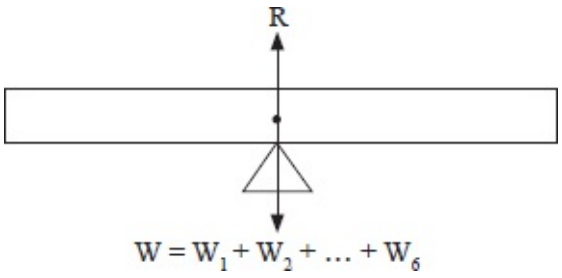



*Fig. 4.3*

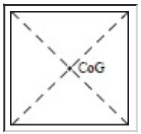
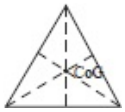
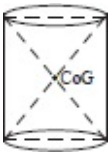
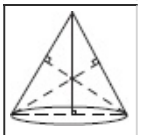
Thus, the centre of gravity of a body is the point of application of the resultant force due to the earth's attraction on the body.

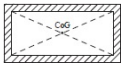
## Centre of Gravity of Regular Shapes

The centre of gravity for a uniform body lies at the geometrical centre.

The centre of gravity can be determined by construction, as shown in Table 4.1.

*Table 4.1: Centre of gravity (CoG) of regular shapes*

| *Object* | *Diagram* | *Centre of Gravity* |
|---|---|---|
| Square plate |  | Construct the diagonals. The point of intersection is the centre of gravity. |
| Rectangular plate |  | Construct the diagonals. The point of intersection is the centre of gravity. |
| Triangular plate |  | Construct the perpendicular bisectors of the sides. Their point of intersection the centre of gravity. |
| Circular plate |  | Construct diameters. Their points of intersection gives the centre of gravity. |
| Cylinder |  | The point of intersection (midpoint of axis) gives the centre of gravity. |
| Sphere |  | Construct the diameters of the sphere. The point of intersection, which is the centre of the sphere, is the centre of gravity. |
| Cone |  | Construct the perpendicular bisectors from the base. The point of intersection which is $\frac{1}{3}$ axis from the base, gives the centre of gravity. |

| | | |
|---|---|---|
| Ring |  | Construct the diameters. The point of intersection, which is at the centre of the ring, is the centre of gravity. |
| L-Shape |  | Divide the L-shape into two rectangles and construct diagonals on each. Join the points of intersection then construct the bisect of the angle at the corner. The point where the bisector meets the line sis the centre of gravity. |
| Rectangular frame |  | Construct the diagonals. The point of intersection of the diagonals is the centre of gravity. |

## Centre of Gravity of Irregular Shapes

**Experiment 4.1: To determine the centre of gravity of an irregular shaped lamina.**

*Apparatus*

Plumbline, thread, stand, cardboard

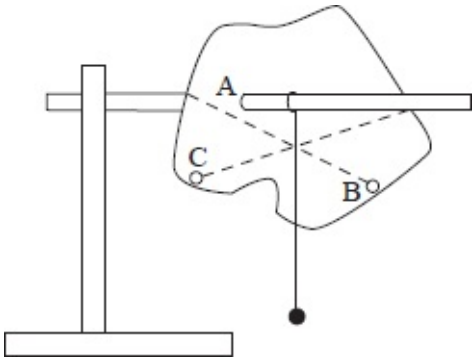



*Fig 4.4*

*Procedure*

- Make three holes, A, B and C on the edges of the cardboard.
- Suspend it by a rod through hole A as shown in figure 4.4.
- Tie a plumbline on the rod beside the cardboard.
- After the cardboard and plumbline have stopped swinging, draw a vertical line on the cardboard as set by plumbline.
- Repeat the experiment using the other holes B and C. The lines intersect at a point.
- Balance the cardboard with the tip of a pencil at the point of intersection of the three lines. what do you observe.
- Repeat the experiment with sheets of different irregular shapes.

*Observation*

The suspended object will always rest with its centre of gravity vertically below the point of support. The object balances on the tip of the pencil if placed at its centre of gravity.

***Note:***

If a body is hollow or if it has legs like a tripod stand, the centre of gravity may be in space outside the material of the body.

***Example 1***

A uniform metal bar ,100 cm long, balances at 20 cm mark when a mass of 1.5 kg is attached at 0 cm mark, see figure 4.5. Calculate the weight of the bar. (Take g = 10N/kg)

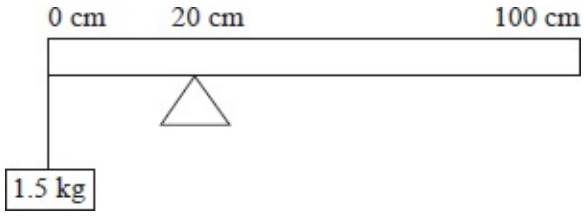



*Fig 4.5*

*Solution*

'Uniform' means that the weight is evenly distributed along the bar and it therefore acts through the centre of gravity, 0.5 m from either end.

$W = 1.5 \times 10$

$= 15$ N

Taking moments about the pivot point;

$0.2 \times 15 = 0.3 \times W$

$$W = \frac{0.2 \times 15}{0.3}$$

$= 10$ N

***Example 2***

A uniform metre rule of weight 0.9 N is suspended horizontally by two vertical strings P and Q, placed 20 cm and 30 cm from its ends respectively. Calculate the force (tension) in each string.

*Solution*

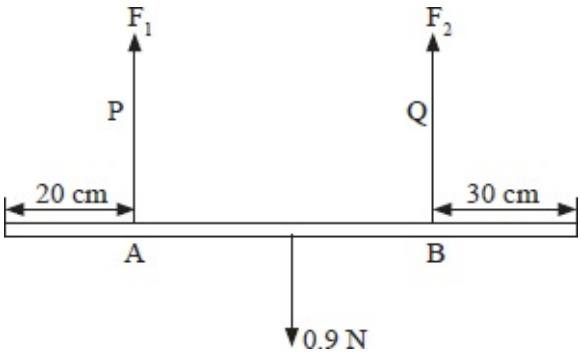



*Fig 4.6*

*Solution*

The weight of the rule acts through its centre, as shown in figure 4.6. Let $F_1$ and $F_2$ be the vertical forces acting on the strings.

Since $F_1$ and $F_2$ are unknown, taking moments about A, $F_1$ is eliminated. Similarly, taking moments about B, $F_2$ is eliminated.

Since the system is in equilibrium;

Sum of the upward forces = sum of downward forces, i.e., $F_1 + F_2 = 0.9$ N

Taking moments about A;

$F_2 \times 0.5 = 0.9 \times 0.3$

Therefore, $F_2 = 0.54$ N

But $F_1 + F_2 = 0.9$

Hence $F_1 = 0.36$ N

## *Activity*

Take moments about B and confirm the values of $F_1$ and $F_2$.

***Example 3***

Figure 4.7 shows a drum of mass 150 kg and radius 0.5 m being pulled by a horizontal force F against a step 0.1 m high. What initial force is just sufficient to turn the drum so that it rises over the step?

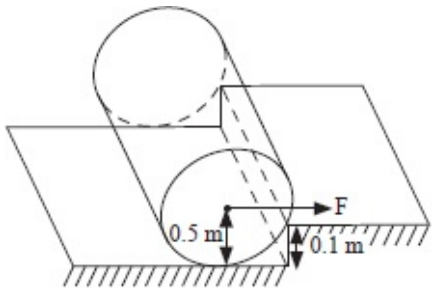



*Fig. 4.7*

*Solution*

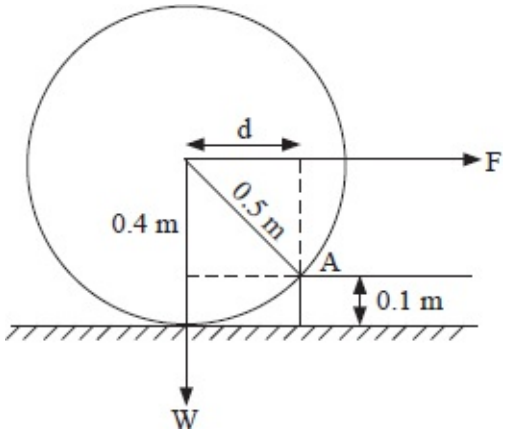



*Fig. 4.8*

Taking moments about A;

$W \times d = F \times 0.4$

But, $W = 150 \times 10$

$= 1500$ N

By Pythagoras theorem

And $(0.5)^2 = (0.4)^2 + d^2$

$d^2 = 0.09$

$d = 0.3$ m

$1500 \times 0.3 = F \times 0.4$

$$F = \frac{1500 \times 0.3}{0.4}$$

$F = 1125$ N

***Example 4***

Calculate the force (F) required to be applied vertically to the wheelbarrow handles in figure 4.9 to lift a load at the centre of gravity as indicated. The combined mass of the wheelbarrow and load is 50 kg.

Take the length a = 70 cm and b = 30 cm. Disregard the mass of the wheelbarrow.

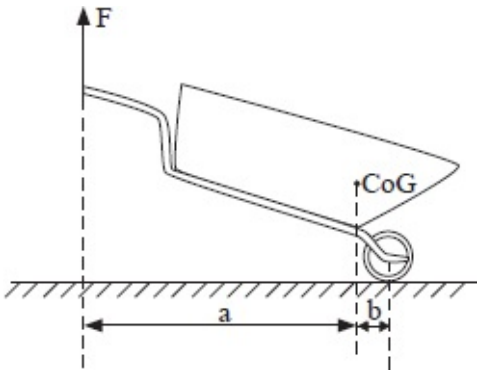



*Fig. 4.9*

*Solution*

Clockwise moments = anticlockwise moments

Load = 50 × 10 N

= 500 N

Taking moments about the centre of the wheel

F × (a + b) = 500 × b

F × 1.0 = 500 × 0.3

F = 150 N

## States of Equilibrium

When a body is at rest, all the forces acting upon it balance one another and the body is said to be in equilibrium. There are three states of equilibrium, namely, stable, unstable and neutral.

To understand the different states of equilibrium, consider a wooden cone resting on a horizontal table in various positions.

## Stable Equilibrium

The cone shown in figure 4.10 (a) has the line of action of its weight L, passing through the centre of the surface on which it is resting. When it is tilted at a small angle by a force F, see figure 4.10 (b). The line of action of its weight is displaced but still passing within the base area. Thus the cone when the force is withdrawn the moment of the weight makes the cone to fall back and lie in its original position. The cone is in stable equilibrium.

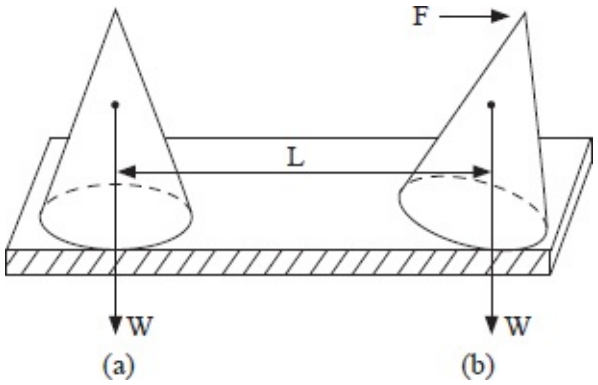



*Fig. 4.10: Stable equilibrium*

## Unstable Equilibrium

The cone in this position, see figure 4.11 (a) has a very small area of the surface on which it rests and a high centre of gravity. A slight push by the force, F, sets the line of action of the weight, L, pass outside the surface on which the cone rests, see figure 4.11 (b).

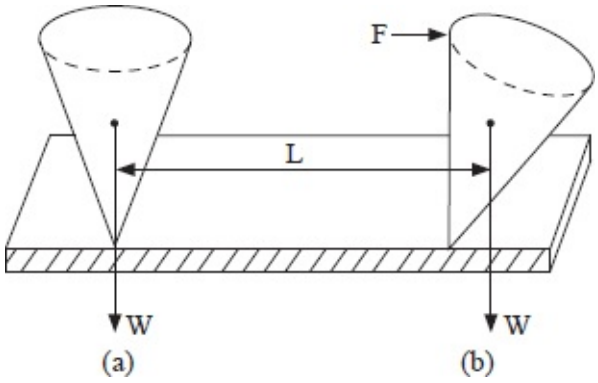



*Fig. 4.11: Unstable equilibrium*

## Neutral Equilibrium

If the cone is laid on its sides as in figure 4.12 and a force applied on it, it will be noticed that no matter how big the force of displacement is, the position of the centre of gravity is neither lowered no raised. This condition is described as **neutral equilibrium**.

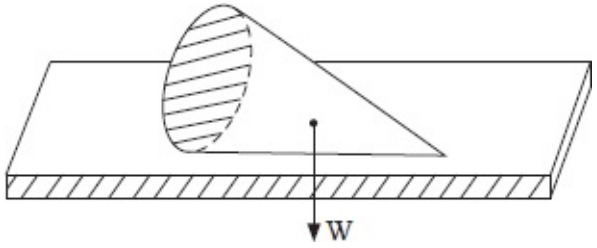


*Fig. 4.12: Neutral equilibrium.*

## Factors Affecting Stability of Objects

The stability of an object depends on the position of its centre of gravity and the turning effect of its weight about an axis or point, in the following ways:

### *The Area of the Base*

If the base area is large, the line through the centre of gravity of the body remains within the base even if the body is tilted through a large angle. Hence, a body with a broad base is more stable than the one with a narrow base.

### *The Position of the Centre of Gravity.*

A body is more stable when its centre of gravity is as low as possible. This can be achieved by making the base heavier. Bodies with high centres of gravity are less stable

## Applications of Stability

(i) Buses are made more stable by having light materials for the upper parts of the body and the heavy chassis and engine as low as possible. Luggage compartments are situated in the lower parts so that the centre of gravity is lowered.

(ii) A racing car has a low centre of gravity and a wide wheel base which allows a large angle of tilt. Hence, it can negotiate sharp corners at high speeds without toppling.



*Fig. 4.13: A racing car*

(iii) A Bunsen burner has a wide heavy base. The heavy base lowers the centre of gravity and the large base area provides large angle of tilt before toppling.

(iv) Chairs, stools, tripods, etc. are provided with three or more legs. The legs are often made slightly inclined outwards to improve stability.

(v) Acrobats in their breathtaking manouvers must ensure that their centre of gravity remains within the defined base area for stability.



*Fig. 4.14: Acrobats*

## Revision Exercise 4

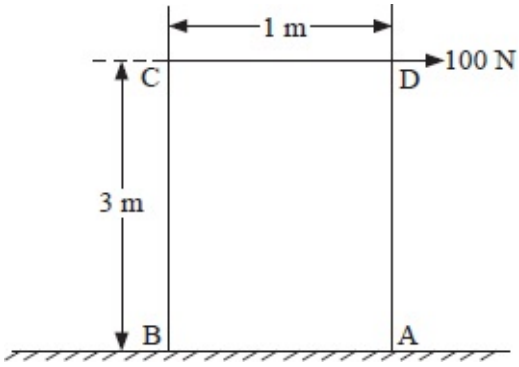
1. (a) Define the centre of gravity of a body.
   (b) Describe an experiment to determine the centre of gravity of
      (i) a uniform regular object like a metre rule
      (ii) A thin irregular shaped metal sheet.
2. Explain why:
   (a) It is not safe for a double decker bus to carry passengers standing on the upper decker.
   (b) Bus body-builders build luggage compartments under the seats rather than on the roof racks.
   (c) Laboratory retort stands are made with wide heavy base.
3. (a) When is an object said to be in stable equilibrium?
   (b) Describe the of equilibrium in:
      (i) A marble at the bottom of a watch glass.
      (ii) A tight-rope walker.
      (iii) A cylinder sitting on its base.
      (iv) A sphere on a level table top.
      (v) A bird perched on a thin horizontal branch of a tree.
4. (a) State :
      (i) Two ways in which the stability of a body can be increased.

(ii) Two practical applications of stability.

(b) Explain how a cyclist maintains the stability of a moving bicycle.

5. Explain why a lorry loaded with bags of maize packed high up is likely to topple when negotiating a corner.

6. The diagram below shows a metal plate 3 m long; 1m wide and negligible thickness. a horizontal force of 100 N applied at point D just makes the plate tilt. Calculate the weight of the plate.




7. State the conditions for the equilibrium of a body which is acted upon by a number of forces.

# Chapter 5

# Reflection at Curved Surfaces

Reflection of light by plane mirrors was covered in Book One. In this chapter, consideration is given to the types of curved surfaces, image formation and their applications.

Curved surfaces have a wide range of scientific and practical applications, for instance, in shaving mirrors, driving mirrors, search lights and telescopes.

## Types of Curved Surfaces

Curved surfaces may be obtained from hollow shapes of spheres, cones or cylinders. When these surfaces are highly polished, they become reflectors.

In a hollow metal sphere for example, if the inner surface is highly polished, then the portion of the sphere is described as a concave reflector.

Conversely, if the outer surface is highly polished, then the portion of the sphere is descsribed as a convex reflector.

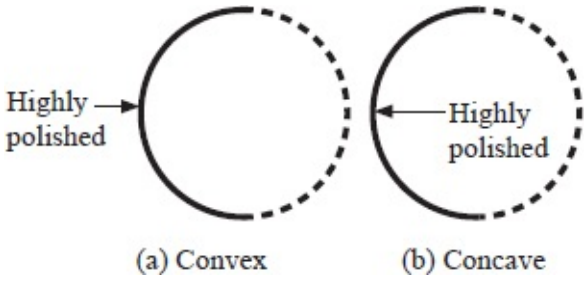



*Fig. 5.1: Shapes of reflectors*

If both inner and outer surfaces of the metal sphere were highly polished, the inner surface becomes concave while the outer becomes convex.

Curved mirrors can be made by applying silvery paint on part of a hollow glass sphere, cylinder or a cone, as shown in figure 5.2 (a), (b) and (c).

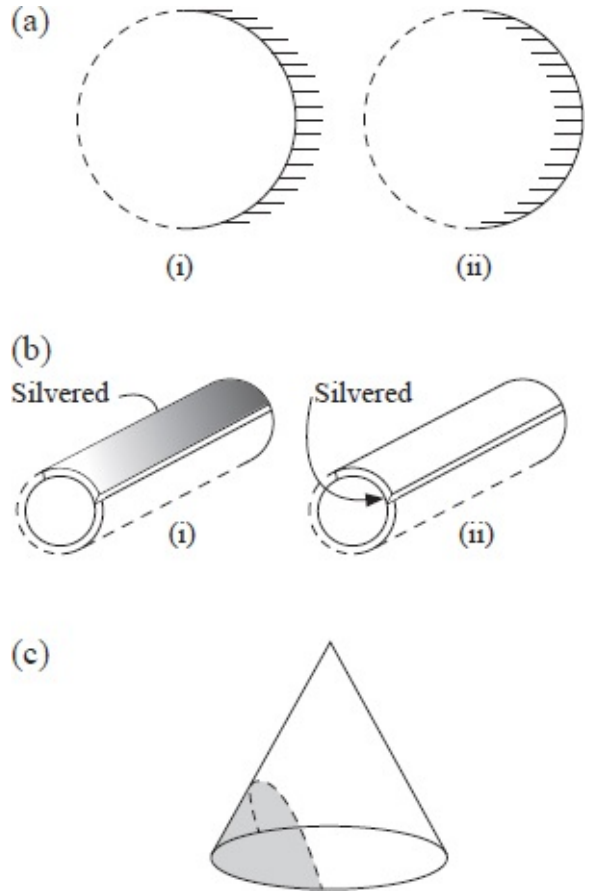



*Fig. 5.2: Mirror shapes*

The silvering gives rise to two types of reflecting surfaces:

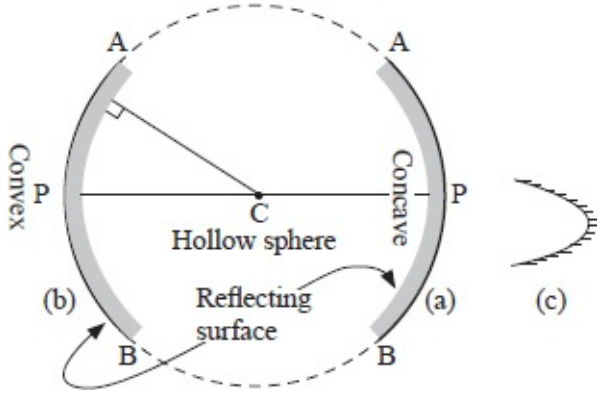



*Fig. 5.3: Curved mirrors*

(i) A reflecting surface curving inwards, see figure 5.3 (a) and (c).

(ii) A reflecting surface bulging outwards, see figure 5.3 (b).

Curved mirrors whose reflecting surfaces curve inwards are called **concave mirrors**. See fig. 5.3 (a), while those with reflecting surfaces bulging outwards are called **convex mirrors**. See fig. 5.3 (b). Mirrors made from spheres are

called **spherical mirrors**.

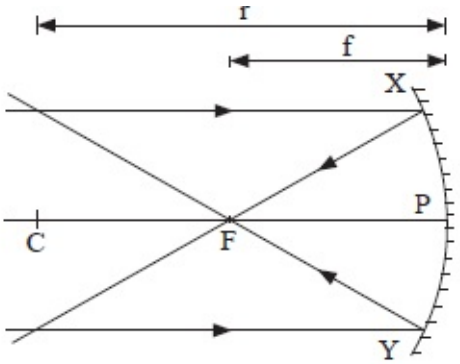
A parabolic mirror is a special mirror cut from a section of a cone, as in figure 5.2 (c) and 5.3 (c). A concave parabolic reflector is obtained by applying silvery paint on the outside of the cone so that the reflecting surface curves in, see figure 5.3 (c)

***Note:***

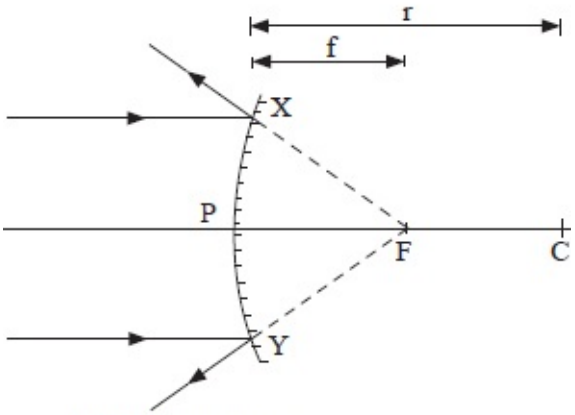
Silvering of the inner surface of glass produces a convex mirror, while a highly polished inner surface gives a concave reflector which behaves like a concave mirror.

## Definition of Terms

In order to understand some terms that are used in describing curved mirrors, consider the mirrors shown in figure 5.4 (a) and (b).




(a) Concave mirror




(b) Convex mirror

*Fig. 5.4: Definition of terms in curved mirrors*

The aperture of the mirror is the effective diameter of the light reflecting area. It is the straight line xy in figure 5.4.

The pole is the centre, P, of the mirror.

The **centre of curvature**, C, is the centre of the sphere of which the mirror is part. In the case of a concave mirror, the centre of curvature is in front of the mirror while in a convex mirror, it is behind.

The **principal axis** is the line drawn through the pole of the mirror and the centre of curvature. It is also called the main axis of the mirror.

The **principal focus**, F, for a concave mirror, is the point at which all rays parallel and close to the principal axis converge after reflection.

For a convex mirror, this is the point at which all rays parallel and close to the principal axis appear to diverge from after reflection by the mirror.

The principal focus of a concave mirror is a real focus, that is, reflected rays actually pass through it, while the principal focus of a convex mirror is a virtual focus because reflected rays only appear to pass through it.

The **focal plane** is a plane perpendicular to the principal axis and passes through the principal focus. Parallel rays which are not parallel to the principal axis would converge at a point on the focal plane, see figure 5.5.

The **radius of curvature**, r, is the radius of the sphere of which the mirror is part. In figure 5.4, it is the distance PC.

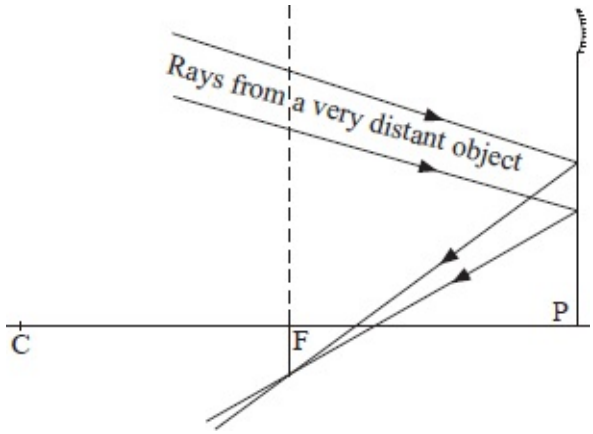



*Fig. 5.5: Focal plane(see explanation of ray diagrams on page 81)*

The **focal length**, f, is the distance from the pole of the mirror to its principal focus.

## Reflection of Light by Curved Mirrors

The effect of the concave and convex mirrors on rays can be studied using a ray box.

Rays parallel and close to the principal axis are made incident on both concave and convex mirrors, as in figure 5.6 (a) and (b).

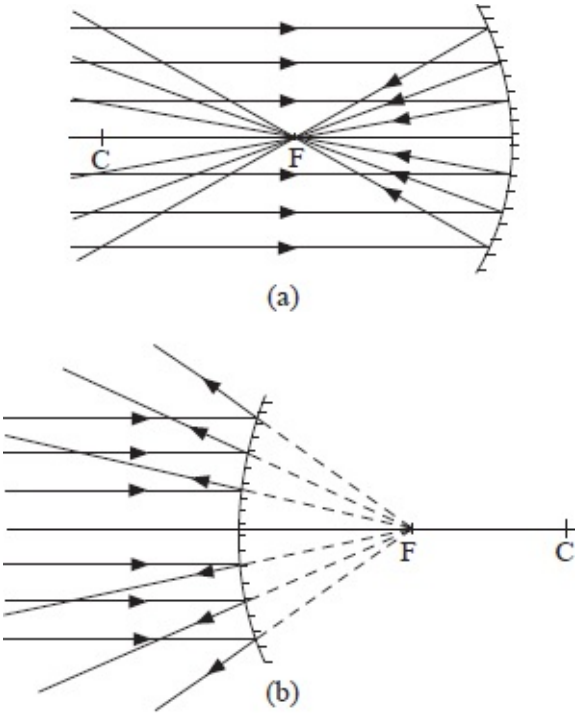



*Fig. 5.6: Reflection of parallel beam*

For the concave mirror, the rays converge at a point F, the principal focus, after reflection. For the convex mirror, the rays are reflected so that they all appear to diverge from the principal focus F behind the mirror. If the ray box is made to produce a beam converging at the principal focus, F, a parallel beam is obtained for both the concave and convex mirror after reflection, see figure 5.7 (a) and (b).

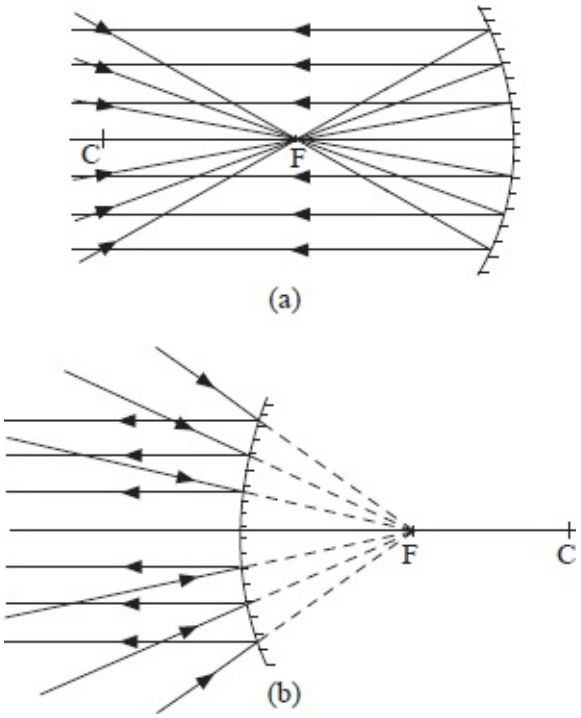



*Fig. 5.7: Reflection of divergent beam*

Compare figures 5.6 and 5.7. They show that the light rays are reversible. This is a demonstration of the **principal of reversibility of light, which states that light will follow exactly the same path if its direction of travel is reversed**.

**Experiment 5.1: To determine the centre of curvature of a concave mirror.**

*Apparatus*

White screen with a hole with cross-wires, mounted concave mirror, lamp or candle, metre rule.

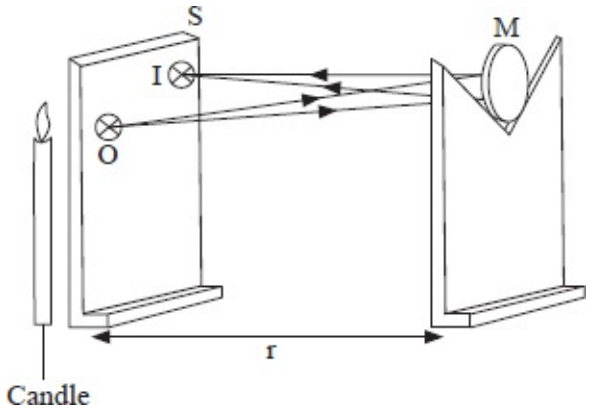



*Fig. 5.8: Measurement of radius of curvature of a concave mirror*

*Procedure*

- Arrange the apparatus as shown.
- Support the white screens at its centre.
- Support a concave mirror M in front of the screen so that the object cross wire O is in line with the pole of the mirror.
- Place a candle or lamp behind the screen to illuminate the cross-wires.
- Adjust the mirror towards and away from S, until a sharp image of O is seen beside O on the screen.
- Measure the distance MI. The object cross-wires O and image I are now practically coincident in position. In this case, O must be at the centre of curvature of the mirror. The distance MI is the radius of curvature,

  A proof given later in this chapter shows that the focal length (f) is half the radius of curvaturer, that is, $f = \frac{r}{2}$. The focal length of this mirror can also be determined from this relationship.

**Experiment 5.2: To determine the centre of curvature by the no-parallax method**

*Apparatus*

Sliding cork on a glass rod, concave mirror, optical pin, clamp, stand, metre rule.

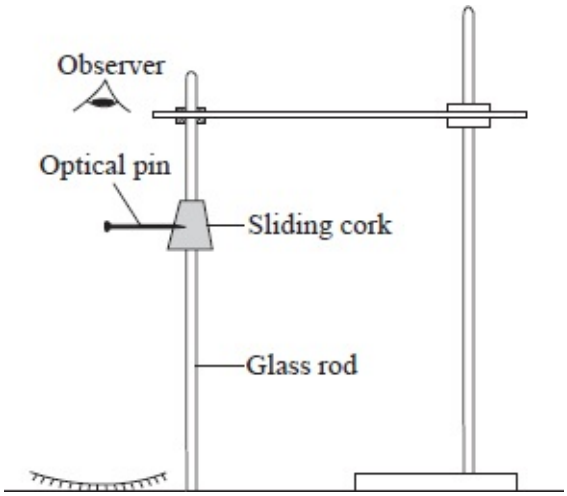



*Fig. 5.9: Centre of curvature of concave mirror by the no-parallax method*

*Procedure*

- Clamp a glass rod with a sliding cork vertically as shown in figure 5.9
- Fix a pin to the cork so that it is horinzontal to the plane of the bench.
- Place a concave mirror on the bench so that the tip of the pin is in the same vertical line with the axis of the mirror. This pin is to act as the object pin.

- Move the cork up and down, viewing it as shown until a real inverted image of the pin is seen.
- Adjust the position of the object pin carefuly until there is no parallax between it and the image, i.e, the image and the object coincide and move in the same direction as the eye.
- Measure the vertical distance from the bench to the pin. This gives the radius of curvature, of the mirror.
- Repeat the experiment to obtain more values of r. Calculate the average of the values.

**Experiment 5.3: To estimate the focal length of a concave mirror**

*Apparatus*

Metre rule, distant object, concave mirror, white screen.

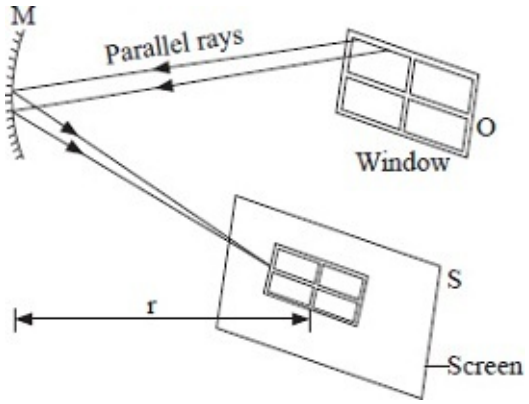



*Fig. 5.10: Estimation of focal length*

*Procedure*

- Hold the mirror M so that its reflecting surface faces an object, e.g, a window.
- Move the white screen S in front of the mirror until an inverted sharp image of the window frame is formed on it, see figure 5.10.
- Measure the distance from M to S.

Parallel rays from a distant window are reflected, converging at the focal plane of the mirror. The distance MS is approximately equal to the focal length, f, of the mirror.

## Laws of Reflection and Curved Mirrors

Consider an incident ray QM, parallel and close to the principal axis, as shown in figure 5.11 (a). At M, the ray is reflected through F. A line drawn from C

through the point of incident M is normal to the surface of the mirror.

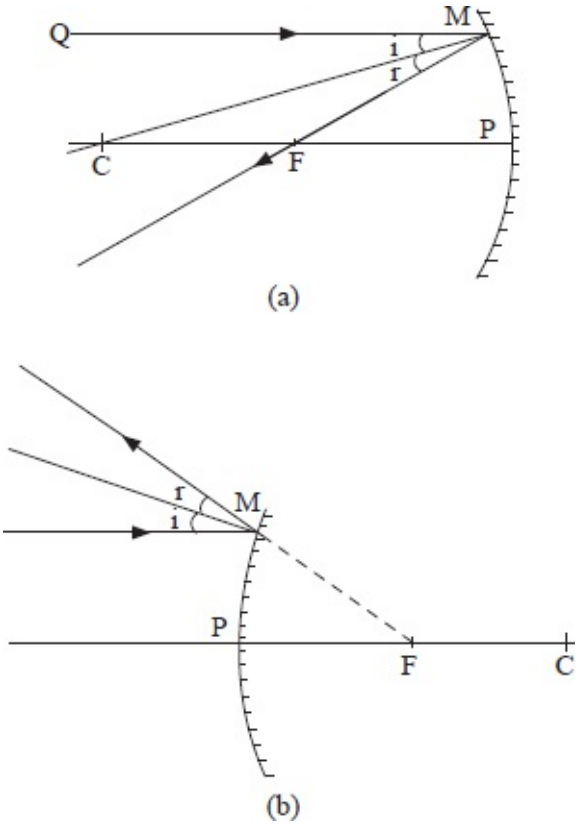



*Fig. 5.11: Law of reflection and curved mirrors*

From geometry, it follows that;

∠QMC = ∠MCF (alternate angles).

It was mentioned earlier that PC = 2PF

Therefore, PF = FC

When M is very close to P, then;

PF = MF

Therefore, ∠MCF = ∠CMF

Since ∠QMC = ∠MCF, it follows that;

∠QMC = ∠CMF

But ∠QMC is the angle of incidence, i, and ∠CMF the angle of reflection, r.

Therefore, i = r.

It follows from this relationship that reflection by curved mirrors obeys the laws of reflection. This can also be proved for the convex mirror, see figure 5.11 (b).

## Ray Diagrams

Ray diagrams can be used to explain how images are formed by curved mirrors and the characteristics of these images. The reflecting surface is represented by a straight line and a small curve is used to show the type of mirror.

The object is represented by a straight line perpendicular to the principal axis, with an arrow to show its tip, see figure 5.12 (a) and (b).

The pole of the mirror is taken as the intersection of principal axis and the mirror line.

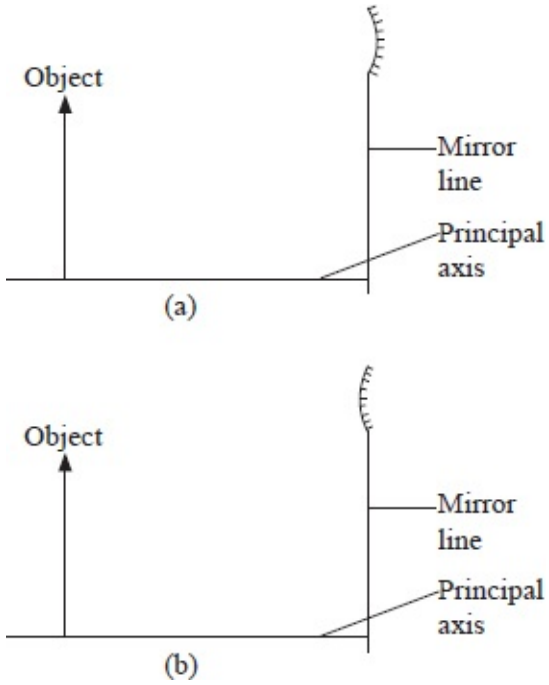



*Fig. 5.12: Representation of concave and convex mirrors*

Among the many rays which could be drawn in constructing a ray diagram, four special ones are considered. These are:

### *(i) A ray through C or appearing to pass through C*

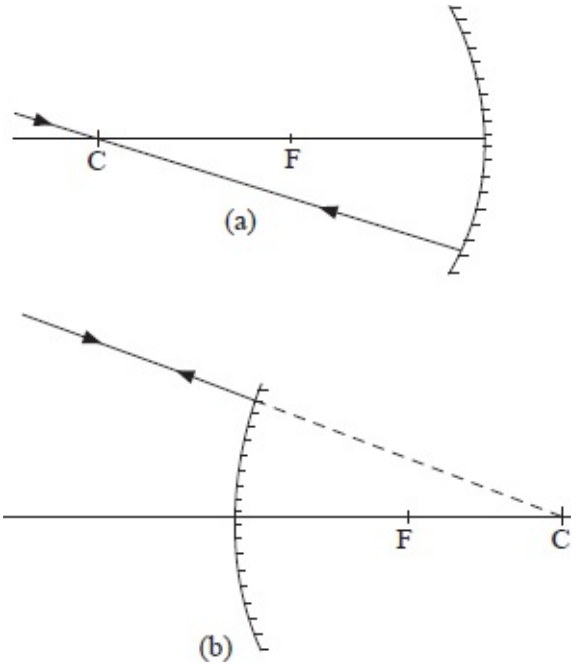



*Fig. 5.13: A ray through C*

This ray is reflected along the same path, see figure 5.13

### *(ii) A ray close and parallel to the Principal Axis.*

In case of a concave mirror, this ray is reflected through the principal focus, while for a convex mirror, the ray is reflected in such a way that it appears to emerge from the principal focus, see figure 5.14 (b).

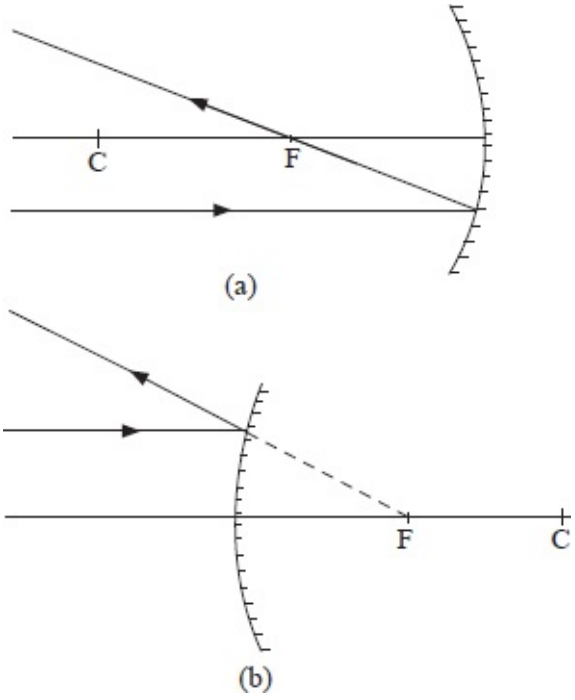


*Fig. 5.14: A ray close and parallel to the principal axis*

### *(iii) A ray through Principal Focus of Concave Mirror or appearing to be directed to Principal Focus of Convex Mirror*

This ray is reflected parallel to principal axis, see figure 5.15 (a) and (b).

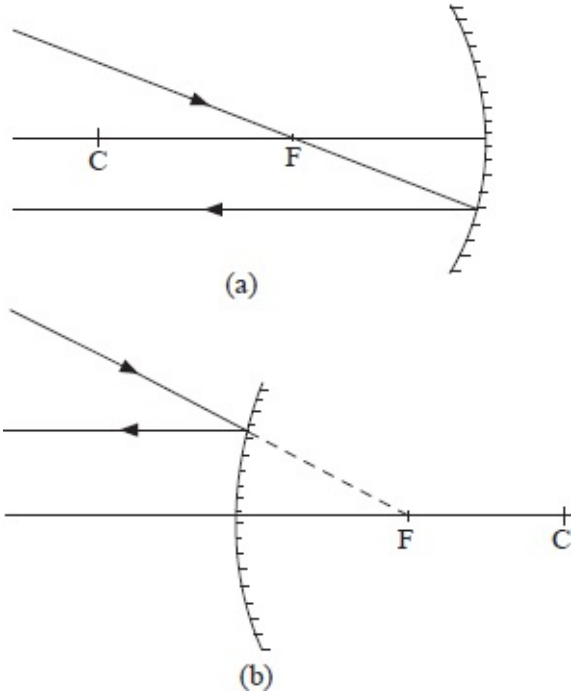



*Fig. 5.15: A ray through F*

### *(iv) A ray at an angle to the Principal Axis and incident to the Pole*

This ray is reflected in such a way that the angle of incidence, i, equals angle of reflection, r, see figure 5.16 (a) and (b).

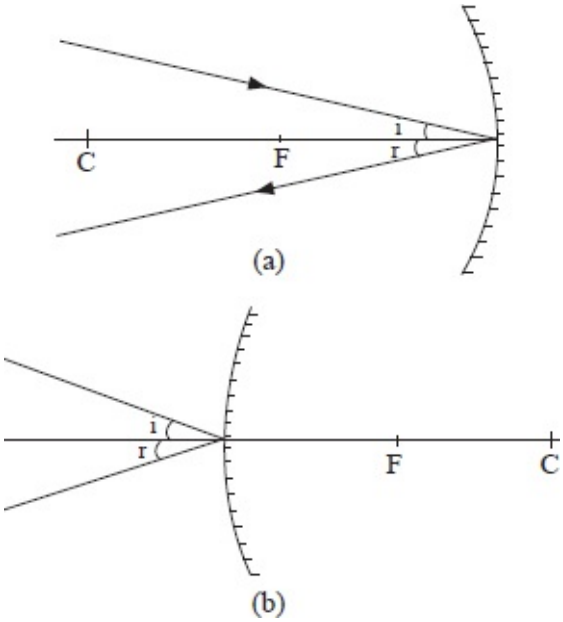



*Fig. 5.16: A ray at an angle to the principal axis*

## Image Formation and Characteristics Concave Mirrors

The nature, size and position of the image of an object formed by a concave mirror depends on the position of the object from the mirror.

**Experiment 5.4: To locate the image formed by a concave mirror**

*Apparatus*

Concave mirror on a holder, screen S, object slit, lamp or candle.

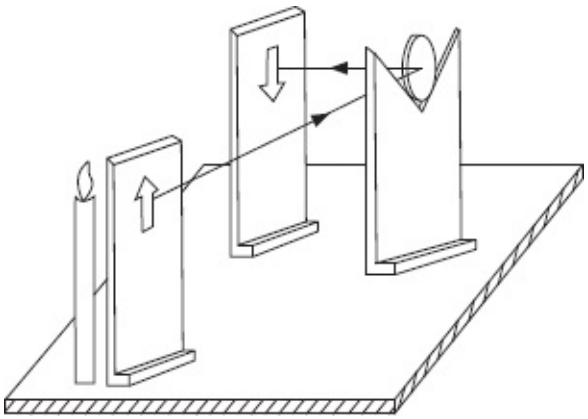


*Fig. 5.17: Image formation by a concave mirror*

The object in this experiment is a slit on a card ‘O’, in form of an arrow.

*Procedure*

- Position the card and place a lamp or a candle behind the slit, as in figure

5.17.

- Support the concave mirror M in front of the object so that the distance OM is greater than the radius of curvature of the mirror.
- Move the white screen S between the object and the mirror until a sharp image is formed on it. Compare the size and appearance of the image with that of the object.
- Repeat the experiment with the object at different positions towards the mirror, until it is very close to it. If no image is formed on S, try to locate it behind O.

*Observation*

When the object is far away from the mirror, the image is real, inverted and smaller than the object.

When the object is moved nearer to the mirror, but still further than F, the image remains inverted, real and becomes bigger.

When the object is at the centre of curvature of the mirror, the image is inverted, real and same size as the object.

When the object is between center of curvature and principal focus of the mirror, the image is inverted, larger than the object and beyond C.

The image becomes larger as the object approaches the principal focus of the mirror. When the object is moved from the principal focus towards the mirror, no image is obtained on the screen.

The following ray diagrams illustrate the observations

*Object at Infinity*

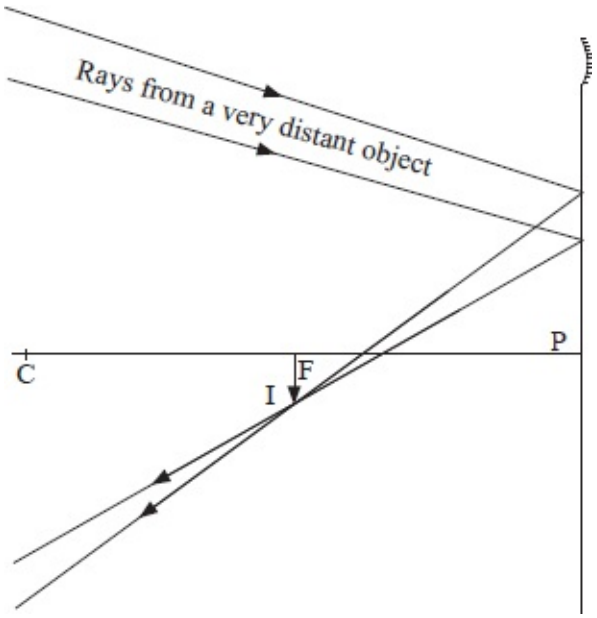



*Fig.5.18 :Object at infinity*

The image formed is:

(i) at F.

(ii) real.

(iii) inverted.

(iv) smaller than the object.

## *Object beyond C*

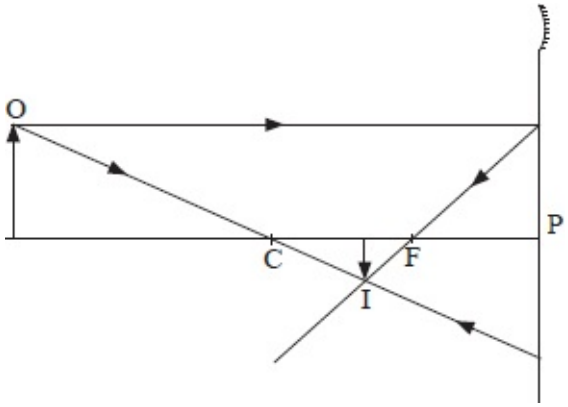



*Fig. 5.19: Object beyond C*

The image formed is:

(i) between C and F.

(ii) real.

(iii) inverted.

(iv) smaller than the object.

### *Object at C*

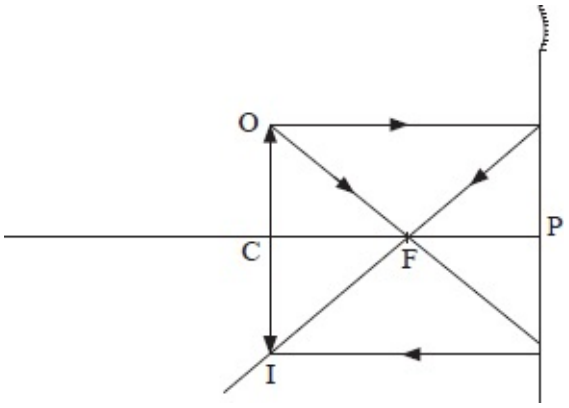



*Fig. 5.20: Object at C*

The image formed is:

(i) at C

(ii) real

(iii) inverted

(iv) same size as the object.

### *Object between C and F*

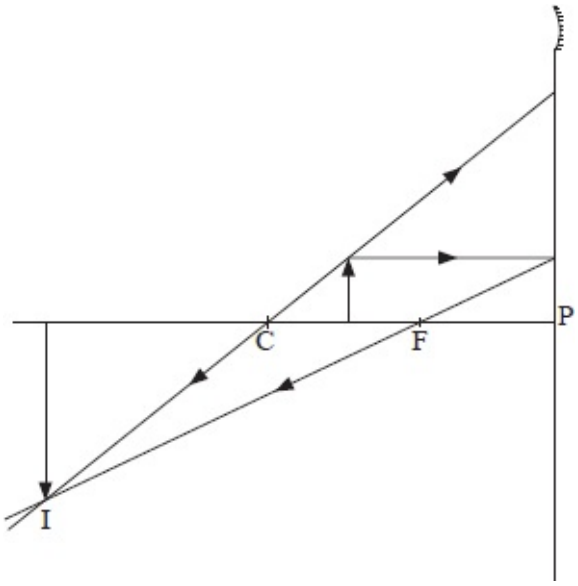



*Fig. 5.21: Object between C and F*

The image formed is:

(i) beyond C.

(ii) real.
(iii) inverted.
(iv) Magnified (larger than the object).

## *Object at F*

The image is formed at infinity, see figure 5.22. This is because the light rays emerge parallel after reflection. Compare this with object at infinity.

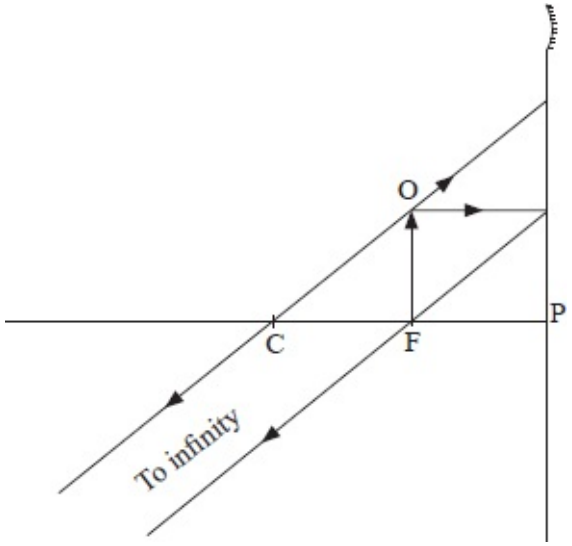



*Fig. 5.22: Object at F*

## *Object between F and P*

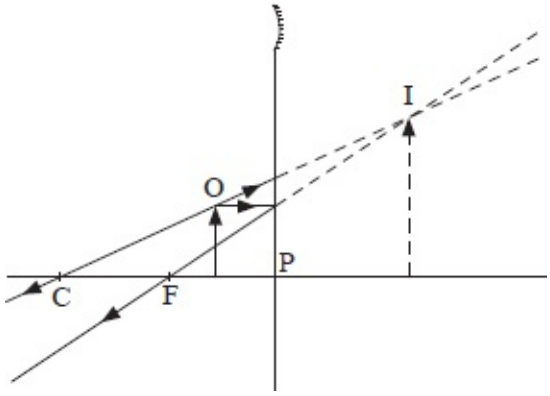



*Fig.5.23: Object between F and P*

The image formed is:
(i) behind the mirror.
(ii) virtual.
(iii) erect (upright).

(iv) larger than the object.

By convention, **full lines represent real rays and objects while dotted lines represent virtual rays and images**. In a ray, an arrow is drawn to show the direction in which the light is travelling.

A real image can be focused on a screen while a virtual image is formed by apparent intersection of rays and cannot therefore be formed on a screen. Note also that a real image is formed by a convergent reflected beam while a virtual image is formed by a divergent reflected beam.

## Convex Mirrors

Whereas concave mirrors form either real or virtual images depending on the position of the object, images formed by convex mirrors are always upright, smaller than the object and between P and F. Figure 5.24 shows the ray diagram for typical image formed by a convex mirror.

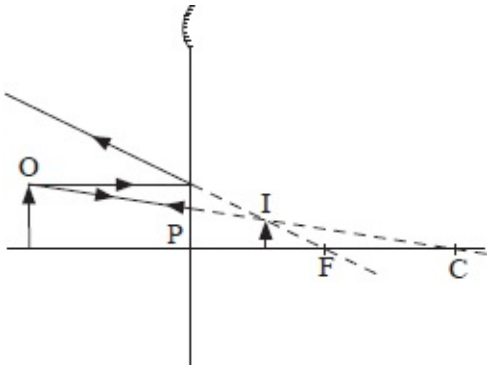



*Fig. 5.24: Image formation by a convex mirror*

## Graphical Construction of Ray Diagrams

The images obtained from a curved mirror can be drawn to scale in a ray diagram. The construction of a ray diagram is best done on a graph paper using suitable scale.

***Note:***

When constructing a ray diagram:

(i) Draw a horizontal straight line, say AB, to represent the principal axis.

(ii) Draw a line, say QR, at right angles to AB at pole P to represent the mirror.

***Example 1***

An object of height 10 mm is placed 50 mm in front of a concave mirror of focal length 30 mm. By scale drawing, determine the:

(a) Position of the image.

(b) Size of the image.

(c) Nature of the image formed.

*Solution*

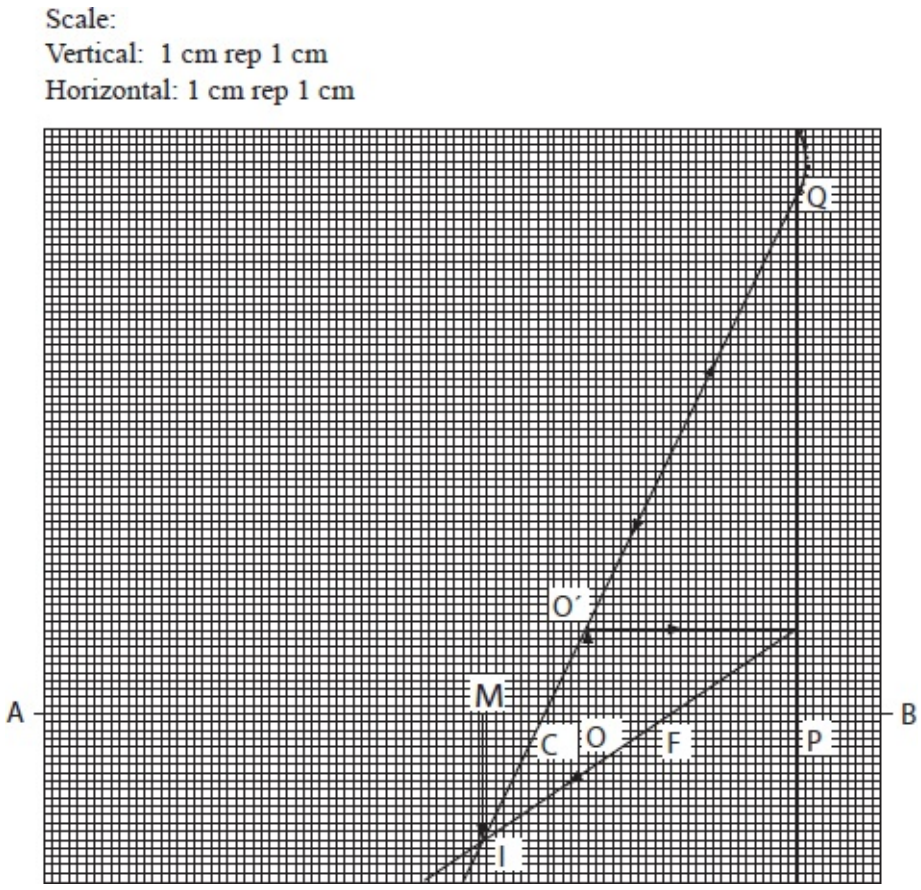



*Fig. 5.25*

A suitable scale is 1 mm on the paper to represent 1mm of actual length on vertical scale and 1 mm to represent 2 mm on horizontal scale.

- Mark the principal focus 30 mm from P.
- Draw a line OO, 10 mm long, perpendicular to AB and 50 mm from P. This represents the object.
- Draw two incident rays from O′.
  (i) A ray from O′ parallel to the principal axis CP, is reflected through F.
  (ii) A ray from O′ through C, is reflected along the same path. A ray from O′ through F can also be used here. These two intersect after reflection to give a real image at I.
- Complete the image by drawing MI perpendicular to the axis PC.

From the complete diagram, and according to the scale used, it can be seen that :

(a) The image is formed 75 mm from P.
(b) The image is 15 mm tall, hence magnified and inverted.
(c) The image is real, because it is formed by actual intersection of rays.

***Example 2***

A convex mirror of focal length 9 cm produces an image on its axis 6 cm away from the mirror. If the image is 3 cm high, determine by scale drawing:

(a) The object distance from the mirror.

(b) The size of the object.

*Solution*

A suitable scale in this case is 1cm to represent 3 cm of actual length on vertical scale and 1cm to represent 4 cm on horizontal scale, see figure 5.26.

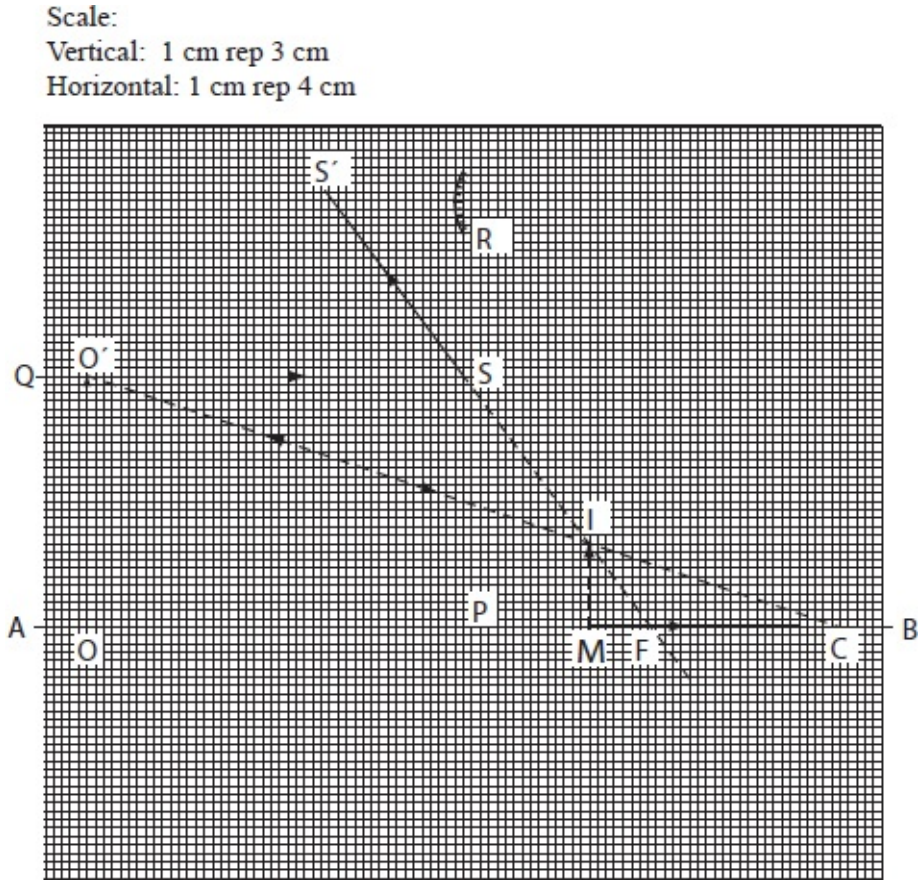



*Fig. 5.26*

- Using the scale, mark the principal focus F and the centre of curvature C, 9 cm and 18 cm respectively from P behind the mirror as shown in the graph.

- Draw a broken line IM, 3 cm long, perpendicular to AB and 6 cm from the pole, P, of the mirror. This represents the image.

  Two rays will be useful in construction of the ray diagram:
  (i) A ray from the top of the object and parallel to the principal axis.
  (ii) A ray from the top of the object through C.
- Draw a dotted line FS and extend it to S′ as a continuous line. SS′ is the reflected ray and S therefore is the point of incidence. From this point, draw a line QS parallel to the principal axis. This is the incident ray and the top of the object lies somewhere on this ray.
- Draw a dotted line from C through I to the mirror. Since this line is normal to the mirror, a ray from the top of the object along this line is reflected along the same path. Extend this line as a continuous line to intersect with QS at O′. O′ is the top of the object.
- Draw a perpendicular line from O′ to meet AB at O. O is the foot of the object.
- Using your scale, determine the distance PO (object distance) and height of object OO′.

  From the complete diagram:
  (a) Object distance, PQ, is 18 cm.
  (b) Object height OO′ is 9 cm.

## Linear Magnification

Images formed by curved mirrors vary in size. It is always important to compare the size of the object with that of the image formed.

The numerical comparison of the image size with object size is called **magnification**. In this chapter, linear or transverse magnification, i.e, magnification of one dimension, is considered.

Linear or transverse magnification, m, is given by the formula:

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

Consider figure 5.27 in which the image has been constructed using a ray from O through C and another ray from O to P.

In the figure, AO is the height of the object and BI the height of the image.

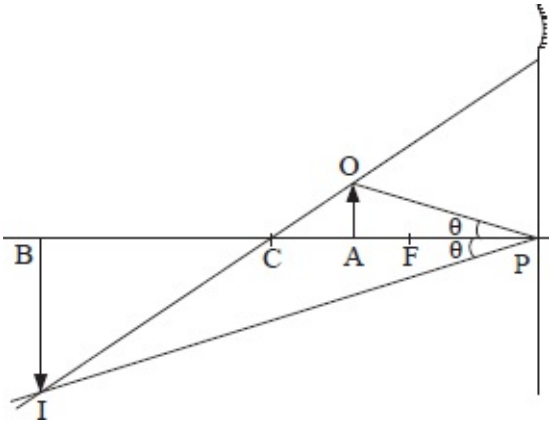



*Fig. 5.27: Linear magnification*

From the definition of linear magnification m;

$$M = \frac{\text{height of image}}{\text{height of object}}$$

$$= \frac{BI}{AO}$$

The right-angled triangles BIP and AOP are similar.

Therefore, m

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

$$= \frac{\text{image distance}}{\text{object distance}}$$

If v is the image distance and u the object distance, then linear magnification can also be given by:

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

Linear magnification has no units since it is a ratio of two lengths.

***Example 3***

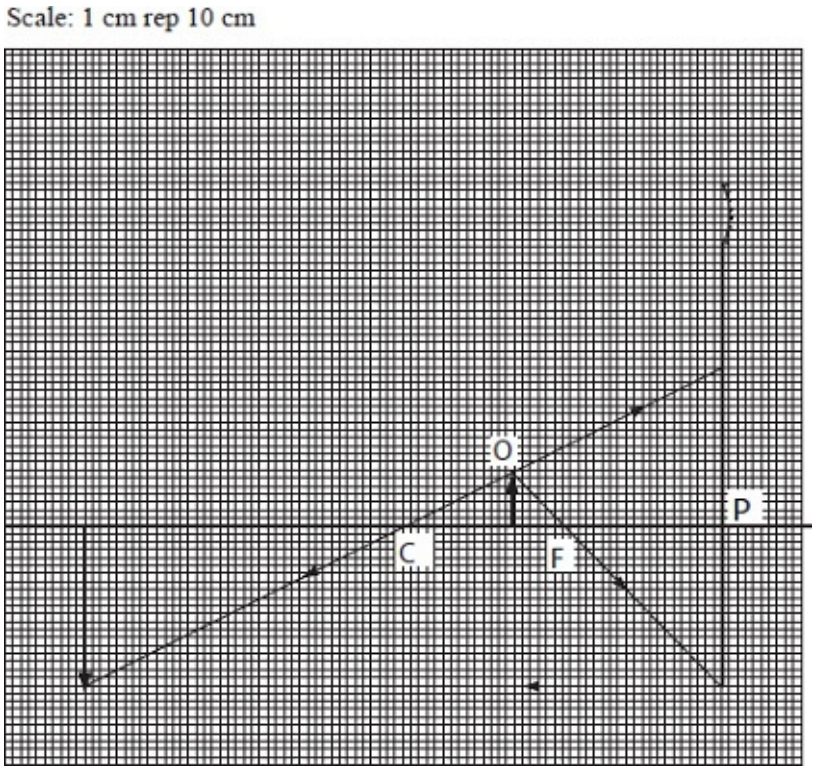



*Fig. 5.28*

A concave mirror of focal length 20 cm forms a sharply focused image of a small object on a screen placed at a distance 80 cm from the mirror.

Graphically determine:

(a) The position of the object.

(b) The linear magnification of the image.

*Solution*

A suitable scale in this case is 1cm to represent 10 cm of the actual length.

- using the scale, mark the principal focus 20 cm from the mirror.
  Mark the centre of curvature C, 40 cm from the mirror (r = 2f)
- Choose a suitable image height such as 20 cm (all real images are inverted, for concave mirror.
- Draw the image 80 cm from the mirror.

A ray from the top of the object through F is reflected parallel to the principal axis. Therefore, a ray from the top of the image parallel to principal axis is reflected through F(principle of reversibility of light). The top of the object therefore lies somewhere on this ray.

- Draw a ray from top of the image through C. This ray is reflected back along

the same path. The intersection of the two rays between C and F above principal axis is the top of the object. Complete the object by drawing a perpendicular line from this point to the principal axis.

From the graph:

(a) The object is 26 cm from the mirror.

(b) Linear magnification, $m = \frac{v}{u}$

$$= \frac{80\ cm}{26\ cm}$$

$$= 3.08$$

*Alternatively*,

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

$$= \frac{20\ cm}{6.5\ cm}$$

$$= 3.08$$

***Example 4***

A concave mirror of focal length 20 cm produces an upright image of magnification 2. Graphically determine the object distance.

*Solution*

Scale: 1 cm represents 10 cm

Since

(i) magnification is 2;

object height: image height = 1 : 2

(ii) the image is erect, it is virtual and behind the mirror.

A suitable scale in this case is 1 cm on paper to represent 10 cm of the actual length, see figure 5.29.

- Draw two lines KH and EG parallel to the principal axis at heights above the axis in the ratio 1 : 2, so as to meet the mirror at H and G respectively.
- Join FH and produce it to meet EG produced at I.I is the top of the image.
- Complete the image by drawing a perpendicular line from I to the principal axis at B.
- Draw a perpendicular line from O the principal axis at A. The object is therefore OA. From the graph, the object distance PA is 8.5 cm.

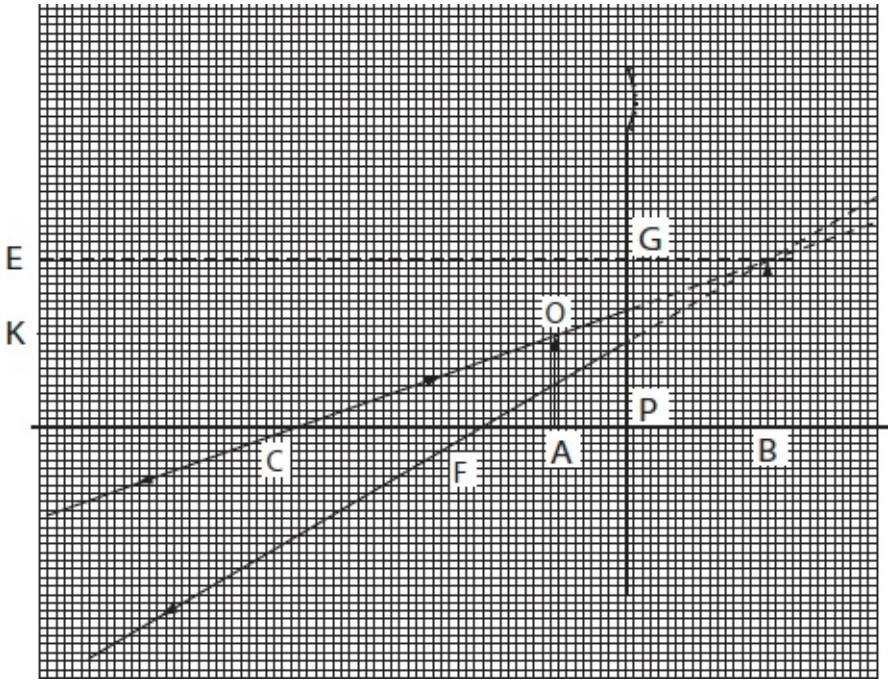



*Fig. 5.29*

***Example 5***

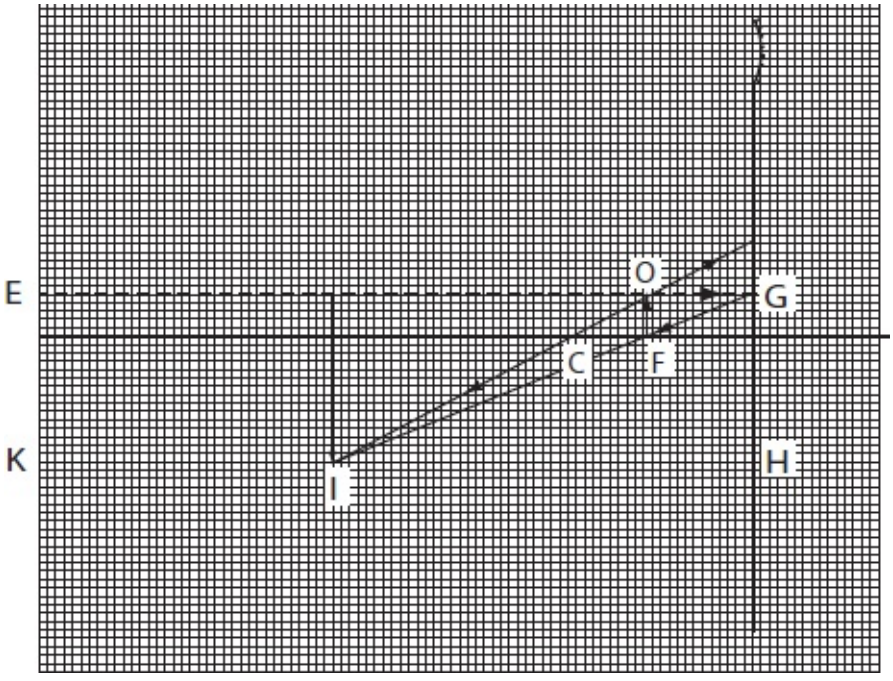



*Fig. 5.30*

A concave mirror of focal length 10 cm forms a real image four times the size of the object. If the object height is 5 cm, determine graphically:

(a) The object distance.

(b) The image distance.

*Solution*

A suitable scale in this case is 1cm to represent 10 cm of actual length.

- Using the scale, draw line EG parallel to the principal axis at a height 0.5 cm (height of object) from it.
- Draw another line KH, 2 cm below and parallel to the principal axis. Note that the ratio of distances of EG and KH from the principal axis is 1: 4 since magnification is 4.
- Draw a line from G through F and produce it to cut KH at I. I is the top of the image.
- Complete the image by drawing a perpendicular line to the principal axis at 1.
- Draw a line from I through C and produce it to meet EG at O so that O is the top of the object.
- Complete the object by drawing a perpendicular line to the principal axis. The object is, therefore, OA.

From the graphs:

(a) The object distance is 12.5 cm.

(b) The image distance is 50 cm.

## Relationship between f and r

We have seen that focal length is half the radius of curvature, that is, $F = \frac{r}{2}$. This relationship holds for spherical mirrors and can be proved theoretically using geometry.

Consider a single ray AB above and parallel to the principal axis and incident to the mirror at B. The ray is reflected at B through F, see figure 5.31.

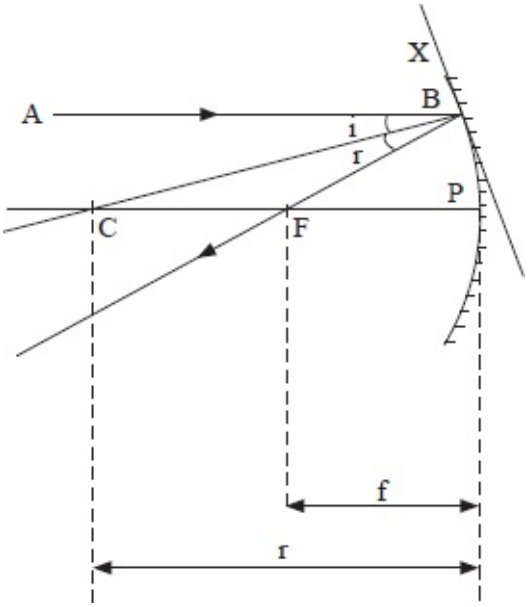



*Fig. 5.31: Relationship between F and r*

By geometry, CB is normal to the tangent to the mirror at B. It therefore follows from the laws of reflection that:

∠ABC = ∠CBF

But ∠ABC = ∠BCF (alternate angles)

Therefore, ∠CBF = ∠BCF

Therefore, BF = FC.

When B is close to P, that is, AB is incident to the mirror and very close to P, then

BF = PF.

Therefore, PF = FC. Hence, F is midway between P and C.

Thus, FP = $FP = \frac{CP}{2}$

But, FP = f and CP = r

Therefore, $f = \frac{r}{2}$

## The Mirror Formula

If an object is at a distance u from a curved mirror of focal length f, its image is formed at a distance v from the mirror. The relationship between u, v and f can be determined experimentally.

**Experiment 5.5: To investigate the relationship between u, v and f for a concave mirror**

*Apparatus*

Two optical pins, ruler, mounted concave mirror.

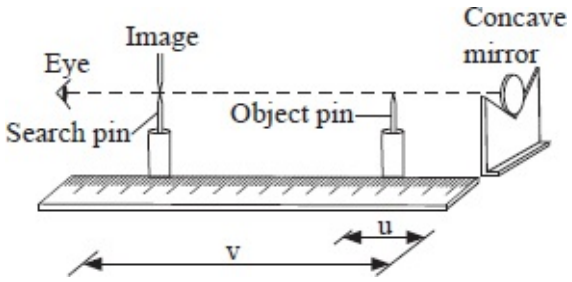



*Fig. 5.32: Relationship between u, v and f*

*Procedure*

- Place an object pin at a distance u = 15 cm in front of the concave mirror, see figure 5.32.
- With the eye positioned as shown, locate the position of the image with a search pin using the 'no parallax' method.
- Record the image distance v in Table 5.1
- Repeat the experiment with object pin at u = 17, 19, 21 and 23 cm.
  Record the corresponding values of v on the table.
- Complete the table and calculate the mean value of $\frac{1}{u} + \frac{1}{v}$
- Compare the mean value of $\frac{1}{u} + \frac{1}{v}$ with $\frac{1}{f}$, the reciprocal of focal length of the, with mirror used.

*Table 5.1*

| *u (cm)* | *v (cm)* | $\frac{1}{u}$ $(cm^{-1})$ | $\frac{1}{v}$ $(cm^{-1})$ | $\frac{1}{u} + \frac{1}{v}$ $(cm^{-1})$ |
|---|---|---|---|---|
| 15 | | | | |
| 17 | | | | |
| 19 | | | | |
| 21 | | | | |
| 23 | | | | |

It is observed that the object distance u, image distance v and the focal length f of the mirror are related by the formula;

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

This is called the mirror formular and applies to all spherical mirrors.

From the formular, $f = \frac{uv}{u+v}$

## Sign Convention

In order to determine the position and nature of the image formed by a curved mirror, a sign convention is normally used.

The sign convention used in this book is real-is-positive sign convention.

### *Real-is-Positive Sign Convetion*

When applying this convention:

(i) All distances are measured from the mirror as the origin.

(ii) Distances of real objects and images are considered positive (+).

(iii) Distances of virtual objects and images are considered negative (–).

In the convention, a concave mirror has a real principal focus and therefore positive focal length, while a convex mirror with a virtual principal focus has negative focal length.

***Example 6***

An object is placed 30 cm from a concave mirror of focal length 20 cm

Calculate:

(a) The image position.

(b) The magnification.

*Solution*

(a) The mirror is concave, hence;

$f = +20$ cm

$u = +30$ cm

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

$\frac{1}{30} = \frac{1}{v} + \frac{1}{20}$

$\frac{1}{v} = \frac{1}{20} + \frac{1}{30}$

$v = +60$ cm

The image is 60 cm from the mirror and since v is positive, it is real.

(b) $m = \frac{v}{u}$

$= \frac{60}{30}$

$= 2$

***Example 7***

An object is placed (a) 18 cm (b) 6 cm in front of a concave mirror of focal length 12 cm. Determine the position and nature of the image formed in each case.

*Solution*

(a) $u = +18$ cm

$f = +12$ cm

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

$\frac{1}{v} + \frac{1}{(+18)} = \frac{1}{(+12)}$

$\frac{1}{v} = \frac{1}{12} - \frac{1}{18}$

$= \frac{1}{v} - \frac{1}{36}$

$v = 36$

The image is formed 36 cm from the mirror, v is positive, so the image is real.

(b) $u = +6$ cm

Substituting in the formular;

$\frac{1}{v} + \frac{1}{+6} = \frac{1}{(+12)}$

$\frac{1}{v} = \frac{1}{12} - \frac{1}{6}$

$\frac{1}{v} = \frac{-1}{12}$

$v = -12$ cm

The image is formed 12 cm from the mirror, v is negative, hence the image is virtual.

***Example 8***

A convex mirror of focal length 9 cm produces an image on its axis 6 cm from the mirror. Determine the position of the object.

*Solution*

f = –9 cm (convex mirror)

v = –6 cm

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

$\frac{1}{(-6)}+\frac{1}{u}=\frac{1}{(-9)}$

$\frac{-1}{6}+\frac{1}{u}=\frac{-1}{9}$

$\frac{1}{u}=\frac{1}{6}-\frac{1}{9}=\frac{1}{18}$

u = + 18 cm

The plus sign shows that the object is real and 18 cm in front of the mirror.

## Graphical Analysis of the Mirror Formular

(i) From Table 5.1 if a graph of = $\frac{1}{u}$ against = $\frac{1}{v}$ is plotted, a straight line with a negative gradient is obtained.

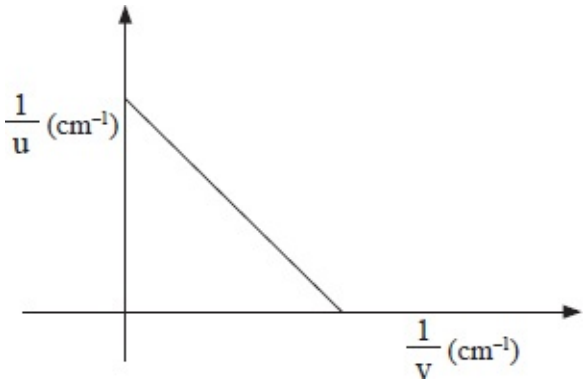



*Fig. 5.33: Graph of* $\frac{1}{u}$ *against* = $\frac{1}{v}$

The x-intercept or the y-intercept gives $\frac{1}{f}$. The gradient is negative, implying that the image is inverted relative to the object.

(ii) A graph of uv against (u + v) is a straight line passing through the origin.

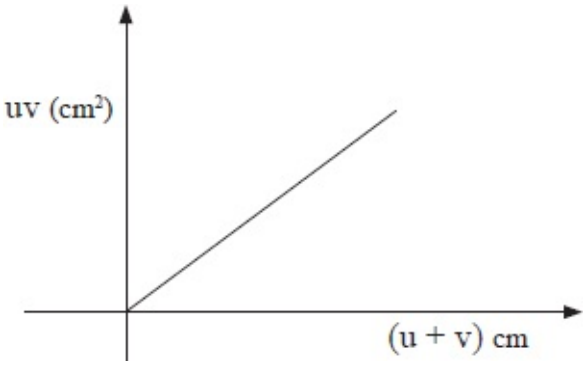



*Fig. 5.34: Graph of uv against u + v*

The gradient gives the focal length f.

Since $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, multiplying through by v gives;

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

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

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

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

(iii) A graph of m against v is a straight line with gradient $\frac{1}{f}$. The y-intercept is –1.

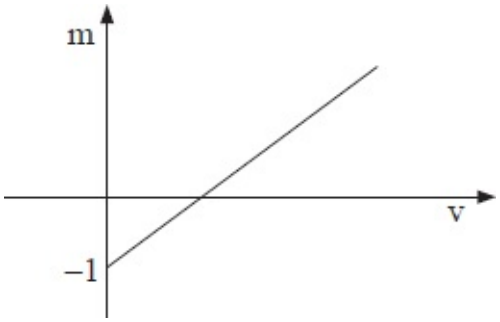



*Fig. 5.35: Graph of m against v*

## Application of Curved Mirrors

### Concave Mirrors

Concave mirrors are used:

*(i) As shaving mirrors*

*(ii) By dentists, when examining teeth.*

In each case, the object is placed within the focal length of the mirror so that a magnified erect image is obtained, see figure 5.36.

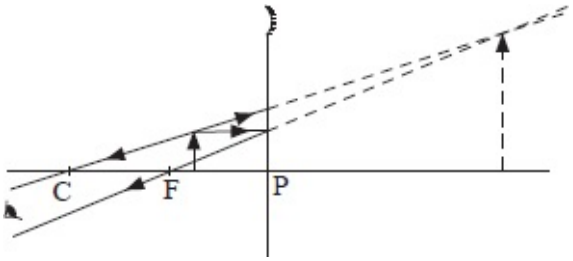



*Fig. 5.36: Use of concave mirror as a shaving mirror*

### *(iii) As Reflector behind a Projector Lamp*

The lamp is placed at the centre of curvature of the concave mirror to reflect light travelling away from the projector, hence increasing the illumination of the slide, see figure 5.37

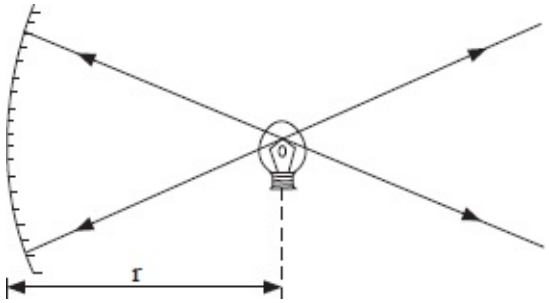



*Fig. 5.37: Concave mirror with projector lamp*

### *(iv) In Telescopes, for Astronomical Observations*

When an object such as a star is very far from the mirror (at infinity), the rays from any point on it appears to originate from a particular point and are therefore parallel. The image is thus formed at the focal point.

### *(v) Solar Concentrators*

The heat and light energy from the sun can be brought to focus by a concave mirror. This fact is employed in solar cookers, where a small oven is placed at the focal point of a large mirror.

## Convex Mirrors

They are used:

*(i) As driving Mirrors*

*(ii) In Supermarkets, so that the attendants can monitor large floor area*

This is because:

- They form an upright image, regardless of the object distance.
- They provide a wide field view, so that the overtaking traffic can be easily seen, see figure 5.38.

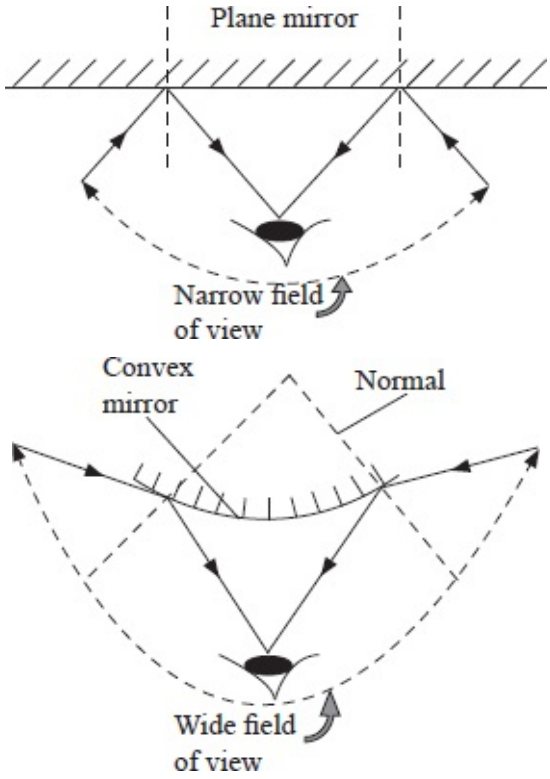



*Fig. 5.38: Narrow and wide field of view*

The only disadvantage of using a convex mirror as a driving mirror is that it forms a diminished image, giving the impression that the vehicles behind are farther away than they actually are. This is dangerous and the driver has to learn to judge distances accurately when using the mirror.

## Defects of Spherical Mirrors

In this chapter, we have used narrow parallel beams of light close to and parallel to the principal axis in studying reflection of light by curved mirrors. For concave mirror in this case, all the reflected rays converge at one definite point, the principal focus. However, if wide parallel beam is incident on a spherical mirror of wide aperture, then parallel rays are not brought to a focus at the principal focus F after reflection.

Rays well away from the principal axis are brought to a different point, such as F1, after reflection, see figure 5.39 (a). The parallel beam, therefore, produces

a blurred focus. This is called **spherical aberration**.

The reflected rays intersect to form a surface called a **caustic curve**, a curved shape centred about the principal focus F.

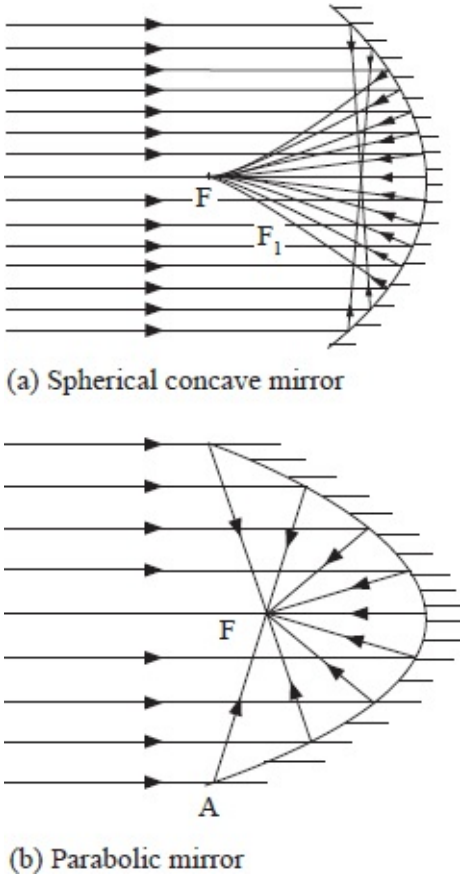



*Fig. 5.39: Caustic curves*

A bright caustic curve is often seen on the surface of tea in a cup. This is formed when light from a distance source is reflected from the inside of the cup, which acts as a curved mirror of large aperture.

From the principle of reversibility of light, it follows that part of the light from a small lamp placed at the principal focus F will be reflected as a divergent beam from the outer parts of the mirror. Since the reflected light energy spreads out from the mirror, it becomes weaker as the distance increases. Due to this, spherical mirrors are used in searchlights or headlamps of cars.

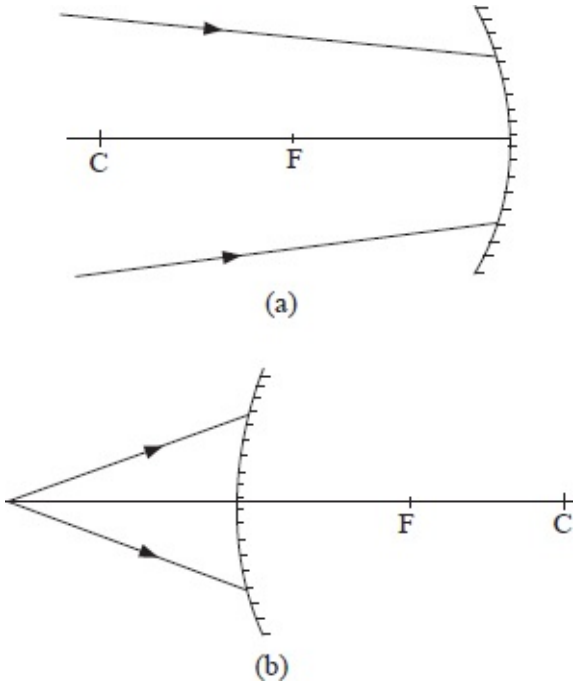
A parabolic mirror overcomes this defect of focus in a spherical mirror. The shape of a parabolic mirror is shown in figure 5.39 (b). All parallel rays are brought to a single focus at the principal focus F.

By the principle of reversibility of light, a light source placed at the principal focus of the parabolic mirror will produce a parallel beam after

reflection. Parabolic concave mirrors are used therefore for the propagation of parallel beams in search lights, car headlights or hand torches. Parabolic reflectors in all these produce a beam of high intensity.

## Revision Exercise 5

1. Define the following terms as applied to concave and convex mirrors:
   (a) Principal focus.
   (b) Centre of curvature.
   (c) Focal plane.
2. You are given two curved reflectors, a spherical concave and a parabolic concave reflector. Which one would you choose for a torch. Explain why.
3. State and explain one advantage and one disadvantage of using a convex mirror as a driving mirror.
4. A dentist has a choice of three small mirrors, a convex, a concave and a plane one to examine the back of your teeth. State which one he should use to give the best view. Give reasons for your choice.
5. (Insert artwork)




Diagrams (a) and (b) show a concave and a convex mirror respectively. Two rays of light are shown in each diagram. Trace the diagrams on paper and draw the approximate path of each ray after reflection.

6. A concave mirror is used to form an image of an object pin. Where must the

object pin be placed to obtain:

(a) An upright, magnified image?

(b) An inverted, diminished image.

(c) An image the same size as the object?

7. A concave mirror with radius of curvature 20 cm produces an inverted image two times the size of an object placed in front of it and perpendicular to the principle axis. By an accurate scale drawing, determine the position of:

(a) The object.

(b) The image.

8. A concave mirror of focal length 10 cm forms a virtual image 5 cm high and 30 cm from the mirror. By an accurate scale drawing, determine:

(a) The position of the object.

(b) The height of the object.

(c) Magnification of the image.

9. A concave mirror of focal length 20 cm forms a virtual image four times the size of the object.

(a) Use a scale diagram to determine the object distance.

(b) Use the mirror formula to determine the object distance.

10. An object is set up 20 cm in front of a mirror A. The details of the image are noted as shown in the table below. The process is repeated with a different mirror B.

| | |
|---|---|
| Mirror A | Real, inverted, magnified and a great distance. |
| Mirror B | Real, inverted, same size as the object. |

(a) State the type of:

(i) Mirror A.

(ii) Mirror B.

(b) Determine the focal lengths of the two mirrors

11. The distance between an object and its magnified real image produced by a concave mirror is 20 cm when the object is placed 10 cm from the pole of the mirror. Determine the :

(a) Linear magnification of the image.

(b) The focal length of the mirror.

12. The distance between an erect image and the object is 30 cm. the image is twice as tall as the object.

(a) What is the object distance?

(b) Determine the radius of curvature.
(c) If the image is virtual, what type of mirror is used?

13. A concave mirror of radius 180 cm forms a real image half its height. Where should the object position be?
14. A Magnified erect image and a magnified inverted image can both be formed by a concave mirror. Draw ray diagrams to show this.
15. Show how parabolic reflectors propagate parallel beams of light.
16. Describe a method that can be used to determine the focal length of a convex mirror experimentally.
17. A concave mirror and illuminated object are used to produce a sharp image of the object on a screen. The object distances and image distances are given below:

| Object distance (cm) | Image distance (cm) |
|---|---|
| 80 | 20 |
| 26.67 | 40 |
| 22.4 | 56 |
| 20.57 | 72 |
| 19.55 | 88 |

(a) (i) Plot a graph of $\frac{1}{u}$ against $\frac{1}{v}$

(ii) Determine the value of $\frac{1}{f}$ from the graph.

(b) Plot a graph of magnification m against v.

(c) Use the graph to find:

(i) The object distance when m = 1.0.
(ii) The image distance when m = 1.0.
(iii) The focal length of the mirror.

(d) (i) Plot a graph of uv against u + v.

(ii) Use the graph to find f, the focal length.

# Chapter 6

# Magnetic Effect of an Electric Current

Professor of physics, Hans Oersted, discovered in the year 1820 that a conductor carrying current has a magnetic field around it. This has led to the understanding that a flow of charge generates a magnetic field.

The magnetic effect of an electric current has been explored and it is now providing mankind with a wide range of devices like electric motors, loudspeakers and electric bells.

This chapter looks into the magnetic field produced by electric current flow, and its applications.

**Experiment 6.1: To investigate the magnetic effect of a current flowing through a conductor**.

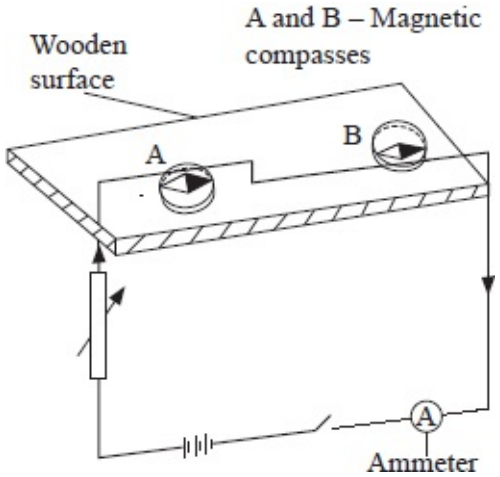



*Fig. 6.1: Magnetic effect of an electric current*

*Apparatus*

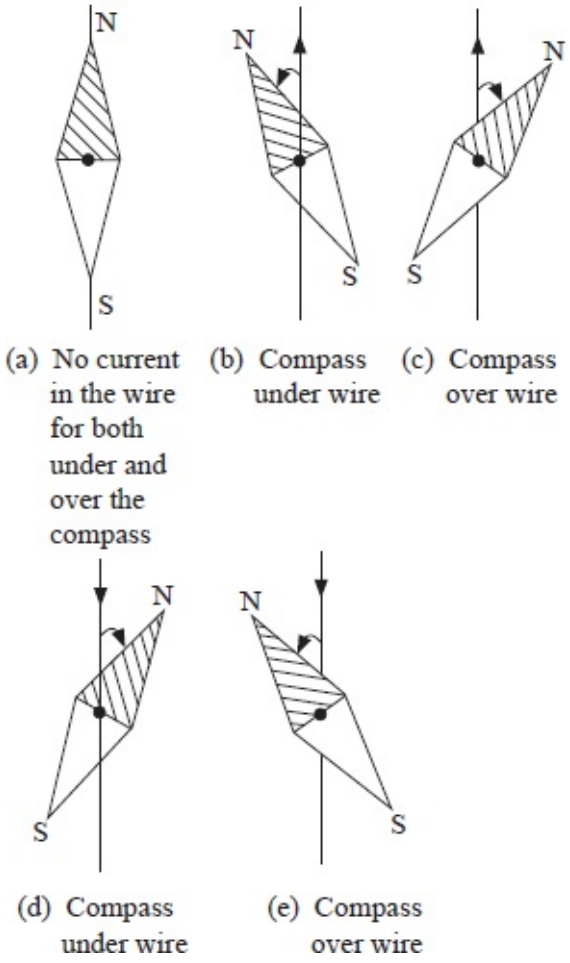
Direct current power source, connecting wires, switch, rheostat, two magnetic compasses and an ammeter.

*Procedure*

- Set up the circuit as shown in figure 6.1.
- Hold the wire over but in line with the compass needle A and in line with but below compass needle B.
- Close the switch and observe the compass needles.
- Vary the strength of the current using the rheostat and note the effect on the needles.
- Open the switch and note the effect on the compass needles.
- Repeat the experiment with the battery polarities reversed, i.e., the direction of current reversed.

*Observation*

(i) When the switch is close, it is observed that the north pole of the compass needles deflect, as shown in figures 6.2 (b) to (e), with respect to the direction of current flow.




(a) No current in the wire for both under and over the compass

(b) Compass under wire

(c) Compass over wire

(d) Compass under wire

(e) Compass over wire

*Fig. 6.2*

(ii) The extent to which the needles deflect increases with the strength of the current flowing.

(iii) Reversing the direction of current reverses the direction of deflection.

(iv) The compass needles settle back into their original positions when the switch which is open, as shown in figure 6.2 (a)

*Explanation*

A flow of current is basically a flow of charge. When charges flow they have an associated magnetic field which interacts with the field of the magnetic compass, causing deflection of the needle.

The strength of the field increases with the strength of the current and hence greater deflection of the compass needle.

Ampere devised a rule, Ampere's swimming rule, to predict the direction of deflection of the compass needle.

**If one imagines to be swimming along a wire in the direction of the current and facing the compass needle, then the north pole of the needle will be deflected towards the swimmer's left hand.**

## Magnetic Field-Pattern of a Straight Current-carrying Conductor.

**Experiment 6.2: To investigate the magnetic field pattern due to a straight conductor carrying current.**

### Using Iron Filings.

*Apparatus*

Iron filings a straight conductor, high current power source, four magnetic compasses and a card.

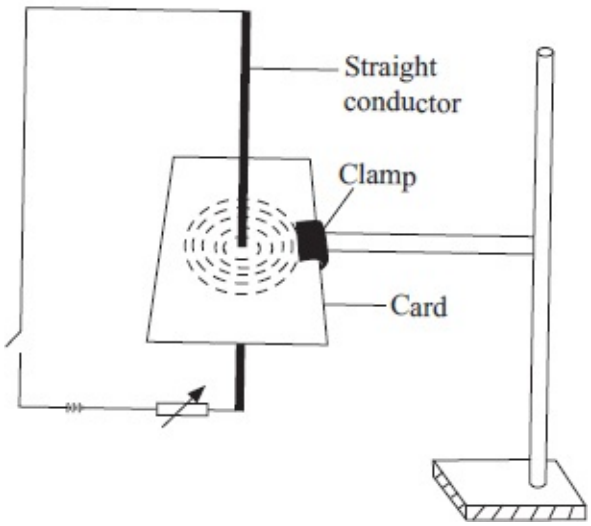



*Fig. 6.3: Iron fillings showing magnetic field pattern*

*Procedure*

- Make a small hole through the card.
- Clamp the card in a horizontal position.
- Pass the conductor through the hole on the card and connect its ends to the power supply through a switch.
- Sprinkle iron filings evenly on the card
- Close the switch and tap card gently.
- Draw the pattern assumed by the iron filings.

*Observations*

The iron filings settle in concentric circles, around the conductor, becoming less the significant as the distance from the centre increases.

## Using Magnetic Compasses

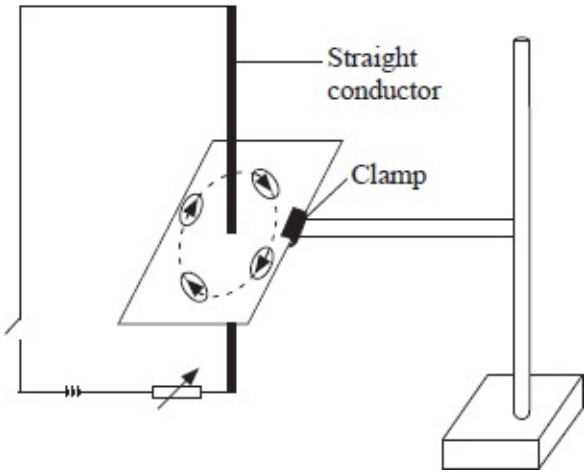



*Fig. 6.4*

*Procedure*

- Set the apparatus as shown in figure 6.4.
- Place the compases equidistant from the straight conductor.
- Close the switch and observe compass needles.
- Repeat the experiment with the compasses placed another equidistance from the straight conductor.

*Observation*

The compass needles are aligned in a circle, pointing in a clockwise direction, see figure 6.4. Whatever the distance from the straight conductor.

*Conclusion*

The magnetic field produced by a straight conductor forms a pattern of concentric circles around the conductor.

The direction of the magnetic field produced by a straight conductor can be predicted using Maxwell's Right-hand grip rule or Maxwell's corkscrew rule.

Maxwell's Right-hand grip rule for a straight conductor carrying current states that **if a conductor carrying current is grasped in the right hand with the thumb pointing along the wire in the direction of the conventional current, the fingers will encircle the conductor in the direction of the magnetic field**.

This is illustrated in figure 6.5 (a) and (b).

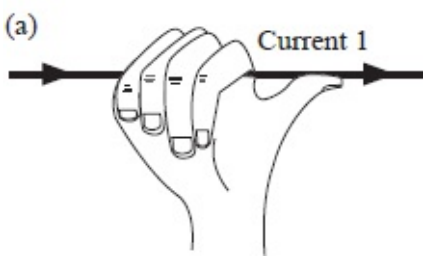



*Fig. 6.5 (a): Right-hand grip rule*

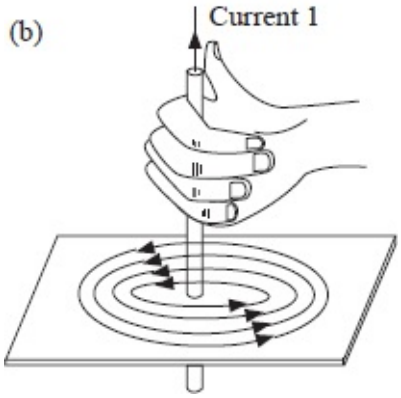



*Fig. 6.5 (b): Right-hand grip rule*

Maxwell's corkscrew rule states that if a right-handed screw is driven forward in the direction of the conventional current, then the direction of rotation of the screw is the direction of the field lines.

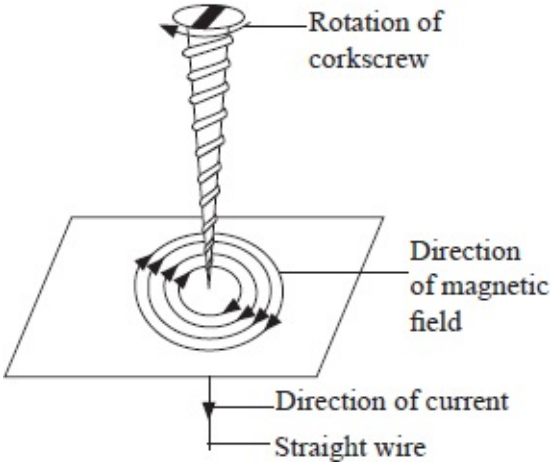



*Fig. 6.6*

## Magnetic Field Pattern of a Circular Current-carrying Loop

**Experiment 6.3: To investigate magnetic field pattern due to a circular current-carrying loop**

*Apparatus*

A card, thick wire, iron filings, magnetic compass, power source and a clamp.

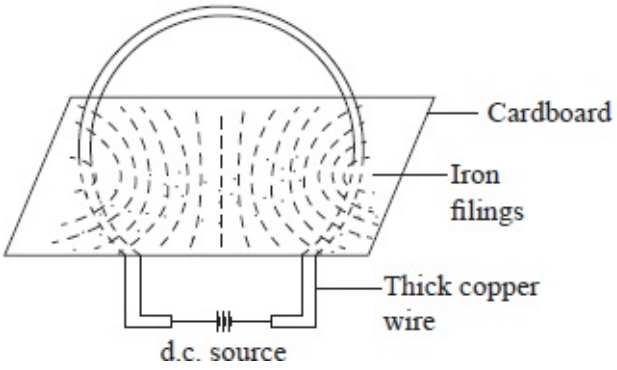



*Fig. 6.7: Alignment of iron filings due to a loop*

*Procedure*

- Drill two holes in the card and pass the wire through the holes to make a loop.
- Set the apparatus as shown in figure 6.7.
- Gently sprinkle the iron filings on the card.
- Switch on the current and tap the card gently. Note the effect on the iron filings.
- Switch off the current and remove the iron filings.
- Switch on the current and, using the magnetic compass needle, trace the magnetic field lines.

*Observation*

The pattern formed by the iron filings is similar to that of a small magnet. The magnetic compass traces the field patten shown in figure 6.8.

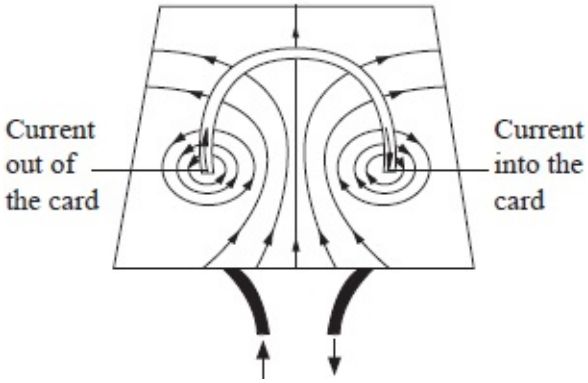



*Fig 6.8: Magnetic field pattern due to a single coil*

The right-hand grip rule for a loop carrying a current asserts that **if the fingers of the right hand encircle the current loop such that they point in the direction of current, the thumb points in the direction of the magnetic field formed through the inside of the loop**, see figure 6.9.

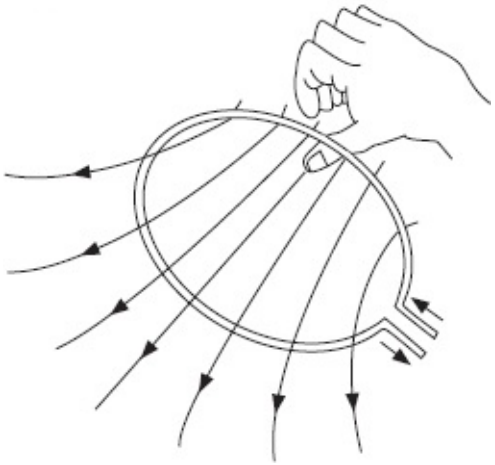


*Fig. 6.9: Right-hand grip rule for a current-carrying loop*

## Magnetic Field Pattern of a Solenoid Carrying Current

The magnetic field aroung a wire carrying current can be intesified by winding the wire into a long cylindrical coil with many connected loops otherwise called solenoid.

Using a number of compasses or iron filings, it can be shown that the field set up by a solenoid is similar to that of a permanent magnet, see figure 6.10. When a compass needle is placed near end X, its north pole is repelled indicating that a north pole is created at end X. The other end of the solenoid is a south pole, see figure 6.10. When a compass needle is placed near end X, its north pole is repelled.

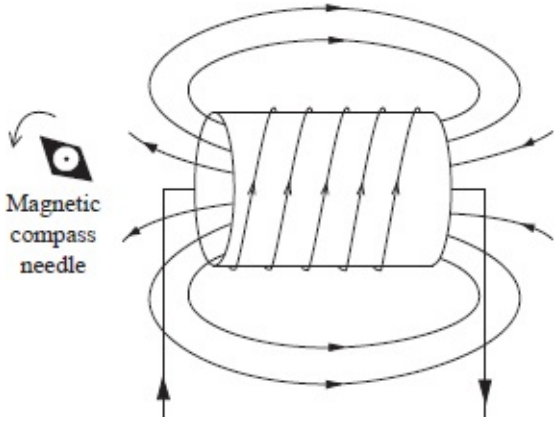



*Fig. 6.10: Magnetic field pattern due to a solenoid*

When the field inside and outside the solenoid is explored, the following properties emerge:

(i) The field resembles that of a magnet.

(ii) The field near the ends is non-uniform compared to the field inside the solenoid.

(iii) The field near the end of the solenoid is weaker than that inside the solenoid.

(iv) The field outside the solenoid is oppositely directed to that inside the solenoid

(iv) The field outside the solenoid is less than that inside the solenoid.

Thus, the solenoid carrying current behaves like a bar magnet. It is referred to as an electromagnet since its magnetism arises from the flow of electric current. The rule can be used to predict the polarities of the electromagnet formed. The rule states that if the direction of current in the coil as observed from one end is clockwise, this end is the south pole and if the current is anticlockwise, the end becomes the north pole.

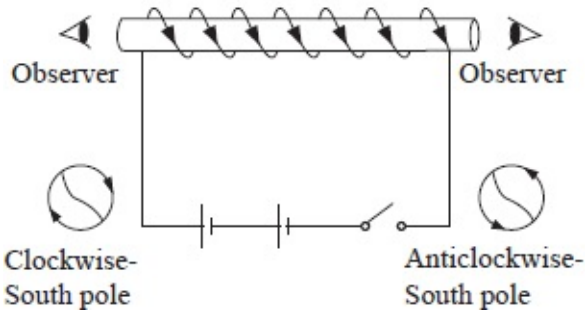



*Fig. 6.11: Clock rule*

The right-hand grip rule can also be used to predict the north pole of the electromagnet as follows;

**If a coil carrying current is held in the right hand such that the fingers encircle the loops while pointing in the direction of the current flow, the thumb points in the direction of the north pole.**

See figure 6.12.

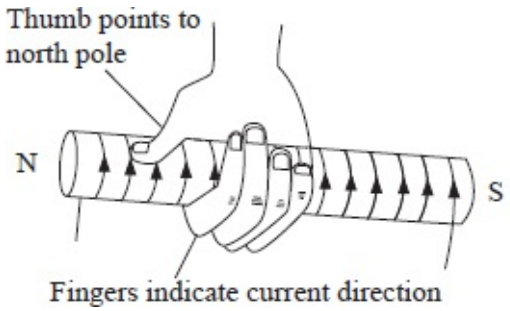



*Fig. 6.12: Right hand grip rule for a coil carrying current*

Practical electromagnets require that the coils be wound on a soft iron core to increase magnetic power,

The factors affecting the strength of an electromagnet include:

(i) the **size of current** in the solenoid.

(ii) the number of **turns** of wire in the solenoid.

(iii) the **shape** of the core.

(iv) the **length** of the solenoid.

The experiments outlined below explore how the size of the current, the number of turns and the shape of the core affect the strength of the electromagnets.

**Experiment 6.4: To investigate how the size of current flowing in the solenoid affects the strength of an electromagnet**

*Apparatus*

Long insulated copper wire, rheostat, ammeter, power source, preferrably a 6.0 V lead-acid accumulator, switch, connecting wires, a dish containing paper pins, balance and iron rod.

*Procedure*

- Wind 20 turns of insulated copper wire tightly round the iron rod.
- Connect it to the battery as shown in figure 6.13.
- Switch on the current and adjust the rheostat to give a current of 0.5 A. Find what mass of the paper pins the electomagnet can support.
- Repeat the experiment with the current of 1.5 A and 2.0 A.

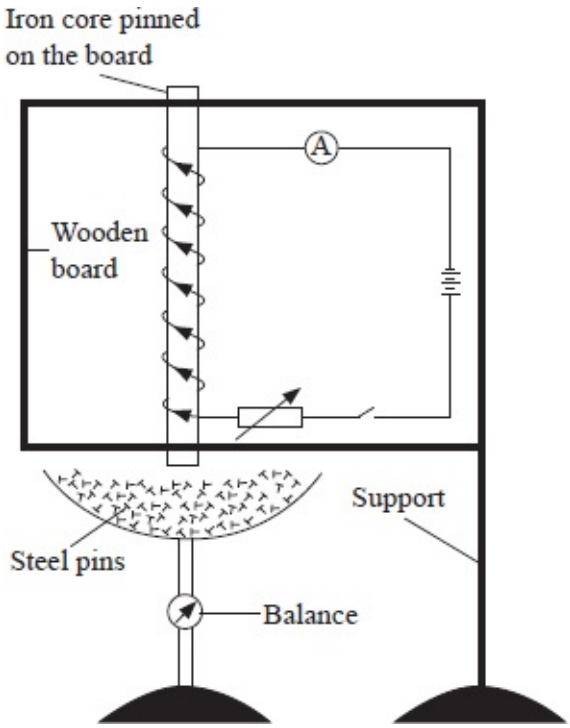



*Fig. 6.13: Effect of size of curent on the strength of electromagnet*

*Observation*

As the current is increased, the mass of the pins supported (representing the strength of the magnet) increases. Beyond a particular value of current, however, the strength of the electomagnet remains constant.

**Experiment 6.5: To investigate how the strength of an electromagnet is affected by the number of turns**

*Apparatus*

Iron core, power source, ammeter, rheostat, steel pins, balance, switch and long insulated wire.

*Procedure*

- Wind five turns of the coil on the iron core.
- Connect the coil to the battery, as shown in figure 6.14.
- Set the current to a constant value, say 1.5 A.

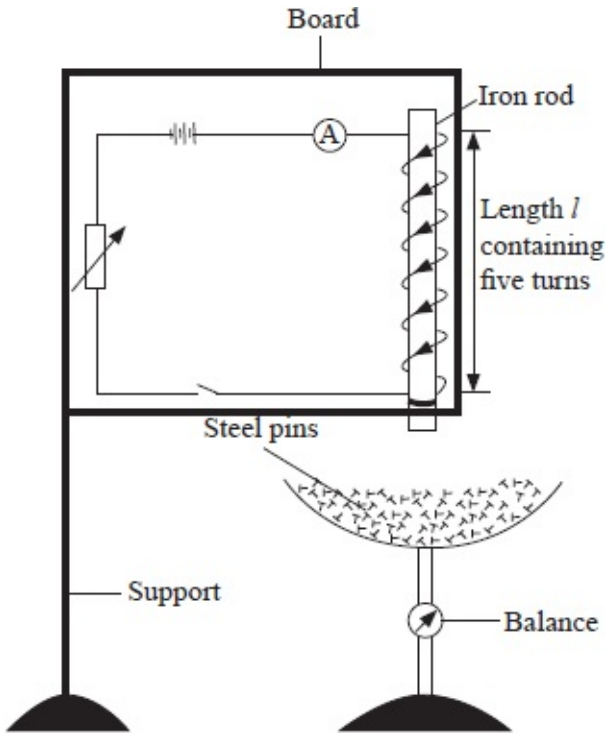



*Fig. 6.14: Effect of number of turns on strength of magnet*

- Record the maximum mass of the clips supported by the electromagnet.
- Now increase the number of turns in steps of five and in each case set the current to the same value as before (1.5 A) with the turns occupying the length L.
- Sketch the graph of the mass of the clips supported against the number of turns.

*Observation*

Increasing the number of turns increases the maximum mass of the pins supported.

In general, the magnetic strength of an electromagnet:

(i) increases with increase in current.

(ii) increases with increase in the number of turns of the solenoid.

(iii) decreases with the length of the solenoid.

Other experiments show that the U-shaped core produces a stronger magnet than that of a straight core.

**Experiment 6.6: To investigate how the shape of the core affects the strength of an electromagnet**

*Apparatus*

U-shaped iron core, straight iron core, light spring with a pointer, iron bar, insulated copper wire, ammeter, metre rule, current source and rheostat.

*Procedure*

- Wind 20 turns of wire on the U-shaped core.
- Set the apparatus as shown in figure 6.13. Note the position of the spring pointer when the switch is open.

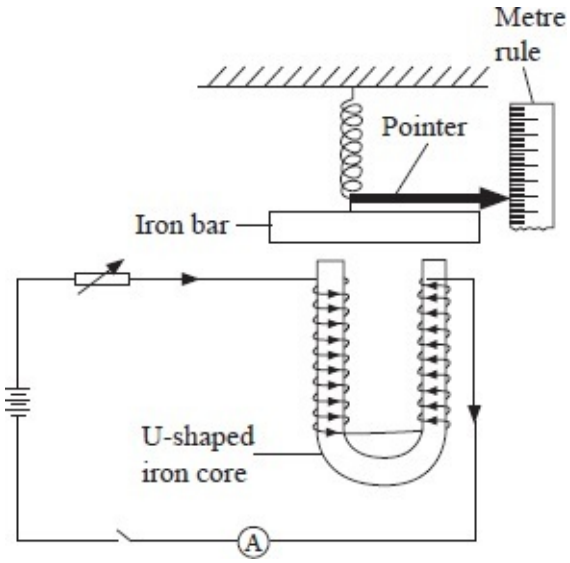



*Fig. 6.13: Magnetic power depends on the shape of the core*

- Switch on the circuit and adjust the current to 0.5 A. Record the extension of the spring.
- Repeat the experiment with currents 1.0 A, 1.5 A and 2.0 A flowing through the coil.
- Replace the U-shaped iron core with the straight iron core having the same number of turns wound on it and repeat the experiment.
- On the same axes, plot graphs of extension against current for U-shaped and straight iron core.

*Observation*

Figure 6.14 shows possible graph resulting from the experiment. The extension produced represents the magnetic force of the electromagnet.

The U-shaped core produces more extension for a given current that the straight core since it attracts the iron bar with two poles. The iron bar provides a path to complete the magnetic field lines, making the U-shaped core more

efficient than the straight iron core that uses only one pole for the attraction. When winding on a U-shaped core, care must be taken to do is in such a way that one end of the core produces a north pole while the other end produces a south pole.

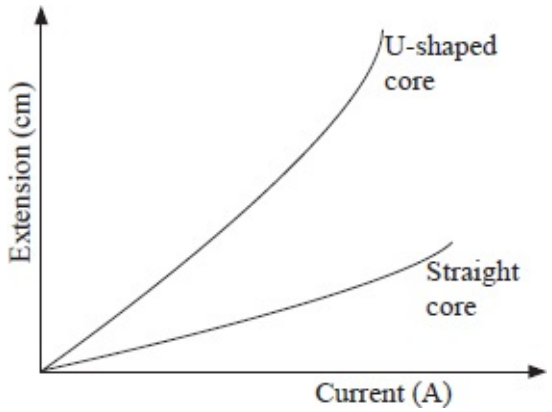



*Fig. 6.14: Comparison of U-shaped and straight core electromagnet*

In general, the magnetic strength of an electromagnet:

(i) increases with increase in current.

(ii) increases with the increase in the number of turns of the solenoid.

(iii) decreases with the length of the solenoid.

(iv) depends on the shape of the core.

## Force on Current-carrying Conductor in a Magnetic Field

The effect of a magnetic field on a current-carrying conductor can be demonstrated in the experiment below.

**Experiment 6.7: To investigate how magnetic field affects a conductor carrying current**

*Apparatus*

U-shaped magnet, two straight brass rods, insulating support, rheostat, switch and battery.

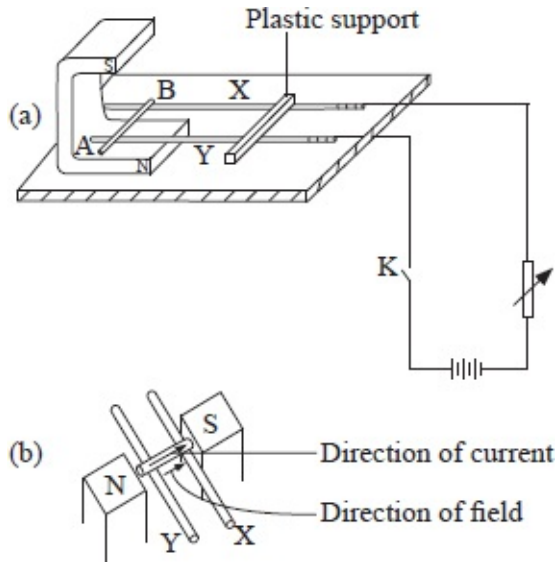



*Fig. 6.15: Conductor in a magnetic field*

*Procedure*

- Mount two stiff straight brass rodsX and Y parallel to each other on a plastic (insulator) support as shown in figure 6.15 (a).
- Clamp the support so that the brass rods are on the same horizontal plane.
- Place another brass rod AB across X and Y.
- Postition a strong horse-shoe magnet so that beam AB is between the poles and perpendicular to the magnetic field.
- Connect a battery and rheostat in series with rods X and Y.
- Switch on the current and observe the behaviour of the rod AB.
- Reverse the direction of the current and note the behaviour change of rod AB.
- Reverse the direction of the magnetic field so that the north pole is up and observe the behaviour of the rod when the current flows in it.
- Increase the strength of the current and repeat the experiment.
- Now turn the magnet so that the field is parallel to the length of the rod AB, as in figure 6.15 (b).
- Observe what happens when the current flows in the rod.

*Observation*

(i) When the current flows along AB, the rod rolls along the brass rods X and Y towards the plastic support.

(ii) When either the direction of the current or that of the magnetic field is reversed, the direction of movement of AB also changes.

(iii) When current is increased, the rod moves faster.

(iv) When the magnet is turned so that the magnetic field is parallel to the length AB, the rod remains stationary.

A force acts on a current-carrying conductor when it is placed in a magnetic field. The magnitude of this force increases with increase in current and therefore field strength. The force is maximum when the angle between the conductor and the field is 90°. The force is minimum (zero) when the conductor is parallel to the magnetic field.

It can also be shown that the force on the conductor can be increased by increasing the length of the conductor in the magnetic field.

*Explanation*

Figure 6.16 (a) shows the field around the conductor AB as viewed from A. This field interacts with the field due to permanent magnet shown in figure 6.16 (b) to form the field pattern shown in figure 6.16 (c). Note that the field tends to concentrate more on one side of the conductor than the other. The weak field on the opposite side is a result of the two fields opposing each other.

Consider the magnetic lines of force acting like plastic bands, concentration of the lines on the other side of the conductor produces a catapult effect that pushes theconductor in the opposite direction to rid the plastic of the strain. When the direction of the current or magnetic field is reversed, the direction of the force on the conductor also reverses.

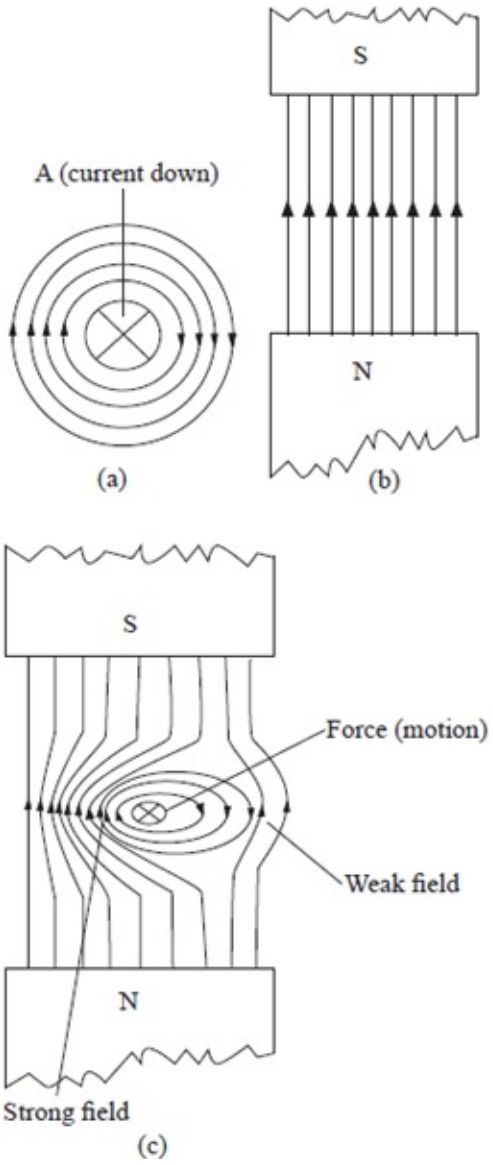



*Fig. 6.16: Force on a conductor carrying current in a magnetic field*

For a conductor carrying current in a magnetic field, the direction of the force acting on it can be predicted using the Fleming's left-hand rule (motor rule), stated below;

**If the left hand is held with the thumb, the first finger and the second fingers mutually at right angles so that the first finger points in the direction of the magnetic field and the second finger in the direction of the current, then the thumb points in the direction of motion**, see figure 6.17.

The direction of current in this rule is the conventional direction. It should be noted that the rule applies only if the magnetic field and current are perpendicular to each other. When the field and current are parallel to each

other, there is no force on the conductor.

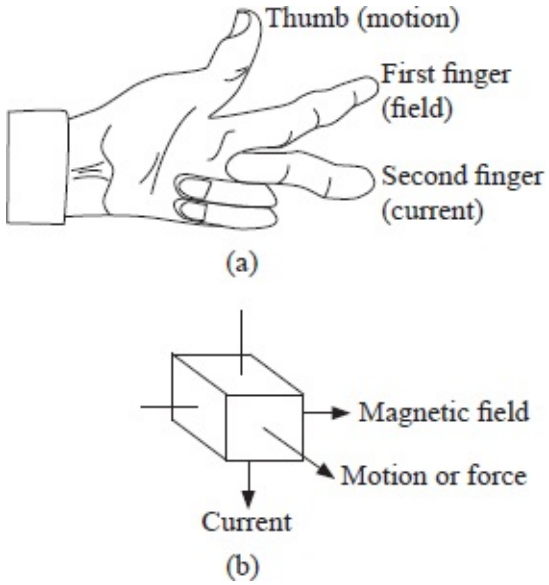



*Fig. 6.17: Fleming's left-hand rule*

## Force on a Current-carrying Coil in a Magnetic Field

Figure 6.18 (a) shows a rectangular coil ABCD put in a magnetic field. When the current flows through the coil in the direction DCBA, the resultant field pattern is shown in figure 6.18 (b).

The catapult force acting on the sides of the coil causes it to turn in clockwise direction. Application of Fleming's left-hand rule makes it easier to predict the direction of motion than drawing the field pattern.

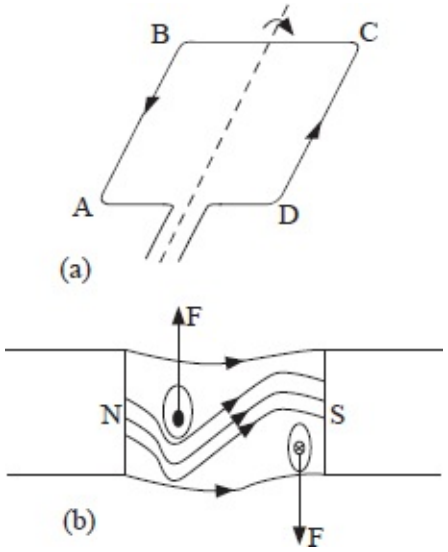



*Fig. 6.18: Magnetic field pattern of a coil in a magnetic field*

## Force on a Charged Particle Moving in a Magnetic Field

Earlier in this chapter, it was stated that moving charges produce a magnetic field. An electron moving through a magnetic field will therefore experience a force, see figure 6.19 (a).

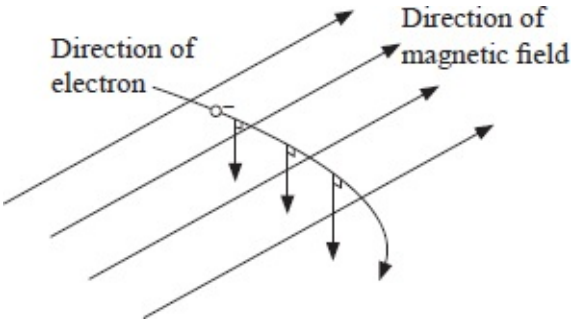



*Fig. 6.19 (a): Electron movement in a magnetic field*

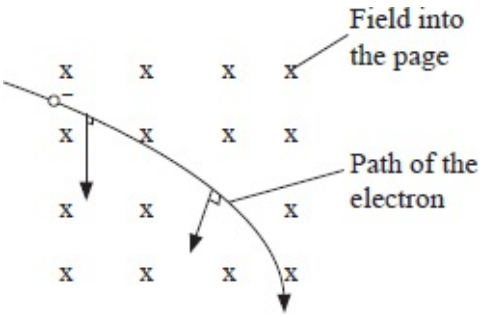



*Fig. 6.19 (b): Electron movement in a magnetic field*

Considering that the direction of movement of an electron is opposite to the flow of coventional current, the direction of the force on the charge can be predicted using Fleming's left-hand rule to be downward, see figure 6.19 (b).

## Force Between Parallel Conductors Carrying Current

**Experiment 6.8: To investigate the force experienced by two parallel conductors carrying current**

*Apparatus*

Two stands with clamps, two aluminium foils 30 cm each, connecting wires, power source and a rheostat.

*Procedure*

- Set the apparatus as shown in figure 6.20 (a), so that current flows in the same direction.
- Close the switch. Observe what happens to the metal foils.

- Increase the magnitude of current flowing in the circuit and observe the effect on the metal foils.
- Repeat with the current flowing in the opposite direction, as shown in figure 6.20 (b).

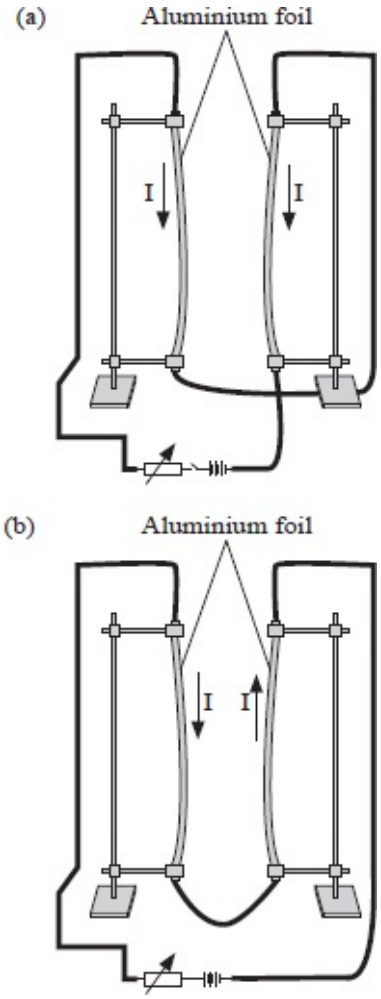



*Fig. 6.20*

*Observation*

The aluminium foil strips attract each other when the current flowing through them is in the same direction and repel when the current is flowing in opposite direction.

*Explanation*

Fig. 6.21 shows the magnetic field pattern for the strips carrying current in the same direction. The field between the strips cancel each other, leaving a region of zero resultant magnetic field called the neutral point (X). The field on the outside part of each strip generates catapult force that pushes the two strips

towards each other.

In figure 6.21 (a), the fields between the strips cancel each other, leaving a region of zero resultant magnetic field called the neutral point (X). The field on the outside part of each strip act as catapult forces, pushing the two strips towards each other.

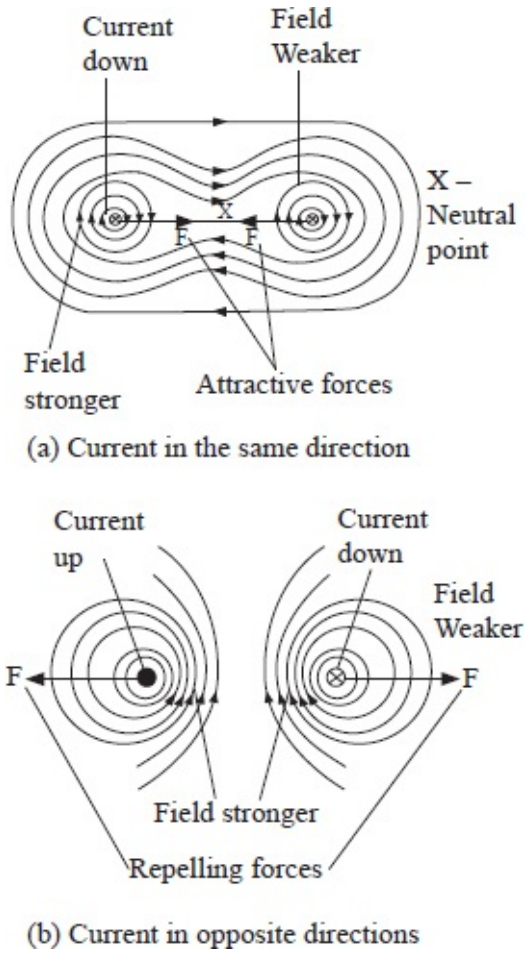



*Fig. 6.21: Magnetic field pattern due to parallel conductors*

In figure 6.21 (b), show the pattern for current flowing in opposite direction, the magnetic fields between the two strips come very close to each other. Since field lines mutually repel one another, the two strips are pushed away from each other. Fleming's left-hand rule can be applied to the two situations, as shown in figure 6.22.

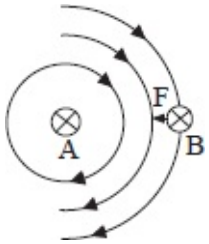



*Fig. 6.22: Fleming's left-hand rule to parallel conductors*

If strip A is taken to produce the field, Fleming's left-hand rule applied at B indicates that the force on B is towards A. If strip B is taken to produce the field, the rule indicates that the force on A is towards B.

The same treatment can be applied to the situation where the currents flow in opposite directions to confirm the repulsion between the strips.

## Magnetic Field Pattern of a Conductor Carrying Current in the Earth's Magnetic Field

The earth's magnetic field lines are taken to be parallel, except at the poles. The interaction of the earth is field and the field due to the conductor produces the pattern shown in figure 6.23. The conductor thus experiences a force F shown.

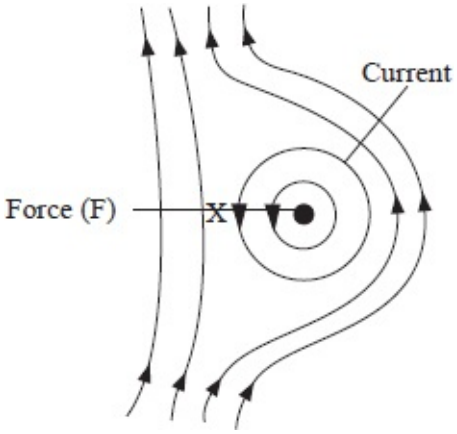



*Fig. 6.23*

## Uses of Electromagnets

Electromagnets are used in various domestic instruments or devices, industrial and even in medicine. Some of the common applications are illustrated below.

### *Electric Bell*

An electric bell consists of a U-shaped electromagnet whose winding on one arm is opposite to that on the other, see figure 6.24. A contact screw presses onto a

soft iron strip, which acts as a spring. The electric circuit is completed through a battery and a switch S.

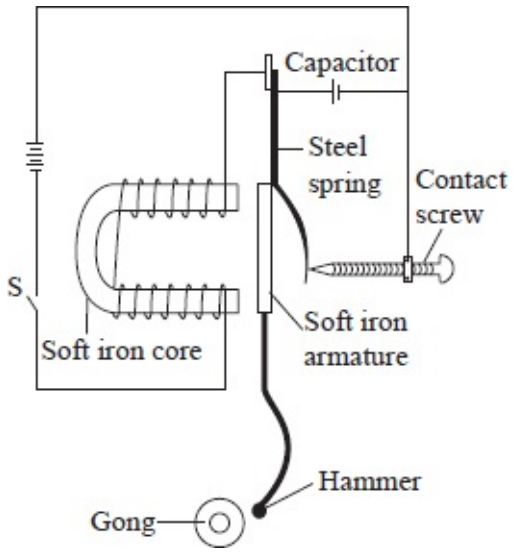



*Fig. 6.24: Electric bell*

When S is closed, current flows through the circuit and the core becomes magnetised. The electromagnet induces magnetism in the soft iron strip (armature), which is then attracted to the poles of the electromagnet. The hammer attached to the armature thus strikes the gong.

The attraction of the soft iron armature separates the contacts, breaking the circuit. The magnetism in the core therefore dies off and the spring returns the armature to its original position. Contact is made again and the process is repeated. So long as the switch is closed, the hammer strikes the gong repeatedly, making continous ringing sound. The steel spring and screw contact where the current is automatically switched on and off constitute a make-and-break mechanism. The frequency at which the make and break takes place is controlled by the screw with the advent of electric sounders such bells are being replaced.

## *Telephone Receiver (Earpiece)*

The telephone receiver has a U-shaped magnet formed by placing a short permanent bar magnet across the ends of two soft iron bars. The arrangement is made in such a way that a steady current flowing through the coils of the electromagnet causes it to exert a pull on the springy magnet alloy diaphragm, see figure 6.25.

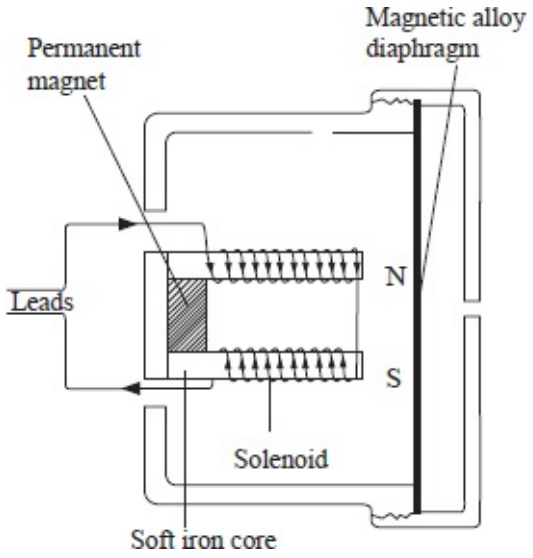



*Fig. 6.25: Telephone receiver*

When a person speaks into the microphone at the other end of the line, a varying electric current representing the speech is set up. When this electric current is caused to pass through the solenoid in the earpiece. The strength of the magnetic field in the diaphragm is altered correspondingly. The diaphragm thus vibrates and reproduces the sound made by the person through the microphone.

## *Electromagnetic Relay*

This is an electrically operated switch that makes use of an electromagnet. It is a system whereby small current flowing in one circuit produces mechanical effect that controls other usually heavy current circuit(s).

A simple relay consists of an electromagnet E and a soft iron armature lever A pivoted at O, see figure 6.26. It has two completely separate circuits, P and Q. When the circuit Q is completed, a small current flows through the solenoid E which acts as an electromagnet and in turn attacts the soft iron armature A. This closes the contact in circuit P by pushing the spring metal strip. When current in circuit Q is switched off, E loses its magnetism and A goes back to its original position, thus switching off the current in circuit P. The same armature lever can operate several sets of contacts.

Thus, in a magnetic relay, current flowing in one circuit is used to activate another circuit without any direct electrical connection between the two circuits. In cases where a relay is used to control circuits carrying high currents, only a small current is needed in the solenoid to energises the soft iron bar that switches on a high voltage or high current supply. Although relays have wide uses in telephone circuits, controlling power supply to sockets and lights in big

industries, they are being replaced by the more efficient electronic systems.

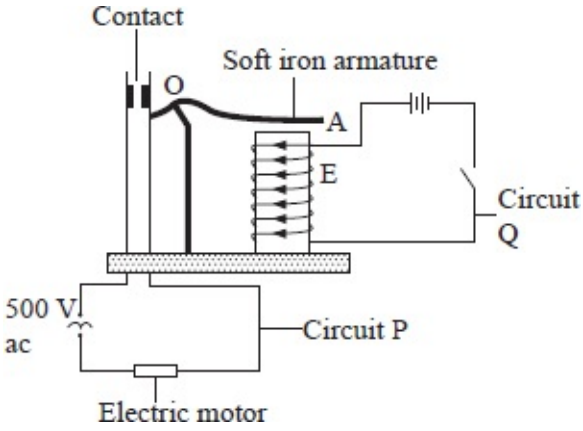



*Fig. 6.26: Magnetic relay*

## *Moving-Coil Loudspeaker*

The moving-coil loudspeaker is used to convert electrical signals from an audio amplifier to sound in radios, television sets and other audio systems. It works by the fact that a current-carrying conductor experiences a force when put in a strong magnetic field. Figure 6.27 shows the main features of a loudspeaker.

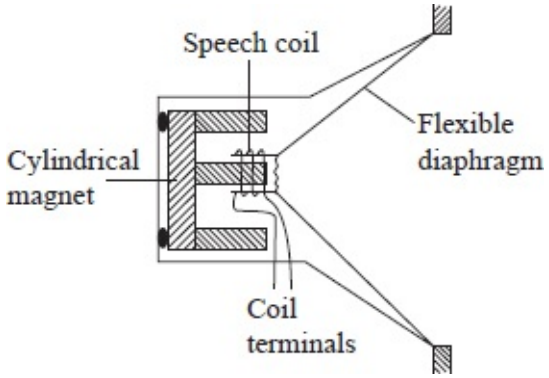



*Fig. 6.27: Moving-coil loudspeaker*

The powerful magnet shown produces a radial magnetic field. A speech coil wound on a cylindrical former and positioned in the narrow gap between the poles of a magnet is free to move back and forth in the magnetic field.

A varying electric current whose frequequency corresponds to the sound to be produced is passed through the speech coil. Since the radial field of the magnet cuts the turn at right angles, a maximum force acts on the coil, moving it in accordance with Fleming’s left-hand rule.

Since the current in the speech coil is varying, the coil experiences a force varying in magnitude and direction and at the frequency of the speech. The

diaphragm (cone) attached to the coil vibrates at the same frequency as the current in the speech coil vibrates at the same frequency as the current in the speech coil. The large mass of air in contact with the diaphragm is thus set into vibration, reproducing the sound. Figure 6.28 (a) and (b) show the cross-section of the moving coil loudspeaker and the radial field produced by the magnet.

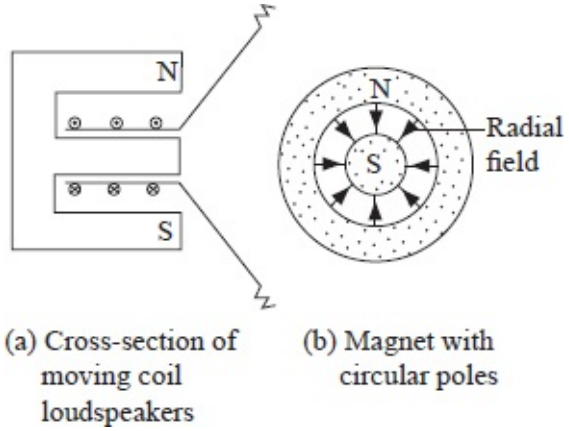



*Fig. 6.28: Cross-section and magnet of a moving coil loudspeaker*

## *Moving-Coil Meter*

Figure 6.29 shows a moving coil meter. The instrument is adapted to measure the strength of current flow or voltage. It has the following components:

(i) A coil of insulated copper wire wound on soft iron core.

(ii) Two hair-springs

(iii) Two jewelled pivots

(iv) Curved magnetic poles

(v) Pointer and scale.

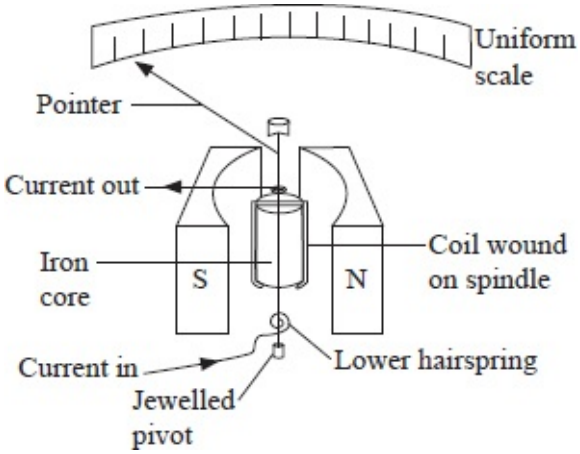



*Fig. 6.29: A moving coil meter*

When an electric current flows through the coil via the hair-springs, the magnetic fiels set up by the coil interacts with the field due to the permanent magnet, producing a force. This force is experienced by the sides of the coil, causing it to turn about the low-friction jewelled pivots. The poles of the magnet are curved and together with the soft iron core produce an intense radial field that cuts the coil at right angles whatever the position of the coil. This ensures that a maximum force that is directly proportional to the current acts on the coil.

As the coil turns, the springs are wound up, producing a mechanical force that opposes the turning of the coil. The turning stops when the restoring force by the springs is equal to the force due to the current. The springs unwind when the current stops flowing in the coil, returning the coil to its original position.

Figure 6.30 shows the coil with respect to the radial field generated by the magnet.

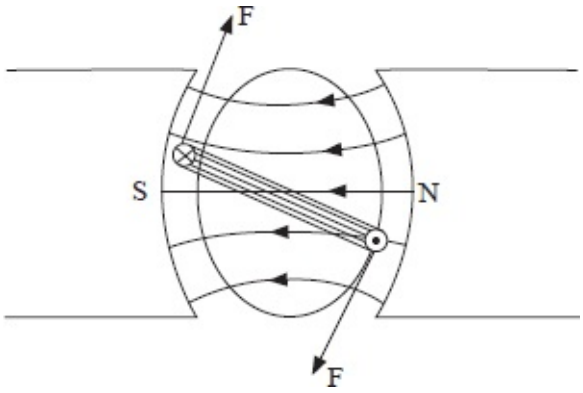



*Fig. 6.30: Coil in a radial field*

It is worth noting that moving-coil meters are being replaced by more accurate electronic ones.

## *Circuit Breakers*

In modern domestic wiring, circuit breakers, and not fuses, often protect electrical components from excessive flow of current, see figure 6.31.

When excess current flows through the circuit, increased magnetic power of the electromagnet opens the switch, stopping electric current flow. Once the problem causing the excessive current flow has been corrected, the switch is closed by mechanical means.

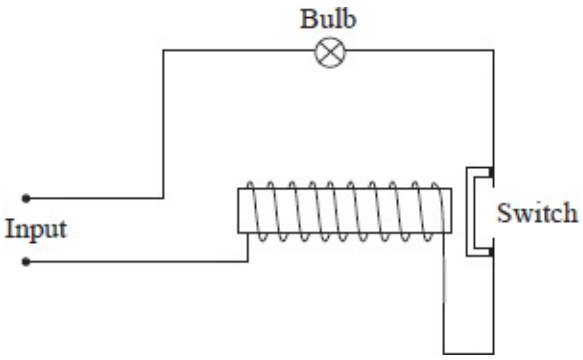



*Fig. 6.31: Circuit breaker*

## *Magnetic Tape Pick-up (Head)*

The magnetic pick-up of a tape recorder has a coil wound on a soft iron core. The music or speech to be recorded is converted to a corresponding electrical current, which flows through the coils of the electromagnet producing a magnetic field of varying power. A magnetic audio moving past the gap has its magnetic coating magnetised corresponding by the intense field of the electromagnet, see figure 6.32.

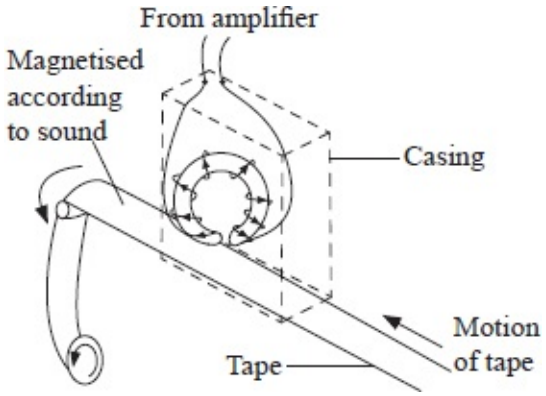



*Fig. 6.32: Magnetic tape pick-up*

## *Electric Motor*

An electric motor is a device that converts electrical energy to rotations kinetic energy. A simple direct current electric motor consists of a coil of insulated wire ABCD, which can turn about a fixed axis, within magnetic field provided by a strong curved permanent magnet, see figure 6.33.

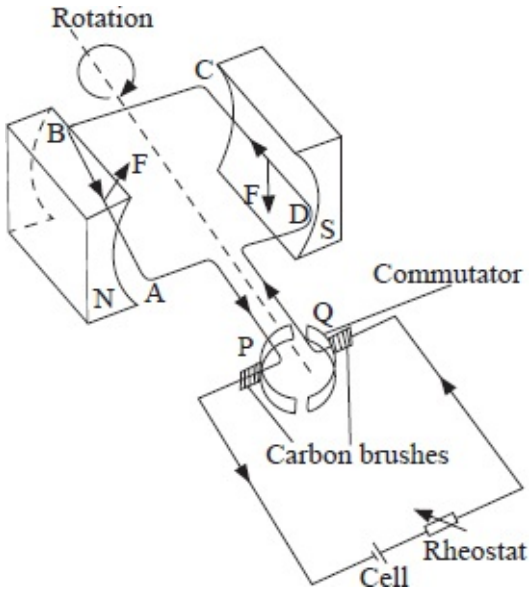



*Fig. 6.33: Electric motor*

current enters and leaves the coil through a split copper ring P and Q called commutator. The two halves are insulated from each other brushes press lightly against the commutator and are connected by battery terminals.

Suppose the coil is in the horizontal position shown. When current is switched on, it flows through the coil in the direction shown. By Fleming's left-hand rule, side AB of the coil experiences an upward force and CD a downward force. Since the current in both sides is same, the forces are equal and opposite. These forces cause the coil to rotate in clockwise direction until it reaches its vertical position with side AB up and CD down.

In this position, the brushes touch the space between the two halves of the split rings, cutting off current flowing in the coil. Consenquently, no force acts on the sides AB and CD. Since the coil is in rotation, its momentum carries it past this position and the two split rings exchange brushes. The direction of current through the coil is reversed and consenquently the direction of force on each side of the coil changes. This process is called commutation. Side AB is now on the right hand side and side CD is on the left hand side. Side AB experiences a downward force and side CD an upward force. The coil ABCD will continue rotating in the clockwise direction so long as the current is flowing through it. The speed of rotation of the coil increases with the increase in the strength of the current flowing through the coil. If the terminals of the battery are inter-changed, the direction of current reverses and the direction of rotation of the coil is also reversed.

Sides AD and BC do not experience any force because current in these sides

is parallel to the direction of the magnetic field.

The simple electric d.c. motor described above is not powerful. It can be improved by:

(i) winding the coil on a soft iron core. The soft iron core becomes magnetised and concentrates its magnetic field in the coil. This increases the force on the coil.

(ii) increasing the number of turns of the rotating coil.

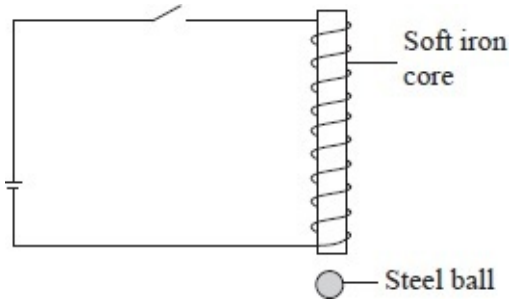
(iii) using a stronger magnet.

(iv) multiplying the number of coils and commutator segments.

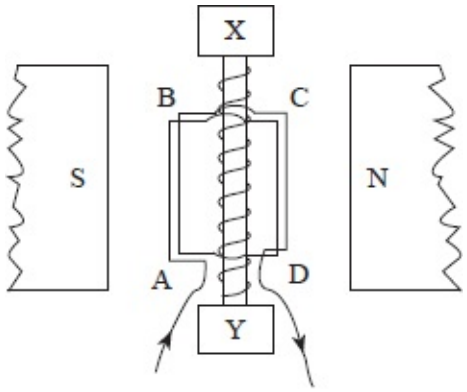
In practical motors, the permanent magnet is replaced by an electromagnet.

## Revision Exercise 6

1. Draw a magnetic field pattern around a circular coil.
2. Draw magnetic field patterns around a straight, current-carrying conductor.
3. State and explain the effect on an electromagnet of:
   (a) removing the core.
   (b) replacing the iron core with a steel core.
4. (a) Draw a labelled diagram of a simple d.c. electric motor.
   (b) State and explain three ways in which the forces on the coil, and hence the speed of the motor, can be increased.
5. A small electromagnet, used for lifting and then releasing a small steel ball, is made in the laboratory as shown in the figure below.




   (a) Explain why soft iron is a better material than steel to use for the core.
   (b) In order to lift a slightly larger ball, it is necessary to make a stronger electromagnet. State two ways in which the electromagnet could be made powerful.
6. The figure below shows a rectangula plane coil ABCD of several turns of wire located in a magnetic field due to two poles north and south. The coil is free to rotate on the vertical axis XY.




When a current is passed through the coil in the direction ABCD the coil starts to turn, and eventually comes to rest. With the aid of a diagram, explain:

(a) why the coil begins to turn.
(b) in which direction it begins to turn.
(c) why it comes to rest.
(d) the position in which it comes to rest.

# Chapter 7

# Hooke's Law

A material is selected for a particular use depending on its ability to withstand the forces it may be subjected to. The following characteristics are used to describe materials:

## Strength

This is the ability of a material to resist breakage when under a stretching, compressing or shearing force. A strong material is one which can withstand a large force without breaking.

## Stiffness

This is the resistance a material offers to forces which tend to change its shape or size, or both. Stiff materials are not flexible and resist bending.

## Ductility

This is the quality of a material which leads to permanent change of size and shape. Materials which elongate considerably under stretching forces and undergo plastic deformation until they break are known as ductile materials. eg lead, copper, wrought iron and plasticine.

Ductile materials can be rolled into sheets, drawn into wires or worked into other useful shapes without breaking. They are used in making such implements as staples, rivets and paper clips.

## Brittleness

This is the quality of a material which leads to breakage just after the elastic limit is reached. Brittle materials are fragile and do not undergo any noticeable extension on stretching but snap suddenly without warning.

Black chalk, bricks, cast iron board, glass and dry biscuits are examples of brittle materials.

### Elasticity

This is the ability of a material to recover its original shape and size after the force causing deformation is removed. A material which does not recover but is deformed permanently, like plasticine, is said to be **elastic**.

## Stretching of Materials

The forces between the molecules in a solid account for its characteristic elastic or stretching properties. When a solid is stretched, the spaces between the molecules increase slightly. The tension felt in a stretched rubber band, for example, is due to all the forces of attraction between the molecules in it.

**Experiment 7.1: To investigate the stretching of a spiral spring**

*Apparatus*

A spiral spring with pointer attached, a metre rule, retort stand, two sets of clamps and bosses, 20 g masses.

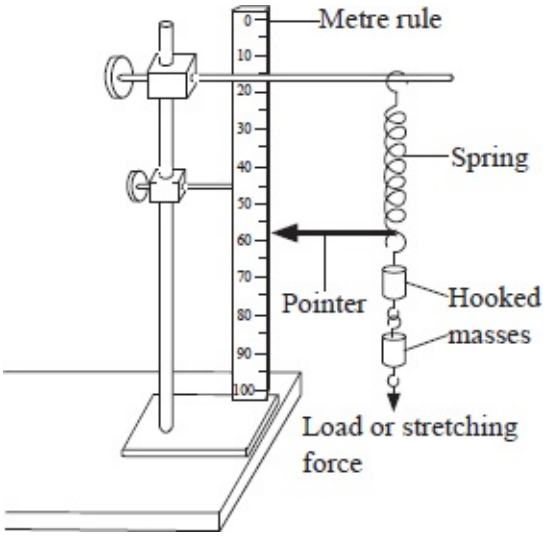



*Fig. 7.1 Stretching a spring*

*Procedure*

- Arrange the apparatus as shown in figure 7.1. Note the position of the pointer when the spring is unstretched, or not loaded.
- Suspend a mass at the end of the spring and note the new position of the pointer.
- Increase the load in steps of 20 g and record the reading of the pointer for

each load in table 7.1 (care should ne taken not to use too heavy weights which would overstretch the spring).

- Unload the spring in steps of 20g and again record the pointer readings.
- Plot a graph of stretching force (F) against extension, e,

*Observation*

Provided weights used are not too heavy, the spring always returns to its original length on unloading. The ratio of stretching force to extension is constant.

The graph of stretching force F against extension e is a straight line through the origin, see figure 7.2.

*Table 7.1*

| Mass on spring m (kg) | Stretching force F = mg (N) | *Scale reading (mm)* | | | Extension e (m) | $\frac{F}{e}$ (N/m) |
|---|---|---|---|---|---|---|
| | | *Loading* | *Unloading* | *Mean* | | |
| | | | | | | |
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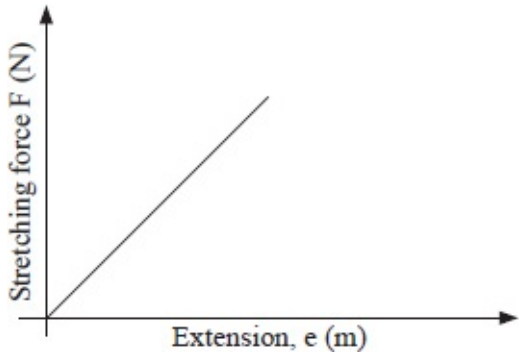



*Fig. 7.2 Graph of stretching force against extension for a spring*

*Conclusion*

The extension, e, of a spring is directly proportional to the stretching force F, i.e, if the stretching force is doubled, the extension is also doubled.

The same kind of result is obtained if a straight steel wire is stretched

If the stretching force is increased beyond a certain value, permanent stretching occurs. The graph of extension against stretching force is shown in figure 7.3.

OP represents the permanent stretching or permanent extension of the spring. Point E is called the elastic limit of the spring. Beyond this point, as in point B, further extension causes permanent extension.

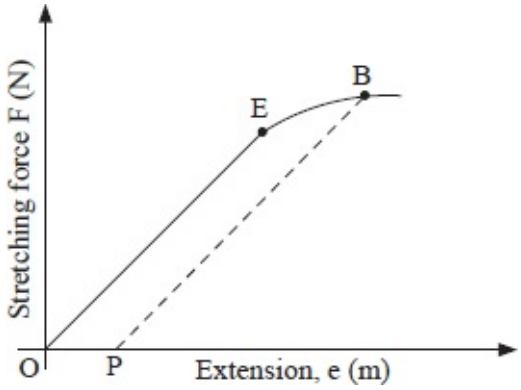



*Fig. 7.3: A steel spring stretched beyond its elastic limit*

## Hooke's Law

Robert Hooke investigated and formulated a law relating the stretching force and extension. The law states that **for a helical spring or other elastic material, the extension is directly proportional to the stretching force, provided the elastic limit is not exceeded**.

The relationship can be expressed as; F e in terms of force (F) and extension e Hence, F=ke, where k is the constant of proportionality which depends on the material of the spring. The constant is referred to as the spring constant.

$$\text{The gradient} = \frac{\text{change in force}}{\text{change in extension}}$$

$$= \frac{\Delta F}{\Delta e}$$

This is the spring constant, whose units are given as $Nm^1$ or N/m.

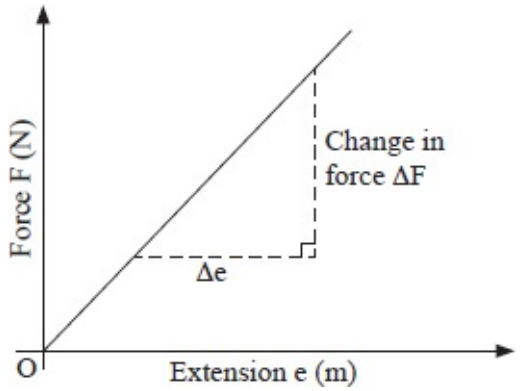



*Fig. 7.4: The spring constant*

The area under a force versus extension graph is equal to the work done in stretching the spring, see figure 7.5.

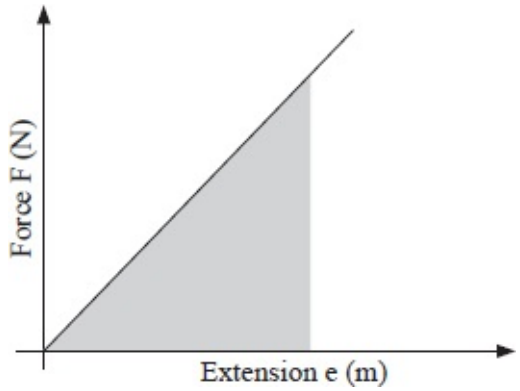



*Fig. 7.5: Work done in stretching a spring.*

Area under the graph = $\frac{1}{2}$ Fe, where F is the force applied and e the extension attained

But F = ke (where k is the spring constant)

Hence, work done = $\frac{1}{2}$ $ke^2$

***Example 1***

A mass of 100 g is suspended from the lower end of a spring. If the spring extends by 100 mm and the elastic limit of the spring is not exceeded, what is the spring constant?

*Solution*

Since the elastic limit is not exceeded, Hooke's law applies, i.e.,

F = ke.

Hence, $k = \frac{F}{e}$

Force $F = 100 \times 10^{-3}$ kg $\times$ 10 $Nkg^{-1}$

$= 1$ N

Extension, $e = 100 \times 10^{-3}$ m

Therefore, spring constant

$$= \frac{1}{100 \times 10}$$

$$= 10\ Nm^{-1}$$

***Example 2***

A metal cube suspended freely from the end of a spring causes it to stretch by 5.0 cm. A 500 g mass suspended from the same spring stretches it by 2.0. If the elastic limit is not exceeded:

(a) Find the weight of the metal cube.

(b) By what length will the spring stretch if a mass of 1.5 kg is attached to its end?

*Solution*

(a) Since the spring obeys Hooke's Law;

$F = ke$

$So, K = \frac{F}{e}$

But $F = mg$

$Therefore, K = \frac{0.5 \times 10}{2 \times 10^{-2}}$

$= 250\ Nm^{-1}$

Since the same spring is used:

weight of the cube $= 250 \times 5 \times 10^{-2}$

$= 12.5\ N$

(b) Let the extension produced by the 1.5 kg mass be e.

Force $= 1.5 \times 10$

$= 15\ N$

From $F = ke$

$e = \frac{F}{k}$

$= \frac{15}{250}$

$= 0.06\ m$ or $6.0\ cm$

***Example 3***

A spiral spring is fitted with a scale pan as shown in figure 7.6. The pointer is at the 40 cm mark on the scale. When a packet of salt is placed in the pan, the pointer moves to the 20 cm mark. When a 20 g mass is placed on top of the packet of salt, the pointer indicates 10 cm.

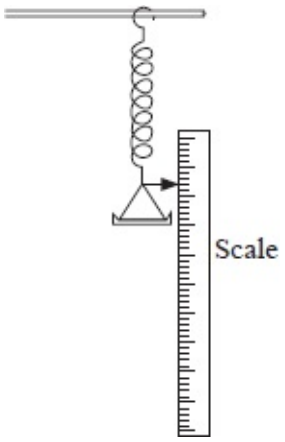



*Fig. 7.6*

Find the:

(a) extension produced by the packet of salt.

(b) extension produced by the 20g mass.

(c) the mass of the salt.

*Solution*

(a) Assuming that the spring does not exceed its elastic limit; extension produced by the packet of salt

= 40 cm – 20cm

= 20 cm

= 0.2 m

(b) Extension produced by the 20 g mass

= 20 cm – 10 cm

= 10 cm

= 0.1m

(c) Using the extension produced by the 20g mass;

$$\text{Spring constant} = \frac{\text{force}}{\text{extension}}$$

$$= \frac{20 \times 10^{-3} \times 10}{0.1}$$

$$= 2.0 \text{ Nm}^{-1}$$

$$\text{Weight of salt} = 2 \times 0.2$$

$$= 0.4 \text{ N}$$

$$\text{Mass of the salt} = \frac{0.4}{10}$$

$$= 0.04 \text{ kg (40 g)}$$

***Example 4***

Two very light identical springs P and Q are arranged as shown in figure 7.7 (a) and (b)

A weight of 4.8 N is supported by each arrangement.

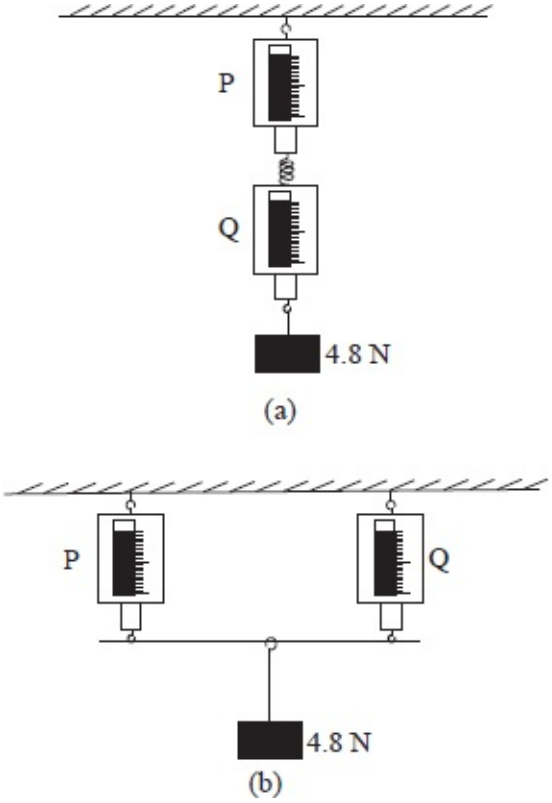



*Fig. 7.7:*

Given that each spring has a spring constant of 10 N/cm, determine the total extension for each arrangement.

*Solution*

Since the springs P and Q are identical,

For figure 7.7 (a) both springs P and Q experience a load of 4.8 N force.

Thus, extension in each spring is $\frac{F}{K}$

$$\text{Therefore, } \frac{F}{K} = \frac{4.8\ \text{N}}{10\ \text{N/cm}}$$

$$= 0.48\ \text{cm}$$

Total extension = 2 × 0.48

= 0.96 cm

In figure 7.7. (b), the two springs share the load

$$2e = \frac{4.8}{10}$$

$$e = 0.24\ \text{cm}$$

or Force per spring is $\frac{4.8}{2} = 2.4\ \text{N}$

$$\text{Since } e = \frac{F}{K}$$

$$\text{Therefore, } e = \frac{2.4}{10}$$

$$= 0.24\ \text{cm}.$$

***Example 5***

The length of a spring is 160 cm. its length becomes 20 cm when supporting a weight of 5.0 N. Calculate the length of the spring when supporting a weight of:

(a) 2.5 N

(b) 6.0 N

(c) 200 N

Comment on the answer to part (c).

*Solution*

Length of loaded spring

= extension + length of unstretched spring.

Extension

= length of loaded spring – length of the unstretched spring.

5.0 N produces an extension of 20 – 16 = 4 cm

Therefore, 1.0 N produces an extension of $\frac{4}{5}$ = 0.8 cm

(a) 2.5 N produces an extension of 2.5 × 0.8 = 2.0 cm.

Therefore, length of spring

= 2.0 + 16

= 18 cm

(b) 6.0 N produces an extension of 6.0 × 0.8 = 4.8 cm

Length of the spring = 4.8 + 16

= 20.8cm

(c) 200 N produces an extension of 200 × 0.8 = 160 cm.

Length of spring = 160 +16

=176 cm

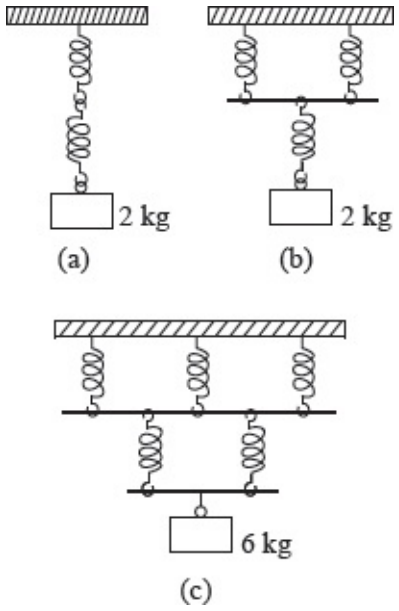
In part (c) the extension is too large and the spring would get straightened out and possibly snap.

## Exercise 7.1

1. A spring stretches by 8.00 mm when supporting a load of 2.0 N.
   (a) By how much would it stretch when supporting a load of 5.0 N?
   (b) What load would make the spring extend by 2.5 cm?
2. A single spring extends by 3.6 cm when supporting a load of 2.0 kg.

   What is the extension in each of the arrangements shown below?

   Assume that all the springs are identical and of neglegible weight.




## Compressing a Spring

When the two ends of a spring are squeezed together, it shortens. There is change in length that is referred to as compression. The spring on its part exerts a counter force which resists the compression.

Figure 7.8 shows the variation of length against compression of a spring which obeys Hooke's Law. Beyond the point E, the turns of coils are virtually pressing onto one another and further increase in the force achieves no noticeable decrease in length.

Some of the applications of compressed spring are top-pan balance, spring shock absorbers in motor vehicles.

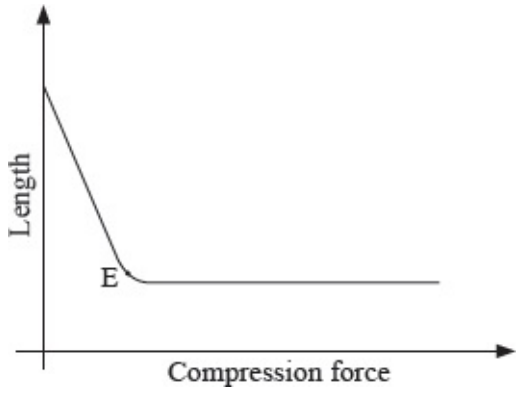



*Fig. 7.8 Compressing a spring*



*Fig. 7.9: Top pan balance*



*Fig. 7.10: Shock absorber*

## Hooke's Law Applied to Loading of Beams

**Experiment 7.2: To investigate the sagging of a loaded beam**

*Apparatus*

Wooden beam of length approximately 50 cm with a pointer, six 100 g masses, G-clamp, metre rule, retort stand, string (about 30 cm long), weight holder.

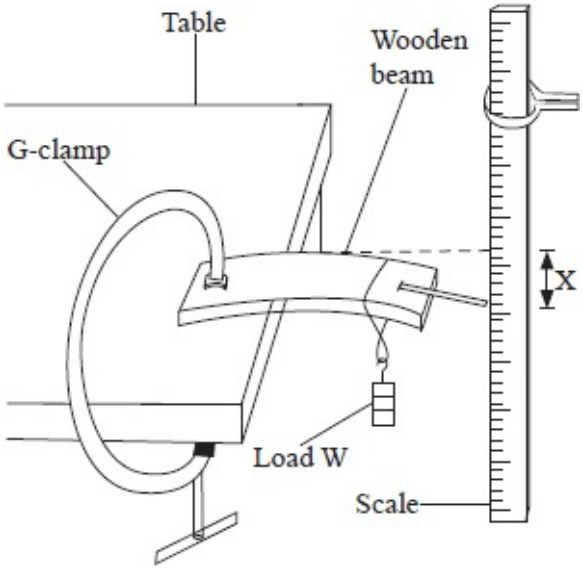



*Fig. 7.11: loading a beam*

*Procedure*

- Arrange the apparatus as shown in figure 7.10.
- Record the pointer reading when no load is suspended on the beam, in Table 7.2.
- Suspend one 100 g mass and record the new pointer reading.
- Continue adding the load in 100 g steps, each time recording the pointer position. Ensure that the beam is not overloaded.
- Determine the amount of sagging, x, and fill in the table.
- Plot a graph of force F against amount of sagging x.

*Table 7.2*

| *Mass (g)* | *Load (N)* | *Pointer reading (cm)* | *Amount of sagging (m)* |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

*Observation*

A graph of load against amount of sagging, x, is a straight line through the origin. This shows that the sagging is in accordance with Hooke's law.

Some materials regain their original shapes after being stretched, even though they do not extend according to Hooke's law. Rubber is one such material. Figure 7.9 shows the variation of force with extension for rubber and materials with similar behaviour.

Initially, rubber stretches by a large amount for a small increase in stretching force but beyond a certain point, tends to stiffen up showing very little extension with increase in force. When the stretching force is withdrawn, there is no permanent extension. This shows that the material is elastic.

Bristle materials like concrete and glass exhibit elasticity but suddenly snap without becoming plastic. Materials like polythene and metal wires display elasticity, but go through plasticity before snapping.

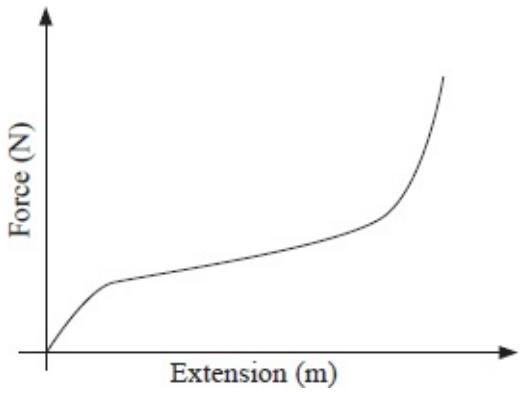



*Fig. 7.12: Stretching rubber*

## Making a Simple Spring Balance

*Apparatus*

String, firm cardboard cylinder or cuboid, strong helical spring with pointer attached, wooden strip with hook, wooden rod, 100 g weights, strip of graph paper, small wooden blocks or stones.

*Procedure*

- Prepare the cuboid so that the spring with the pointer and wooden strip with the hook hand freely, as shown in the figure 7.12.
- Fix the strip of graph paper on one side along the slot. The spring balance is now ready for calibration.
- With no mass on the hook, mark the pointer position as the zero on the scale.
- Suspend a 100 g mass on the hook and mark the new pointer position as 1 N.
- Continue adding the masses in steps of 100 g while marking the corresponding pointer positions.

This is your spring balance

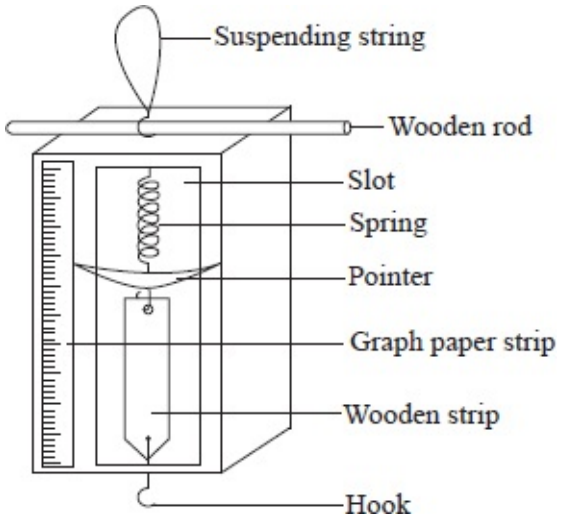



*Fig. 7.13: A Simple spring balance*

### *Activity*

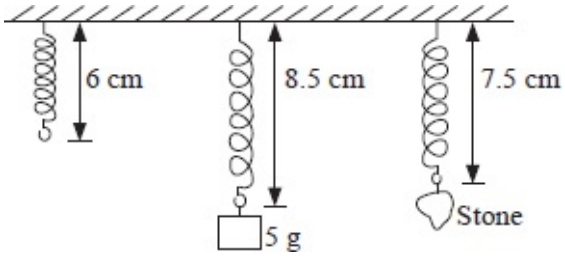
Determine the weights of objects provided to the nearest one newton.

## Revision exercise 7

1 (a) You are given a scale which is graduated in newtons. You are also provided with masses of 20 g, 50 g, 100 g, 200 g and a spring balance calibrated in grams, explain how you would calibrate the spring balance in newtons.

(b) A spring stretches by 1.2 cm when 600g mass is suspended on it What is the spring constant?

2. The figure below shows a spring when unloaded, when supporting a mass of 5g and when supporting a stone. Study the diagrams and use them to determine the mass of the stone.




3. The following readings were obtained in an experiment to verify Hooke's Law using a spring.

| Mass(g) | 0 | 25 | 50 | 75 | 100 | 125 |
|---|---|---|---|---|---|---|
| Reading (cm) | 10.5 | 11.5 | 12.5 | 13.5 | 14.4 | 16.0 |

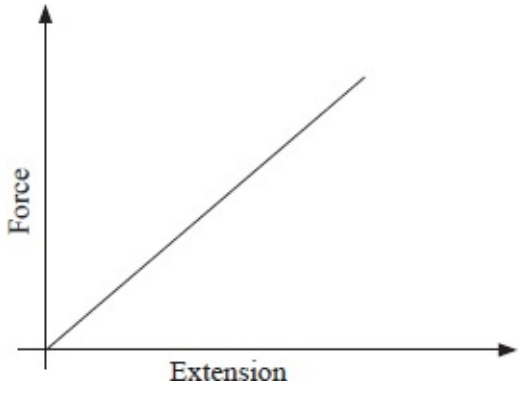
(a) For each reading, calculate:
  (i) The value of force applied.
  (ii) The extension in mm.

(b) Plot a graph of extension against force. Does the spring obey Hooke's law?

(c) From the graph determine the:
  (i) elastic limit.
  (ii) spring constant.
  (iii) weight of a bottle of ink hung from the spring, if the reading obtained is 12 cm.
  (iv) extension in millimetres, when a force of 0.3 N is applied.
  (v) scale reading, in centimetres for a mass of 0.02kg

4. A piece of wire of length 12 m is stretched through 2.5 cm by a mass of 5 kg. Assuming that the wire obeys Hooke's law:
   (a) Through what length will a mass of 12.5 kg stretch it?
   (b) What force will stretch it through 4.0 cm.

5. The figure below shows the variation of force with extension for a steel coil spring. In the same diagram, sketch the variation of force with extension for a wire from which the spring is made. Explain the difference between the sketches.




6. The data below represents the total length of a spring as the load suspended on it is increased:

| Mass(g) | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
|---|---|---|---|---|---|---|
| Total (cm) | 7.5 | 8.0 | 8.5 | 9.0 | 9.5 | 10.0 |

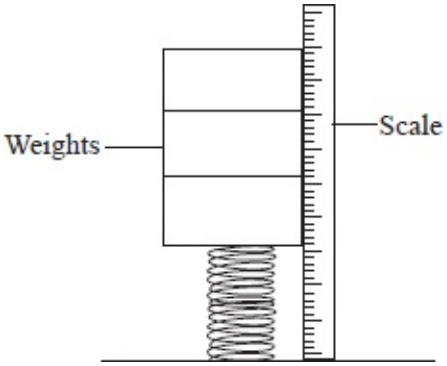
(a) Plot a graph of total length (y-axis) against weight:

(b) Use the graph to determine the.

(i) length of the spring.

(ii) spring constant.

7. The figure below shows a simple apparatus for studying the behaviour of a spring when subjected to forces of compression.




(a) Describe how the apparatus may be used to obtain readings of compression force and corresponding length of spring.

(b) In a similar experiment, the following readings were obtained:

| MAForce of compression (N)ass(g) | 0 | 5.0 | 10.0 | 15.0 | 17.5 | 22.5 | 25.0 | 30.0 | 35.0 | 40.0 | 45.0 | 50.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Length of spring (cm) | 14.5 | 13.0 | 11.5 | 10.0 | 9.25 | 7.75 | 7.00 | 6.50 | 6.25 | 6.00 | 6.00 | 6.00 |

Plot a graph of:

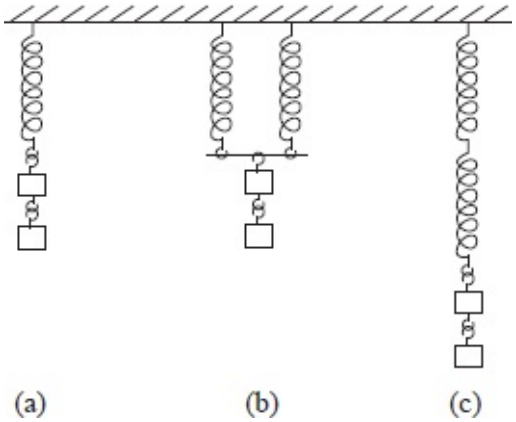
(i) Compression force versus length of the spring.

(ii) Compression force versus compression of spring. From the graph plotted, determine the minimum force that will make the spring coils to just come into contact.

8. The figure below illustrates systems of identical springs. Equal masses are suspended on the springs to study the variation of extension with force.

(a) On the same axes, sketch the variation of extension with stretching force for each of the systems.

(b) Explain the differences between the sketches.




9. A 60 g mass is suspended from a spring. When 15 g more is added, the spring increases 1.2 cm. Given that the spring obeys Hooke's Law, find:
   (a) Spring constant.
   (b) Total extension of the spring.

# Chapter 8

# Waves

A pebble thrown into a pond sends out ripples in the water. The disturbance spreads out on the water surface in a form of concentric circles around the point of origin. A toy boat in the path of the disturbance will be observed to bob on the water as the ripples (waves) move outwards. The boat is however not moved to the side to the pond. The disturbance sets up waves in the water, which only transfer the energy without dragging the water from one end to the other.

Waves have many uses in daily life. Radio television transmission, mobile communication, remote control systems and heat energy radiation are all applications of waves.

A view of the wave profile for water and waves appears as illustrated in figure 8.1. The water surface is distorted in the form of crests and troughs.



*Fig. 8.1: Waves in water*

A wave therefore is the transmission of a disturbance. Waves can be classified as electromagnetic in nature or mechanical.

## Electromagnetic waves

Electromagnetic waves do not require material medium for transmission, e.g, radio waves, radiant heat, light and microwaves.

## Mechanical Waves

Mechanical waves require material medium for transmission. This transmission is effected by the vibration of the particles in the medium. Examples are water waves and sound waves. Mechanical waves can be either transverse or longitudinal.

## TransverseWaves

In transverse waves, the vibration of the particles is at right angles to the direction of wave travel. Water waves, waves on a string and electromagnetic waves (light, radio, microwaves, etc) are examples of transverse waves.

To illustrate the formation of transverse waves, a slinky spring or a rope may be used. The spring or rope is stretched along a smooth floor or bench top. One end is attached to a rigid support while the other end is held in the hand. The end held in the hand is swung up and down at right angles to the spring or rope, as in figure 8.2. Such a wave travels as a series of crests and troughs.

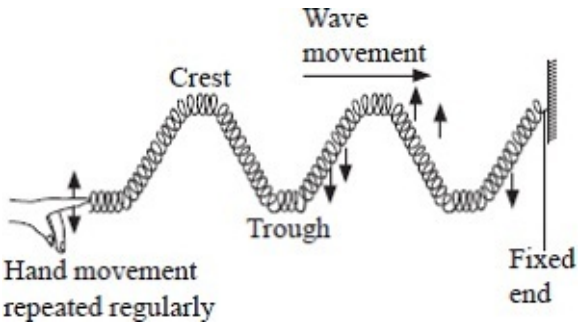



*Fig. 8.2 Transverse waves on a slinky spring.*

Figure 8.3 shows the displacement of an individual particle in relation to the direction of wave motion.

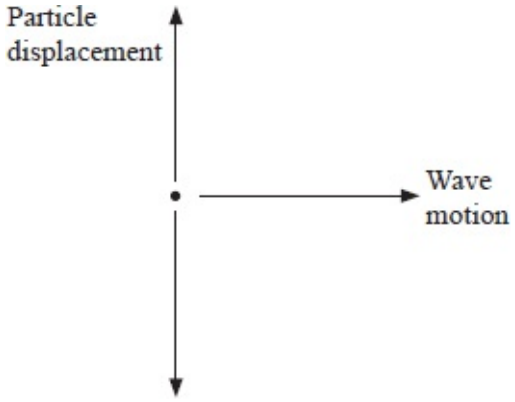



*Fig. 8.3: Particle displacement in a transverse wave*

## Longitudinal Waves

## Longitudinal Waves

In longitudinal waves, the vibration of the particles is in a direction parallel to the direction of the wave travel. Examples of longitudinal waves are sound waves.

To illustrate the formation of a longitudinal wave, a slinky spring may be used. The spring is stretched along a smooth floor or bench top. One end is fixed to a rigid support and the other held in the hand. This end is vibrated in a to-and-fro movement continually along its length as shown in figure 8.4.

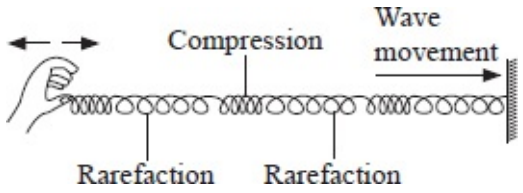



*Fig. 8.4: Longitudinal waves on a slinky spring*

The continuous to and fro movements at one end result in the formation of sections of compression alternating with rarefactions along the length of the spring. Figure 8.5 illustrates the displacement of a particle in a longitudinal wave in relation to the direction of wave motion.

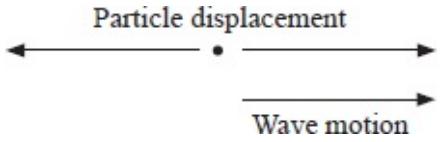



*Fig. 8.5: Particle displacement in a longitudinal wave*

Note that individual particles in the slinky spring are set into periodic vibrations in line with the direction of the wave motion.

The wave motion affects the inter-particle spacing. Particles in the sections of compression are pushed closer together while those in the sections of rarefactions are pulled slightly farther apart. Variation in inter-particle separation is accompanied by variation in pressure, so that sections under compression are at a higher pressure while those under rarefaction are at low pressure. This pressure variation causes the wave motion.

## Progressive Waves

These are waves that move continually away from the source. They can be transverse or longitudinal. If a long slinky spring is continuously vibrated at one end, the waves move forward, carrying the energy of the vibrations along its length. Similarly, if a stone is dropped onto a water surface, the resulting water

waves move outwards, carrying the energy of the impact away from the source as in figure 8.1. As the wave moves away from the source, the energy is spread over an increasingly large area. This causes gradual decrease in its amplitude.

### Pulses

A pulse is generated when a single vibration is sent through a medium. It can be transverse or longitudinal in nature. Figure 8.6 (a) and (b) represents pulses of transverse and longitudinal nature respectively.

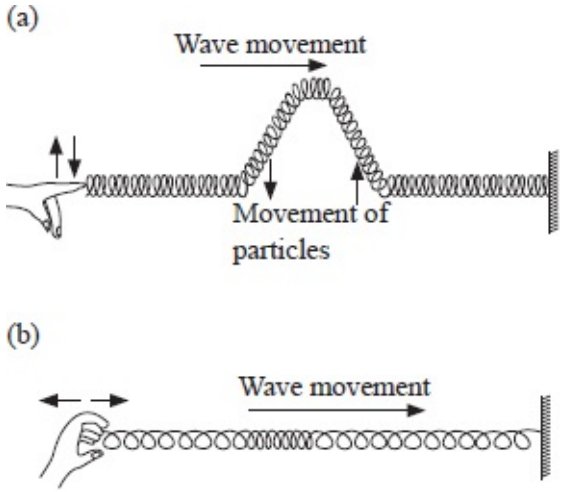



*Fig. 8.6: Transverse and longitudinal pulses*

Wave trains are generated as a result of continuous vibrations at a constant rate in a medium. The medium is distorted into repeated patterns of crests alternating with troughs for a transverse wave (Figure 8.2), while for the longitudinal wave train, the medium is set into repeated patterns of sections of compression alternating with those of rarefaction (figure 8.4).

## Characteristics of Wave Motion

The characteristics of wave motion can be explained with reference to the oscillatory motion of a mass attached to a spring or that of the bob of a swinging pendulum, see figure 8.7 (a) and (b).

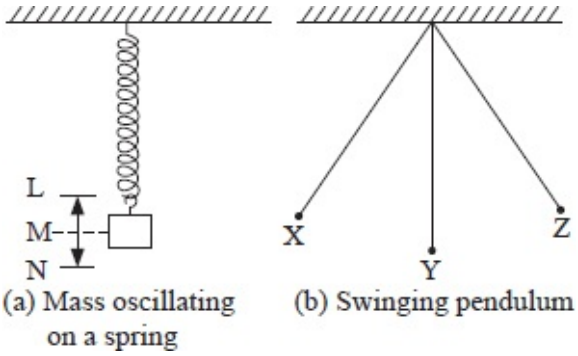



*Fig. 8.7: Oscillating spring and pendulum*

Consider the mass at rest at the end of a spiral spring (position M). If the mass is depressed slightly to position N and released, it oscillates up and down about the mean position M. One complete oscillation occurs when the mass moves through positions N-M-L-M-N, i.e., when it has returned to its starting position and is moving in the same direction.

If, for example, the mass starts at M, then M-N-M is not a complete oscillation. This is because although the mass has returned to its starting position, it is moving in the opposite direction.

For the pendulum, the bob makes a complete oscillation when, after an initial displacement to, say, position X, it swings through X-Y-Z-Y-X, see figure 8.7 (b).

If the mass in figure 8.7 (a) takes two seconds to make a complete oscillation, a sketch of displacement-time for the motion will appear as in figure 8.8. Similar graph would be obtained for the swinging pendulum.

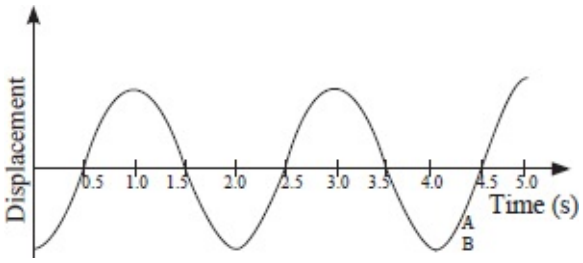



*Fig. 8.8: Displacement time graph for a mass oscillating on a spring*

The displacement-time graph is a sine curve similar to the profile of transverse waves (compare with figure 8.2). With reference to figure 8.7 and 8.8, the following terms associated with waves are defined:

## Amplitude

The amplitude (A) of a wave is the maximum displacement on either side of the mean position. Its S1 unit is the metre. In figure 8.7 (a), the amplitude is the distance LM or MN while in 8.7 (b), the amplitude is distance XY or YZ.

## Frequency

The frequency (f) of a wave is the number of complete oscillations made by a particle in one second. The unit of frequency is the hertz (Hz) or cycles per second.

## Period

The period T of oscillation is the time taken by a particle to complete one oscillation. The S1 unit of period is the second (s). In figure 8.8, the particle takes 2 s to go through 1 complete oscillation and its period is therefore 2 seconds.

It follows that $f = \frac{1}{T}$, thus, the frequency for the oscillation shown is; $\frac{1}{2} = 0.5$ Hz.

## Phase and Phase Difference

Waves can be of the same amplitude but different frequency or same frequency but different amplitude. Figures 8.9 and 8.10 illustrate the two cases.

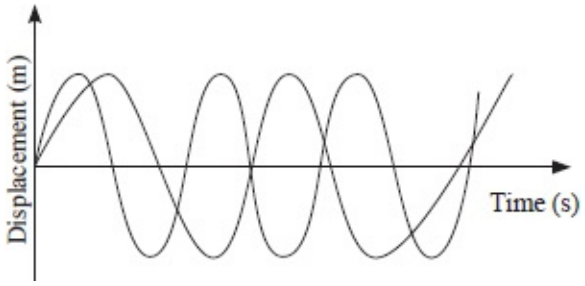



*Fig. 8.9: Waves of the same amplitude but different frequency*

The wave with higher frequency has a smaller period.

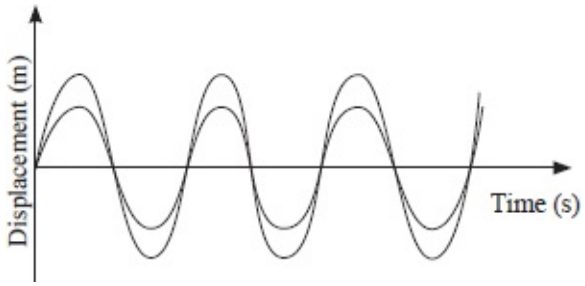



*Fig. 8.10: Waves of the same frequency but different amplitude*

Consider two identical pendulums with bobs P and Q, see figure 8.11. If the two masses are both given some displacement towards the left and then released simultaneously, they will be set in oscillation. The masses pass through rest position Y at the same time as they move in the same direction. They attain amplitude displacement together at Z and swing back to complete the oscillation together at X. At any one time, the two masses will be moving in the same direction and at the same level of displacement in their oscillations. The masses are said to be oscillating in phase.

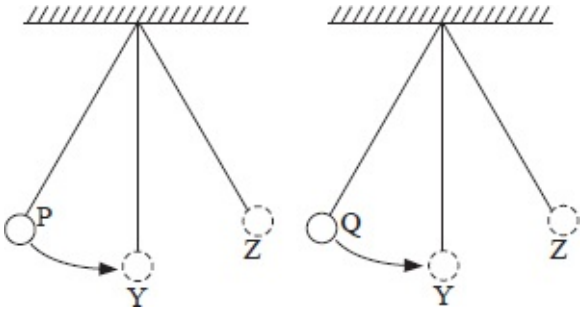



*Fig. 8.11: Masses oscillating in phase*

Particles in a wave motion which happen to be oscillating in the same direction and at the same level of displacement in their oscillation are said to be in phase. The displacement-time graphs for such particles are identical, see figure 8.12.

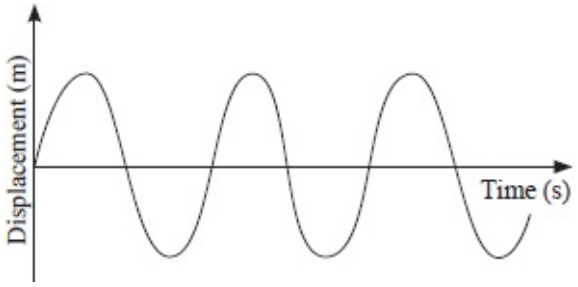



*Fig. 8.12: Particles oscillating in phase*

Particles in wave motion can be in phase even though they have different amplitude. Thus, for masses P and Q above, if P is initially given a larger displacement than Q, the two will still oscillate in phase even though P will always be at larger magnitude of displacement than Q. The resulting displacement-time graphs are shown in figure 8.13.

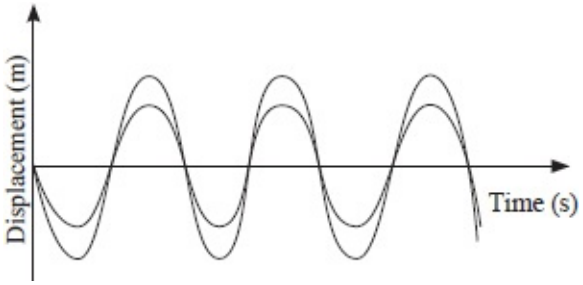



*Fig. 8.13:Oscillations of different amplitude but in phase for particles*

Suppose masses P and Q are now displaced one to position X and the other to position Z, see figure 8.14.

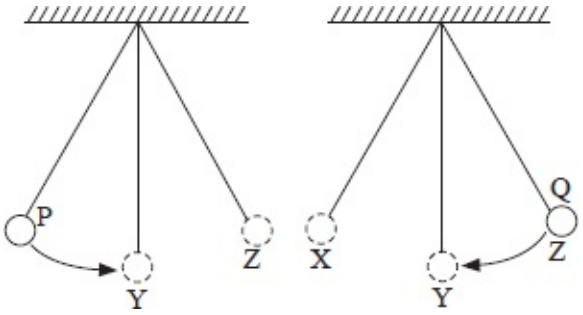



*Fig. 8.14: Oscillations that are 180° out of phase*

When released simultaneously, they pass through the rest position at the same time, but moving in opposite directions. They reach positions of maximum displacement, but on opposite sides of the rest position. Thus, they are always on opposite levels of displacement in their oscillations and moving in opposite directions. They are said to be opposite in phase (180° phase difference). Figure 8.15 is a sketch of the displacement-time graph for the two oscillations.

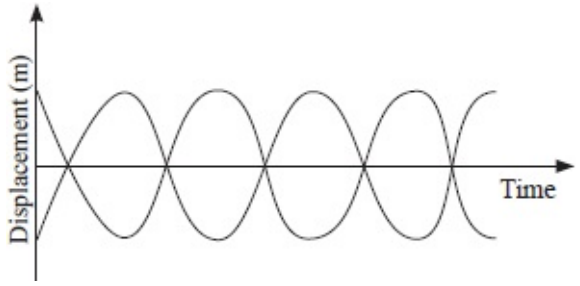



*Fig. 8.15: Oscillations that are 180° out of phase*

The oscillations can be at other levels of phase difference. Thus, for the masses P and Q above, if they are both displaced to position X and P is released first then Q as P crosses position Y, the resulting oscillations will be 90° out of phase. The displacement-time graph is as shown in figure 8.16.

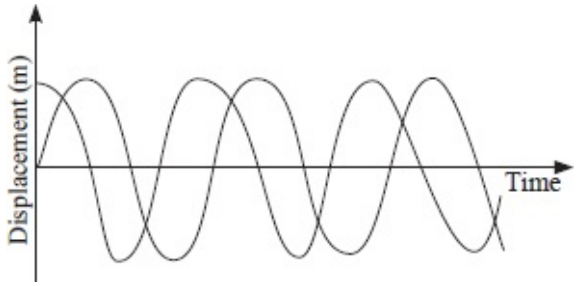



*Fig. 8.16: Oscillations that are 90° out of phase*

## Wavelength

A transverse wave train, for example, waves on water viewed from the side would give a displacement-position graph as in figure 8.17.

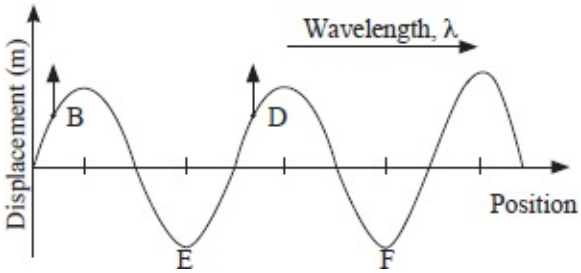



*Fig. 8.17: Displacement-position graph*

The wavelength, λ, is the distance between two points on a wave train which are in phase. It may also be defined as the distance between two successive crests or troughs in a transverse wave or the distance between two successive rarefactions or compressions in a longitudinal wave. The S1 unit for wavelength is the metre. In figure 8.17, distance AC, and BX and EF are all equivalent to one wavelength.

## Speed

The speed v is the distance covered by a wave in one second. Its S1 unit is metres per second.

### *Relationship Between Speed, Wavelength and Frequency*

Suppose the period of a wave is T. Then, the distance covered in time T is λ.

$$\text{Now, } v = \frac{\text{distance}}{\text{time}}$$

$$\text{But } T = \frac{1}{f}$$

$$\text{Hence, } v = \frac{1}{\frac{1}{f}}$$

This simplifies to $v = f\lambda$

It should be noted that while the rate of vibration of the source determines the frequency of the waves, the speed in a given medium is constant. From the relationship $v = f\lambda$, an increase in frequency results in a decrease in wavelength, see figure 8.18.

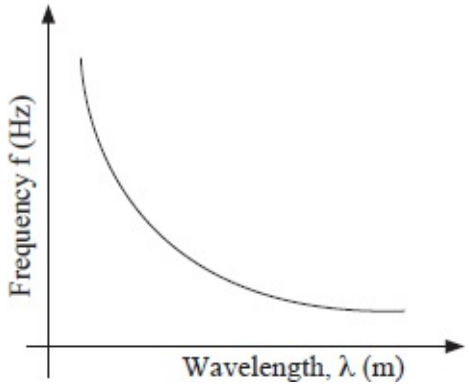



*Fig. 8.18: Variation of frequency with wavelength*

***Example 1***

Waves on a spring are produced at the rate 20 wavelength every 5 s.

(a) Find the frequency of the wave motion.

(b) If the wavelength of the waves is 0.01 m, find the speed of the waves.

(c) Find the period of the waves.

*Solutions*

(a) $\text{Frequency} = \frac{\text{number of complete wavelenlengths}}{\text{time taken}}$

$\text{Therefore, } f = \frac{20}{5}$

$= 4 \text{ Hz.}$

(b) Using $v = f\lambda$,

$v = 4 \times 0.01$

$= 0.04\ ms^{-1}$

(c) Period, $T = \frac{1}{f}$

$= \frac{1}{4}$

$= 0.25\ s$

***Example 2***

A water wave travels 12 m in 4 s. If the frequency of the waves is 2 Hz, calculate:

(a) The speed of the wave.

(b) The wavelength of the wave.

*Solution*

(a) Speed $= \frac{\text{distance}}{\text{time}}$

$= \frac{12}{4}$

$= 3\ ms^{-1}$

(b) Speed = frequency × wavelength

$(v = f\lambda)$

Therefore, $3 = 2 \times \lambda$

Hence, $\lambda = \frac{3}{2}$

The wavelength is 1.5 m.

***Example 3***

Figure 8.19 shows a wave form in a string. The numbers in the diagram shows the scale in centimeters. The speed of the wave is 10.0 $ms^{-1}$.

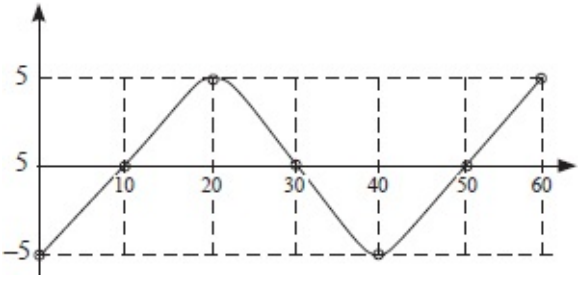



*Fig. 8.19*

With the reference to this wave motion, determine the:

(a) Wavelength

(b) Amplitude
(c) Frequency
(d) Period of the oscillation

*Solution*

(a) Wavelength = 40 cm

(b) Amplitude = 5 cm

(c) From $f = f\lambda$;

$$f = \frac{v}{\lambda}$$

$$= \frac{10\ ms^{-1}}{40 \times 10^{-2}\ m}$$

$$= 25\ Hz$$

(d) Period $T = \frac{1}{f}$

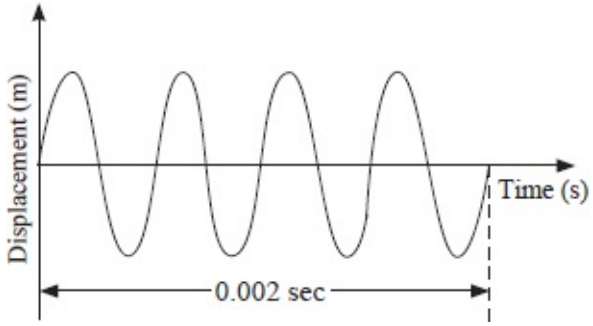
$$= \frac{1}{25}$$

$$= 0.04\ s$$

## Revision Exercise 8

1. (a) Explain the following terms; progressive wave, wavelength, frequency and amptitude.
   (b) State the equation relating speed, frequency and wavelength of a wave.
2. Give one example of:
   (a) A transverse wave.
   (b) A longitudinal wave.

   What is the main difference between these two types of waves?
3. The figure below shows the displacement-time graph for a wave:




   (a) How many complete cycles are shown?
   (b) What is the frequency of the waveform shown?

(c) Draw a diagram to show the wave form of a wave whose frequency is twice and whose amplitude is half the one shown in the diagram.

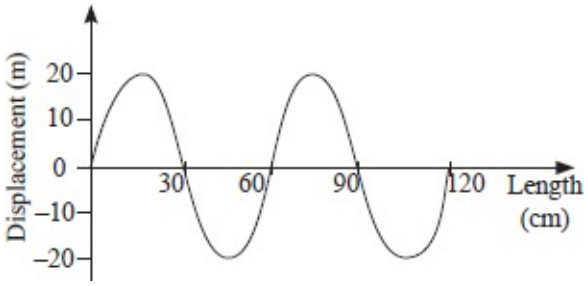
(d) A radio wave has a frequency of 3 MHz and travels with a velocity of 3 × 108 $ms^{-1}$. What is its wavelength?
(1 MHz =106 Hz).

4. What ripples are caused to travel across the surface of a shallow tank by means of a straight vibrator. The distance between successive crests is 3.0 cm and the waves travel 25.2 cm in 1.25 seconds. Calculate the wavelength and the velocity of the waves. Find also the frequency of the vibrator.

5. Waves enter a harbour at a rate of 30 crests per minute. A man watches a particular wave crest passing two buoys which are 12 m apart along the direction of travel of the waves. The time the wave takes to move from one buoy to the other is 2.0 seconds.
Calculate:
(a) The frequency of the wave motion
(b) The wavelength of the waves

6. A vibrator is sending out eight ripples per second across a water tank. The ripples are observed to be 4 cm apart. Calculate the velocity of the ripples.

7. The diagram below shows a displacement-position graph for a slinky spring as it is continually vibrated at one end:




(a) What type of waves are generated in the slinky?
(b) What is the:
(i) Amplitude of displacement?
(ii) Wavelength of the waves?
(c) In the same diagram, show the waveform when:
(i) The rate of vibration is doubled.
(ii) The amplitude is halved.
(d) On the same axes, draw a waveform whose vibration is opposite in phase and the amplitude half the one shown.

# Chapter 9

# Sound I

Sound originates from vibrating bodies. The nature of these vibrations determines the type of sound produced. In some cases, the vibrations may be felt or seen, for example, when a string of a guitar is plucked or when a tuning fork is struck. In other cases, the vibrating origin of the sound may not be so obvious, for example, wind rushing through a small opening or the noise produced by a thunderstorm.

## Some Sources of Sound

### Vibrating Wooden Strip

When a thin strip clamped at one end in a vice is struck sharply, the free end vibrates to-and-fro, producing sound, see figure 9.1.

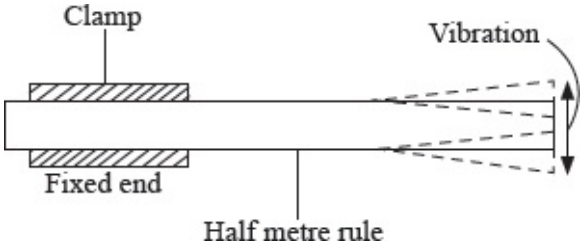



*Fig. 9.1: Vibrating strip*

### Vibrating Wire

A wire is tightly tied on two pegs that have been fixed on a wooden box, as shown in figure 9.2.

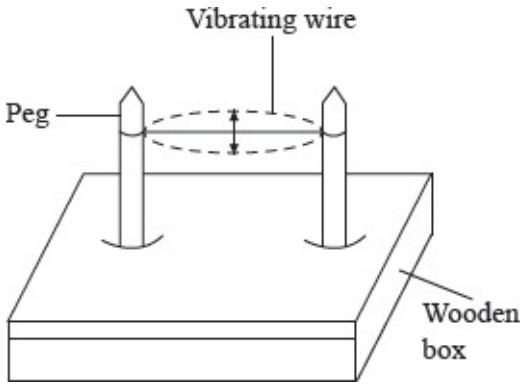



*Fig. 9.2: Vibrating Wire*

When plucked at its middle point, the wire vibrates as shown, producing sound. When a light feather is placed on the wire, the feather jumps off, confirming that the wire is vibrating.

## Vibrating Drum

When a drum is struck, it vibrates, producing sound.



*Fig. 9.3: Drums*

If a few grains of dry sand are placed on a vibrating drum, the grains are displaced up and down, showing that the skin vibrates.

## Tuning Fork

The prongs of a tuning fork are made to vibrate by striking them against a hard surface. The sound produced can be heard more clearly when the stem of the fork is fixed tightly on a hollow box as shown in figure 9.4. Pressing the stem of the fork on a bench produces similar results.

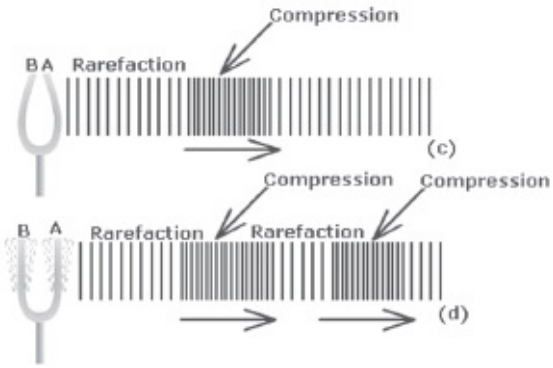



*Fig. 9.4: Photo of vibrating tuning fork*

A tuning fork of higher frequency when struck vibrates faster than one of lower frequency, producing sound of a higher note.

When the prongs are made to touch the water surface, the water splashes, confirming that the prongs are vibrating.

## Vibrating Air Columns

If air is blown across the mouth of a test-tube, sound is heard. This is because the column of air in the tube is set in vibration. Sounds of different frequencies are produced depending on the of the air column.

Air Siren in form of a disc with a ring of equally spaced holes which are equidistant from the centre is used in this case. When it is rotated at a constant rate and air blown through the holes as shown in figure 9.6, sound of a given note is heard. The disc may have concentric sets of holes about its axis to vary the frequency.

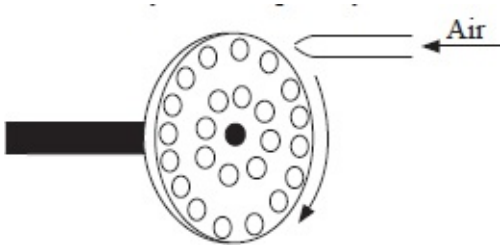



*Fig. 9.5: A siren*

## Cog Wheel and Card

A cog wheel is rotated with a stiff card pressing lightly against the teeth. The teeth of the rotating wheel strike the card, producing sound.

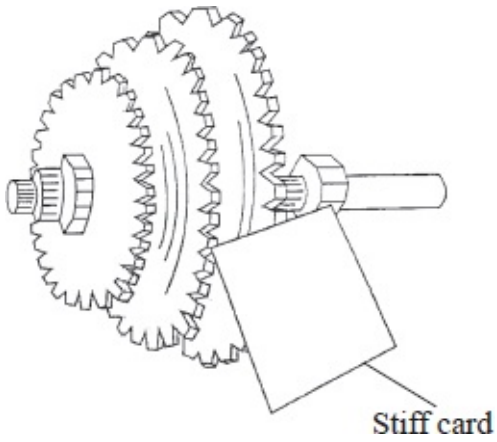



*Fig. 9.6 Cog wheel*

If the teeth are equally spaced, the wheels with fewer teeth produce sound of lower frequency.

## Voice Box (Larynx)

The human voice box contains vocal cords which vibrate to produce sound. Other examples of vibrating bodies are loudspeakers and cellphone or telephone membranes.

## Propagation of Sound Energy

Vibrating prongs of a tuning fork produce compressions (areas of high pressure) and rarefactions (areas of low pressure) of air molecules. This is illustrated in figure 9.8.

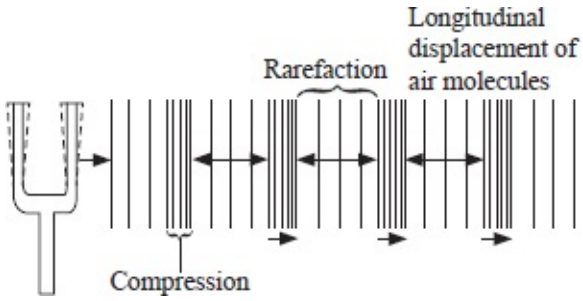



*Fig. 9.7: Propagation of sound waves*

As the prong of the tuning fork moves from A to B, it compresses the air molecules, transferring energy to the molecules in the direction in which the compression occurs. A high pressure region is thus created. This leaves a region of low pressure (a rarefaction) on the left of A. The prong moves back to A and then to C and the process is repeated. A series of compressions and rarefactions are thus produced, transferring energy to the air particles (molecules) to the left

and right. The energy transfer alternates in direction just as the motion of the prong. We may describe a progressive sound wave in air as a travelling pressure wave, as shown in figure 9.9.

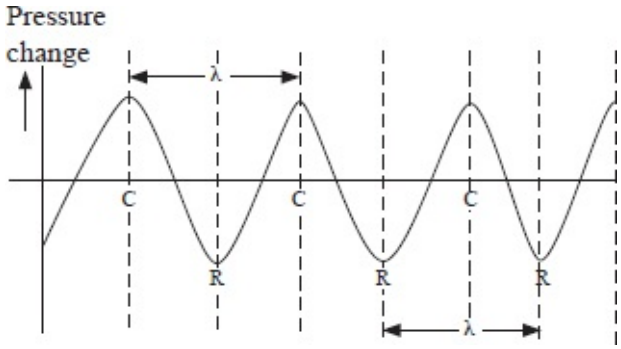



*Fig. 9.8: Propagation of sound waves*

Sound energy moves forward in the medium without net forward movement of the medium. The direction of vibrations of the particles is parallel to the direction of the movement of sound energy. Hence, sound wave is a longitudinal wave.

## Experiment 9.1: To show that sound requires a medium for propagation

*Apparatus*

An electric bell, switch, bell-jar, vacuum pump, rubber bung, flexible connecting wires, cells, glass plate, rubber cord.

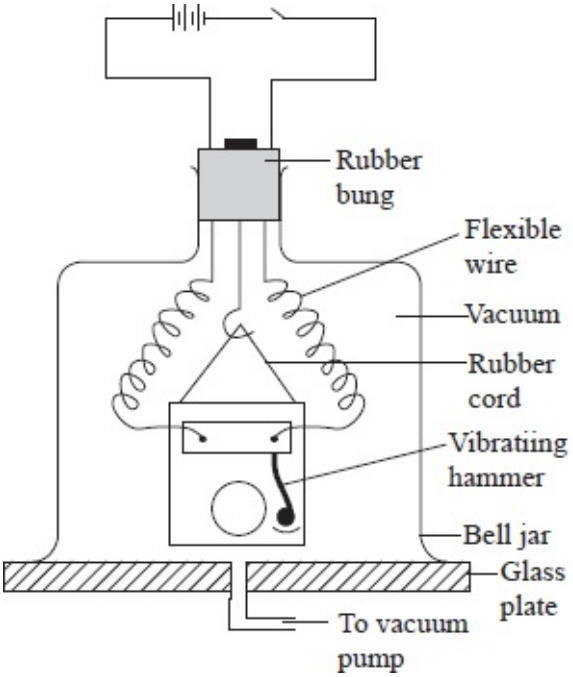


*Fig. 9.9: Sound requires a material medium for propagation*

*Procedure*

- Set the apparatus as shown in figure 9.9.
- Switch on the current to make the bell ring continuously as air is pumped out slowly using the vacuum pump. Observe what happens.

*Observation*

The intensity of sound diminishes as the air in the jar becomes less.

*Explanation*

The sound grows faint because the jar is deprived of air. A vacuum does not transmit sound and the little sound that reaches us does so only through the connecting wires, rubber and the walls of the jar.

## Factors Affecting Velocity of Sound

In air the speed of sound is about 330 m/s. This speed is dependent on various factors, namely;

- Temperature of air.
- Humidity in the air.
- Wind direction.

Sound travels faster in air at high temperature. It also happens that when the moisture content in the air is high, sounds are generally transmitted at a faster rate. Wind affects the velocity of sound in that when the two, i.e., wind and sound happens to be moving in the same direction, the velocity of sound is increased.

Generally, solids transmit sound at a speed of 6 000 m/s. This velocity varies from solid to solid, depending on density of the material. Denser solids transmit sound faster.

In addition to gases and solids, liquids also propagate sound energy. A swimmer easily hears sound of water waves when underneath the water and fish similarly respond to sounds produced in water. Liquids transmit sound energy at different speeds depending on their densities.

The velocity of sound in fresh water is 1400 m/s and in salty water 1500 m/s. Gases transmit sound slowest, while solids transmit sound fastest.

## Reflection of Sound

When a sharp sound falls on an obstacle, it is reflected. Reflected sound is called an **echo**.

Reflected sound is more pronounced from hard surface such as wood, stone walls and metal surfaces. Reflection from liquid surfaces is considerably weaker.

In some halls, sound waves are reflected from the walls, floor and ceiling. Since the echo time is short, the echo overlaps with the original sound. The original sound thus seems to be prolonged, an **effect** called **reverberation**.

Surfaces of materials such as cotton wool and foam rubber absorb most of the energy of incident sound waves. Because of this property, such materials are used in places where echo effects are not desirable. The walls of broadcasting studios and concert halls are thus made of absorbent materials.

### Experiement 9.3: To demonstrate reflection of sound

*Apparatus*

Two plastic tubes, a tickling clock, smooth hard wall.

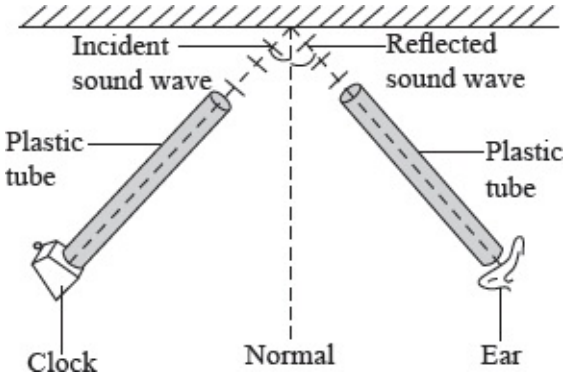



*Fig. 9.11: Reflection of sound*

*Procedure*

- Place the clock near the end of one of the tubes as shown in figure 9.11
- Point the open end of the tube towards a hard wall at an angle of incident, i
- With the ear close to the end of the second open tube, listen to the reflection of the sound from the wall at different angles of reflection, r, and note the angle at which the reflected sound is loudest.

*Observation*

It is observed that maximum loudness of the reflected sound occurs when:

(i) The angle of reflection, r, is equal to the angle of incidence, i.

(ii) Both tubes and the normal to the reflecting surface lie in the same plane.

*Conclusion*

Sound waves obey the laws of reflection.

## Applications of Reflection of Sound

### *Determination of the Speed of Sound*

**Experiment 9.4: To determine the speed of sound in air by echo**

*Apparatus*

Hard smooth wall, two pieces of wood, stop-watch.

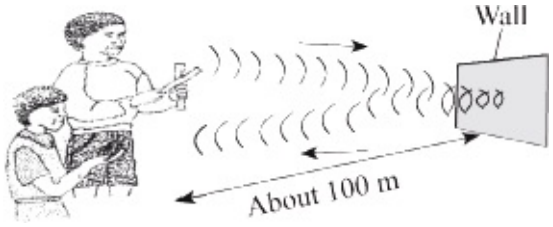



*Fig. 9.12: Determination of velocity of sound by echo*

*Procedure*

- Stand some distance away from and directly in front of a large high wall.
- Tap the two pieces of wood together and listen to the echo, see figure 9.12.
- Now tap repeatedly and try to arrange the next tap to coincide with the echo heard.
- Time a number of successive taps and determine the average time between successive taps.
- Measure the perpendicular distance between the observer and the wall as in the figure.

Since the echo from one tap coincides with the sound from next tap, it means that the time taken to make a tap after the preceding one equals the time taken by sound to travel from the observer to the wall and back. If the distance between the observer and the wall is d metres, the number of tap intervals n and the time t seconds, the sound travels 2d metres in $\frac{t}{n}$ seconds.

$$\text{Hence, speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

$$= \frac{2d}{\frac{t}{n}} = \frac{2nd}{t} \text{ ms}^{-1}$$

## *Pulse-Echo Technique*

The pulse-echo technique involves measuring distances by producing sound of known speed and measuring the time taken to receive the echo. Sound of frequency of over 20 kHz (ultrasound) is used, because it penetrates deepest and can be reflected easily by tiny grains.

The distance of the reflecting obstacle from the source of sound is then calculated using the formula;

distance (d)

$= \text{speed of sound} \times \frac{1}{2} (\text{time taken}).$

This technique is used in chips to determine the depth of the sea, see figure 9.14.

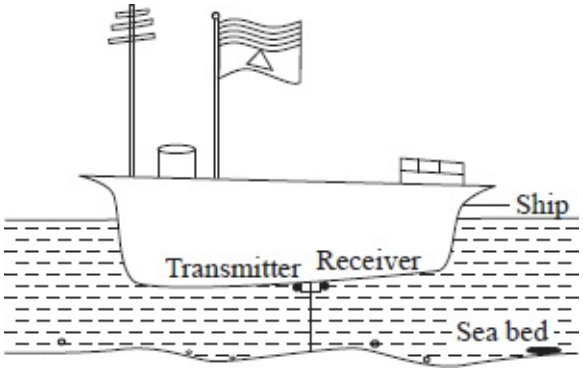



*Fig. 9.13: Using pulse-echo technique*

The technique is also used:

(i) In under-water exploration for gas and oil.

(ii) In fishing boats with pulse-echo equipment to locate shoals of fish.

(iii) In special types of spectacles used by blind people to tell how far objects are ahead of them. The spectacles have transmitters that emit ultrasound and receivers that collect the echo and convert them into audible sound.

Bats use echoes to detect the presence of obstacles in their flight path.

## *Example 1*

A disc siren with 100 holes is rotated at constant speed making 0.20 revolutions per second. If air is blown towards the holes, calculate:

(a) The frequency of the sound produced

(b) The wavelength of the sound produced, if velocity of sound in air is 340 m/s.

*Solution*

(a) Number of holes receiving air per second

$$= \frac{100 \times 0.20}{1}$$

$= 20$ holes

Frequency of the sound

$$= \frac{20 \text{ vibrations}}{1 \text{ sec}}$$

$= 20$ Hz

(b) $$\text{Wavelength} = \frac{\text{velocity}}{\text{wavelength}}$$

$$= \frac{340}{20}$$

$= 17$ m

## *Example 2*

A cog wheel rotating uniformly produces sound of wavelength 1.65m. If it makes 10 revolutions per second, find the number of teeth on the wheel, given that the velocity of sound in air is 330 m/s.

*Solution*

$$\text{Frequency } f = \frac{\text{velocity}}{\text{wavelength}}$$

$$f = \frac{330}{1.65}$$

$= 200$ Hz

$$\text{Number of teeth} = \frac{\text{frequency}}{\text{no. of revolutions}}$$

$$= \frac{200}{10}$$

$= 20$ teeth

## *Example 3*

Two boys stand 200 m from a wall. One bangs two pieces of wood together while the second starts a stop-watch and stops it when he hears the echo. If the time shown on the stop-watch is 1.2 seconds, calculate the speed of sound.

*Solution*

$$\text{Distance travelled by sound} = 2 \times 200$$
$$= 400 \text{ m}$$
$$\text{Speed of sound} = \frac{\text{distance travelled}}{\text{time taken}}$$
$$= \frac{400 \text{ m}}{1.2 \text{ s}}$$
$$= 333.3 \text{ ms}^{-1}$$

## *Example 4*

The speed of sound in air is 340 $ms^{-1}$. A loudspeaker placed between two walls A and B, but nearer to wall A than wall B, is sending out constant sound pulses. How far is the speaker from wall B if it is 200 m from wall A and the time between the two echoes received is 0.176 seconds?

*Solution*

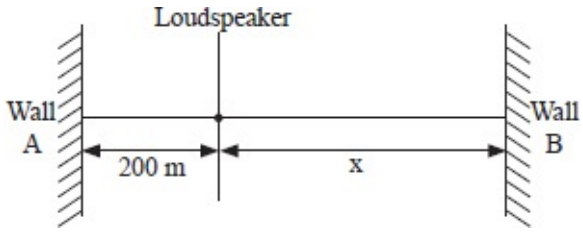



*Fig. 9.15*

Speed of sound is 340 $ms^{-1}$.

Let the time taken to hear echo from walls A and B be $t_1$ and $t_2$ respectively.

Then, $t_2 - t_1 = 0.176$ seconds

If distance between the loudspeaker and wall B is x metres, then;

$t_2 = \frac{2x}{340}$

$t_1 = \frac{2 \times 200}{340}$

$\frac{2x}{340} - \frac{340}{400} = 0.176$

$2x - 400 = 0.176 \times 340$

$2x - 59.84 + 400$

$2x - 459.84$

$x - 229.9$ m

### *Example 5*

The ship sends out an ultrasound whose echo is received after 10 seconds. If the wavelength of the ultrasound in water is 0.05 m and the frequency of the transmitter is 50 kHz, calculate the depth of the ocean.

*Solution*

Velocity of waves

= frequency × wavelength

= 50 000 × 0.05

= 2 500 $ms^{-1}$

Depth d = $(2\ 500 \times \frac{1}{2} \times 10)$ m

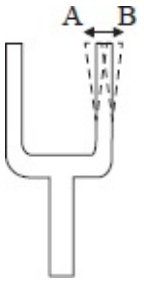
= 12 500 m

## Revision Exercise 9

1. (a) How is sound produced?
   (b) State the law of reflection of sound and explain how an echo is produced.
   (c) Why is the inside of some concert halls covered with soft material?
2. (a) How does a sound wave differ from the waves produced when a water surface is disturbed?
   (b) The range of audible frequencies varies from 20 Hz to 20 kHz. If the speed of sound is 340 $ms^{-1}$, what is the corresponding range of wavelength?
3. A man standing in a gorge between two large cliffs claps his hands at a

steady rate and hears two echoes. The first comes after 2 seconds and the other after 3 seconds. If the speed of sound is 340 $ms^{-1}$, find the distance between the two cliffs.

4. (a) A girl stands 160 m away from a high wall and claps her hands at a steady rate so that each clap coincides with the echo of the one before. If she makes 60 claps in one minute, calculate the speed of sound.
   (b) If she moves 40 cm closer to the wall, she finds that the clapping rate has to be 80 per minute. Calculate the speed of sound.
5. (a) How is sound propagated?
   (b) What evidence is there to show that sound is a wave motion?
   (c) Describe experiments, one in each case, to show that:
      (i) The source of sound is a vibrating body.
      (ii) A material medium is necessary to transmit sound.
6. State two differences between sound and light waves.
7. A person standing 49.5 m from the foot of a tall cliff claps his hands and hears an echo 0.3 second later. Calculate the velocity of sound in air.
8. Two people stand facing each other 200 m apart on one side of a high wall and at the same perpendicular distance from it. When one fires a pistol, the other hears a report 0.6 sec after the flash and a second sound 0.25 sec later. Explain this and calculate:
   (a) Velocity of sound in air
   (b) Perpendicular distance of the people from the wall.
9. (a) What is the relationship connecting the frequency, wavelength and velocity of sound in air?
   (b) An echo sounder in a ship produces a sound pulse and an echo is received from the sea bed after 0.2 sec. If the velocity of sound in water is 1 400 m/s, calculate the depth of the sea.
   (c) If the echo sounder had produced continuous waves of frequency 25 kHz, what would be their wavelength in the water?
10. In determining the depth of an ocean, an echo sounder produces ultrasonic sound. Give reasons why this sound is preferred.
11. The figure below shows a vibrating tuning fork. The time interval for the prong to go from A to B is 0.005 sec.

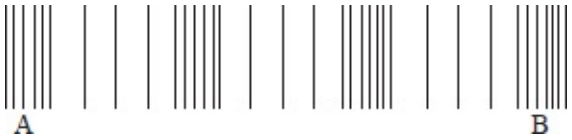



Find the:

(a) Frequency of the fork.

(b) Wavelength of the vibrations, if the velocity of sound in air is 340 $ms^{-1}$.

12. The diagram below is a representation of sound waves passing through air. Study it and answer the questions that follow.




(a) Label the following:

(i) Compression

(ii) Rarefaction

(iii) Wavelength

(b) The wavefront takes 0.1 sec to travel from A to B, find the:

(i) The frequency.

(ii) The wavelength, if velocity of sound in air is 330 $ms^{-1}$.

13. A wooden strip presses on a cog wheel as it rotates at 300 revolutions per second. If the wheel has 100 teeth, find the frequency and the wavelength of sound, given that its velocity in air is 330 $ms^{-1}$.

14. Air is blown into the holes of a disc siren as it is rotated at 10 revolutions per second so that it produces sound of frequency 5 kHz. Find the number of holes on it.

# Chapter 10

# Fluid Flow

The term ‘fluid’ refers to both gases and liquid. A fluid flows as a result of pressure difference. Examples of fluid flows include the flow of water along a riverbed, flow of hot water in central heating systems and convection currents. The study of moving fluids is very important because of their varied applications in day, to, day life, for example, the dynamic lift on an aeroplane wing, the working of a paint spray-gun and the bunsen burner. A flowing fluid experiences internal friction, which is known as viscosity, between its layers. In this chapter, it is assumed that the viscosity of any fluid under discussion is negligible.

## Types of flow

The flow of a fluid can be classified as streamline (steady), laminar or turbulent.

### Streamline (steady) flow

If all the particles of a fluid passing through any given point in the fluid have the same velocity, then the flow is said to be streamline or steady. The path traced by the particles is called the line of flow, which is represented by a line and an arrow, see figure 10.1 (a). A streamline is a curve whose tangent at a given point is along the direction of the displacement of the fluid particles at that point, see figure 10.1 (b). When the streamline and the line of flow coincide, the flow is steady or streamline.

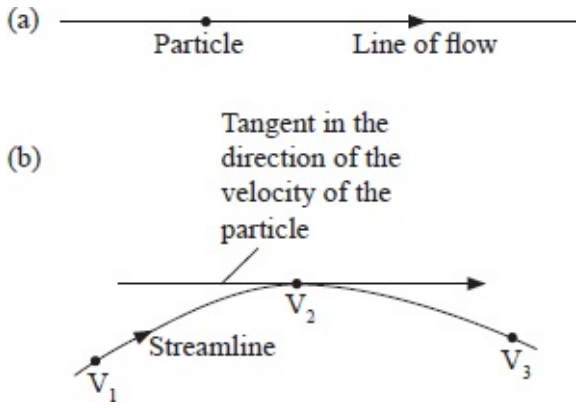


*Fig. 10.1: Line of flow and streamline*

## Laminar Flow

This term is taken to mean steady flow. A moving fluid has many streamlines or layers. The flow is laminar if the particles in a given streamline or layer have the same velocity. Which may be different from other particles in the adjacent parallel layers, see figure 10.2 (a) and (b).

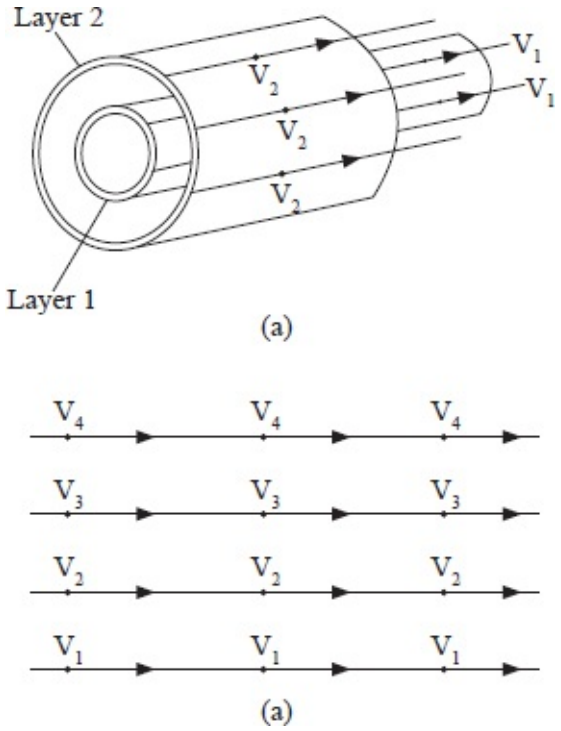



*Fig. 10.2: Fluid flow as series of concentric cylinders in a pipe*

## Turbulent flow

Turbulent fluid flow occurs when the speed and direction of the fluid particles passing through a point vary with time.

**Experiment 10.1: To investigate the effect an object e.g. a ruler on streamlines.**

*Apparatus*

Ruler, a basin of water

*Procedure*

- Move the ruler with its sharp edge cutting through water and note the following:

- The force required to move the ruler.
- The ripples on the water caused by its movement.
- Repeat the experiment with the blunt or flat side of the ruler.

*Observation*

The streamlines obtained are as shown in figure 10.3 (a) and (b). Figure 10.3 (a) shows streamlines around the edge of the ruler while 10.3 (b) shows what happens to the streamlines when the experiment is repeated with the blunt or flat side. It is observed that with the flat side of the ruler, more effort is required to move the ruler than when it is moved with its sharp edge cutting through the water. Ripples are set up in the water, which tend to follow the ruler as it moves.

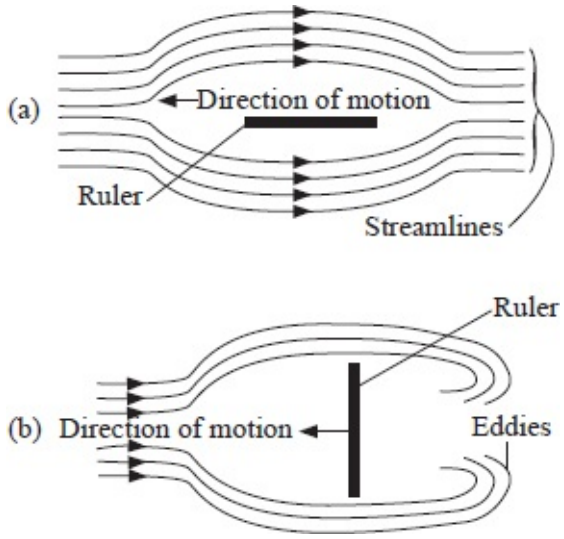



*Fig. 10.3: Effect of a ruler on streamlines*

This breaking of streamline into ripples (disorderly flow) is referred to as turbulent flow. The ripples or eddies have a drag effect on the object moving through the fluid.

**Experiment 10.2: To investigate the effects of various shapes on streamlines**

*Apparatus*

Basin of water, pieces of wood of different shapes, strings, hooks

*Procedure*

- Fix a string at the end of each shapes as shown in figure 10.4 (a), (b) and (c):
- Pull it through a pool or a large container of water. In each case, note the effort required to pull the object through the water and the ripples or eddies as

the object sails through.

*Observation*

The streamlines obtained are as shown in figures 10.5 (a), (b) and (c).

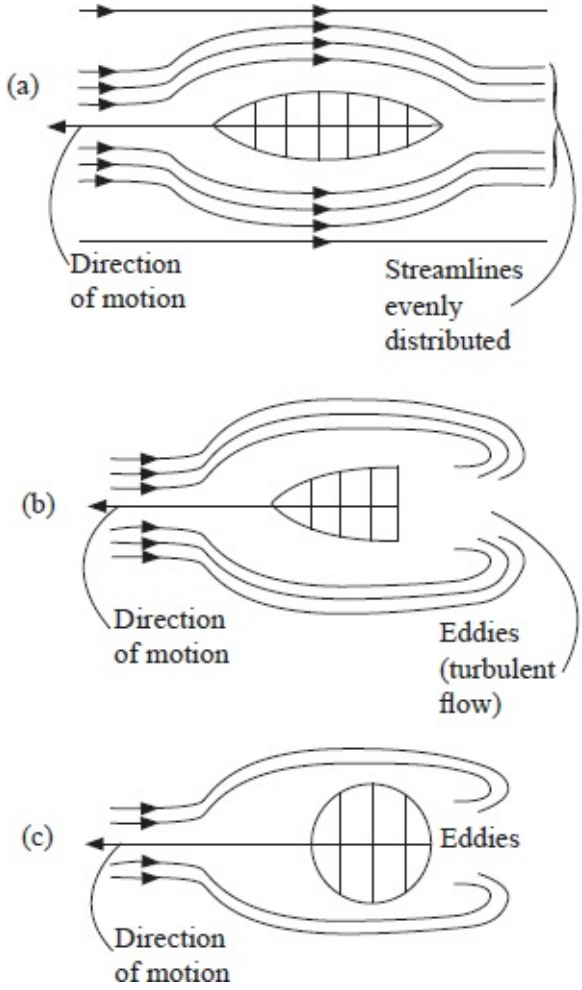



*Fig. 10.4: Effect of shapes on streamlines*

Shape (a) requires little effort to move, and has no eddies behind it. Shape (b) requires more effort than (a) and gives rise to more eddies than (c). Shape (c) requires more effort than (a), but less effort than (b).

*Conclusion*

Objects with sharper or pointed ends require relatively less force to move through the fluid as they cause less turbulence (drag effect). Objects with streamlined shapes cause less turbulence to a fluid flow.

## Shapes Designed for Streamline Flow

Shapes suited to streamline flow are designed in such a way that they easily cut

through fluids and reduce the formation of eddies behind them. This reduces resistance to their motion.

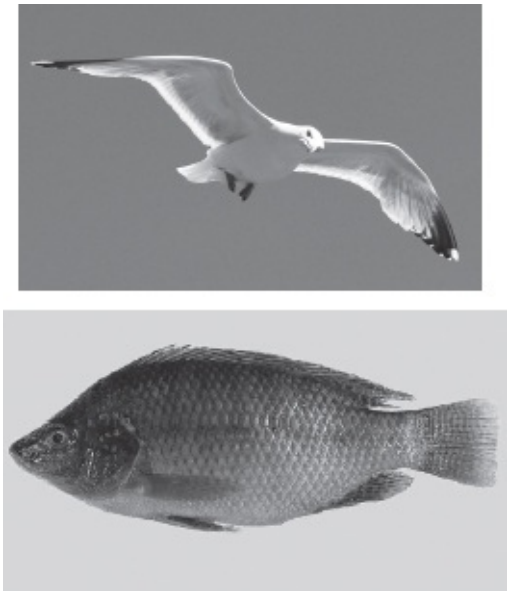


*Fig. 10.5: Aquatic and flying animals*

In nature some animals have bodies that are shaped to make their movement easy. Examples include aquatic and flying animals.



*Fig. 10.6: Bodies designed for streamline flow*

## Effect of Speed of Flow on Streamlines

The arrangement in figure 10.7 can be used to study the effect of speed of flow on streamlines.

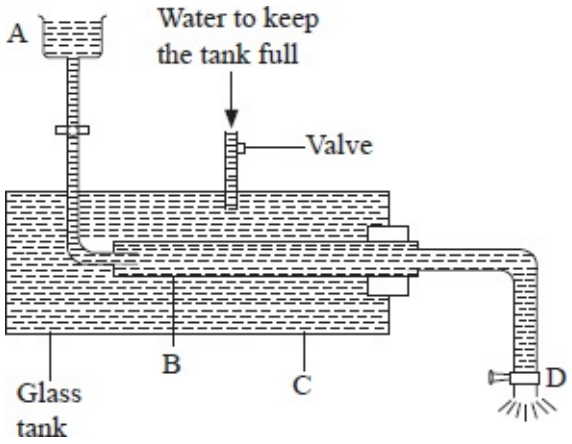



*Fig. 10.7: Effect of speed on streamlines*

Reservoir A contains potassium permanganate solution, which is released in controlled amounts into the water flowing through a cylindrical glass jacket C by a fine jet B. The speed of water through C is varied by the clip D. If a small amount of water is allowed to flow out through D, a fine coloured stream is observed along the tube C, indicating a steady flow. But when a large amount of water is allowed to flow out, the velocity of water in the tube C increases rapidly and this breaks the coloured stream, indicating that turbulence has set in. Turbulence sets in when the fluid flow is beyond a certain velocity known as critical velocity.

## The Equation of Continuity

In deriving this equation, the assumptions made are that the fluid is:

(i) Flowing steadily.

(ii) Incompressible, i.e. changes in pressure produce insignificant change in its density.

(iii) Non-viscous.

## Some useful definitions

*Volume flux (flow rate)*

Consider a tube of flow with region W having cross-section area of AW and region X with cross-section Area AX.

The volume flux is the volume of a fluid passing through a given section of a tube of flow per unit time, see figure 10.8.

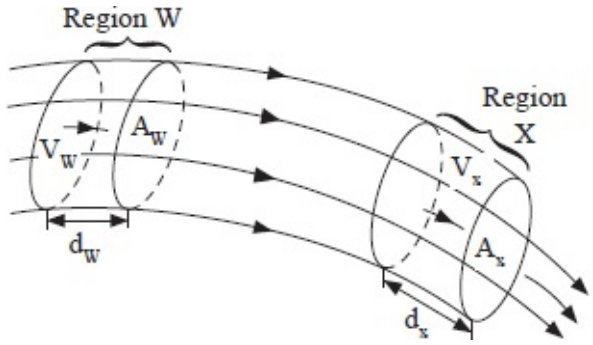



*Fig. 10.8: Volume flux*

Let the velocity of the fluid through region X be vx and the average cross-section area be Ax. If the distance covered by the fluid per unit time is dx then the volume flux through that region is given by:

Volume flux = area of cross-section × distance

$$= A_x \times d_x$$

$$\text{But velocity } v_x = \frac{\text{displacement}}{\text{time}}$$

$$= \frac{d_x}{t}$$

Hence, velocity $v_x = d_x$ since t = 1 sec.

Thus, volume flux = $A_x v_x$

If $A_x$ is in $m^2$ and $v_x$ is in m/s, then the unit of volume flux is $m^2 \times m/s = m^3/s$ ($m^3s^{-1}$).

## Mass flux

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

Mass = density × volume

Hence, mass flux = density × volume flux

$$= \rho \times A_x V_x$$

$$= A_x v_x \rho$$

If volume flux is in $m^3s^{-1}$ and density is in $kgm^{-3}$, then the unit of mass flux is kg/s ($kgs^{-1}$).

**Mass flux is therefore the mass of the fluid that flows through a given section per unit time.**

Since the fluid is incompressible, the mass of the fluid entering region X is equal to the mass of the fluid leaving region W within the same period, i.e., mass is conserved.

Mass flux at W = mass flux at X

$A_w v_w \rho = A_x v_x \rho$

Hence, $A_w v_w = A_x v_x$

This is the **equation of continuity**. Aw $v_w$ or $A_x v_x$ is also called the **flow rate** and is constant, i.e;

Area × velocity = constant

AV = k

Therefore, it can be deduced that for a non-viscous steady flow, the area of cross-section of the fluid is inversely proportional to the velocity of the fluid.

The speed of the fluid increases when it flows from a pipe of big cross-section area to a smaller one. The converse is also true, see figure 10.9.

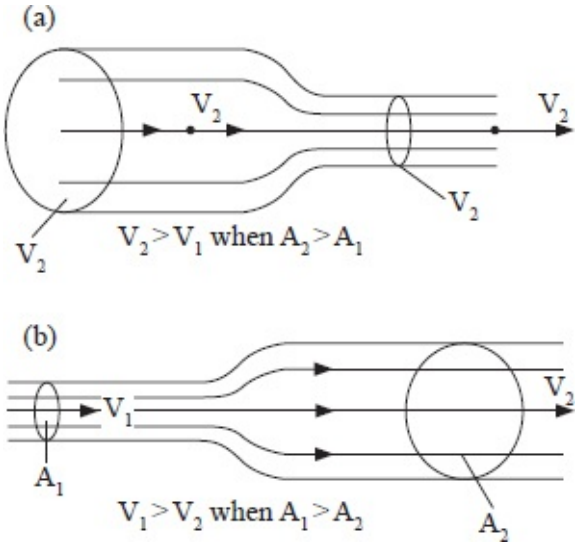



*Fig. 10.9: Velocity change with area*

## *Example 1*

A lawn sprinkler has 40 holes, each of cross-section area $2.0 \times 10^{-2}$ $cm^2$ .

It is connected to a hose-pipe of cross-section area 1.6 $cm^2$. If speed of the water in the hose-pipe is 1.2 $ms^{-1}$, calculate the:

(a) The flow rate in the hose-pipe

(b) The speed at which water emerges from the holes

*Solution*

(a) Flow rate

= cross-section area x speed

$= 1.6 \times 10^{-4}\ m^2 \times 1.2\ ms^{-1}$

$= 1.92 \times 10^{-4}\ m^3s^{-1}$

(b) The flow rate is constant.

Volume efflux (volume of water coming out)

$= v \times 2.0\ 10^2 \times 10^{-4} \times 40$

$= 8 \times 10^{-5}v\ m^3s^{-1}$

Volume influx = Volume efflux

$8 \times 10^{-5}v = 1.92 \times 10^{-4}$

$v = 2.4\ ms^{-1}$

## *Example 2*

Water flows along a horizontal pipe of cross-section area 40 $cm^2$ which also has a constriction of cross-section area 5 $cm^2$. If the speed at the constriction is 4 $ms^{-1}$, calculate the

(a) Speed in the wide section.

(b) Mass flux (take the density of water to be $1 \times 10^3\ kgm^{-3}$).

*Solution*

(a) Volume flux in the wider section

$= 40 \times 10^{-4} \times v$

Volume flux in the constriction

$= 5 \times 10^{-4} \times 4$

But volume flux = constant

$40 \times 10^{-4}v = 5 \times 10^{-4} \times 4$

$$v = \frac{20 \times 10^{-4}}{40 \times 10^{-4}}$$

$= 0.5 ms^{-1}$

Mass flux = density x volume flux

$= 1 \times 10^3 \times 2 \times 10^{-3}$

$= 2\ \text{Kgs}^{-1}$

### *Example 3*

It is noted that 250 $cm^3$ of fluid flows out of a tube, whose inner diameter is 7 mm, in a time of 41 s. What is the average velocity of the fluid in the tube?

*Solution*

Area $A = \pi r^2 = 3.142 \times (3.5 \times 10^{-3})^2$

$= 3.85 \times 10^{-5} m^2$

$$\text{Volume flux} = \frac{\text{volume}}{\text{time}}$$

$$= \frac{250 \times 10^{-6}\ m^3}{41\ s}$$

$$= 6.098 \times 10^{-6}\ m^3 s^{-1}$$

Since volume flux = Av

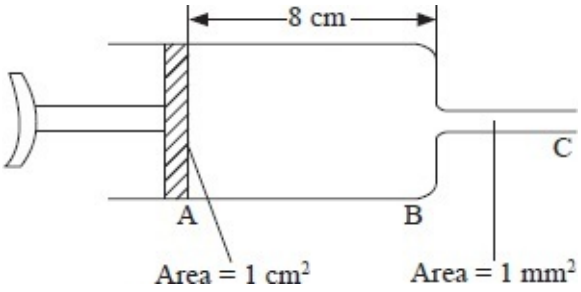
Therefore $6.098 \times 10^{-6} = 3.85 \times 10^{-5} \times v$

$$v = \frac{6.098 \times 10^{-6}}{3.85 \times 10^{-5}}$$

$$= 0.158\ ms^{-1}$$

### Exercise 10.1

1. Distinguish between the following terms:
   (a) Streamline flow and turbulent flow.
   (b) Steady flow and laminar flow.
2. Water flows through a horizontal pipe at a rate of 1.00 $m^3$/min. Determine the velocity of the water at a point where the diameter of the pipe is:
   (a) 1.00 cm.
   (b) 4.00 cm.
3. In the figure below, the tube ABC is filled with a liquid. The piston moves from A to B in 1 second.




Calculate:

(a) the volume of the liquid in part AB.

(b) the velocity of the liquid between A and B.

(c) the velocity of the liquid through BC.

4. A garden sprinkler has small holes, each 2.00 $mm^2$ in area. If water is supplied at the rate of $3.0 \times 10^{-3}$ $m^3s^{-1}$ and the average velocity of the spray is 10 $ms^{-1}$, calculate the number of the holes.

5. Oil flows through a 6 cm internal diameter pipe at an average velocity of 5 m/s . Find the flow rate in $m^3/s$ and $cm^3/s$.

6. The velocity of glycerine in a 5 cm internal diameter pipe is 1.00 m/s. Find the velocity in a 3 cm internal diameter pipe that connects with it, both pipes flowing full.

## Bernoulli's principle

The pressure of a fluid at rest in a uniform horizontal tube is the same at all points in the tube. However, if the fluid flows, the pressure will vary from point to point, see figure 10.10.

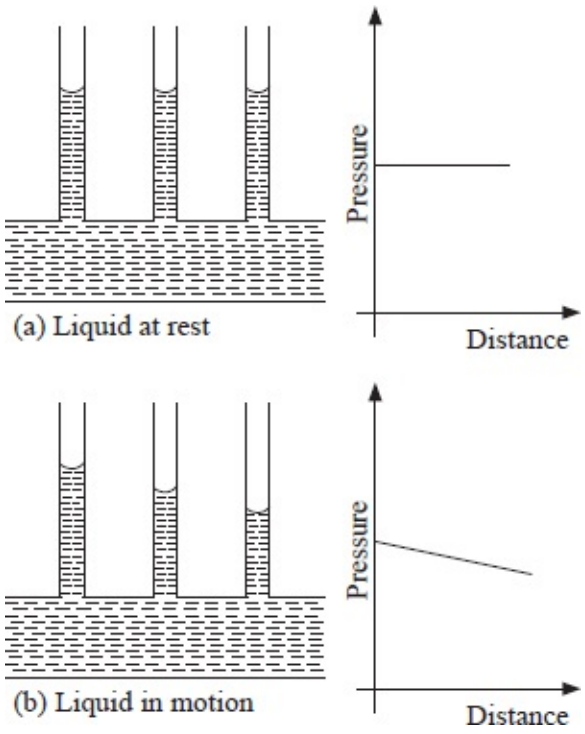



*Fig. 10.10: Pressure variation*

A pressure gradient is needed to make a liquid flow through a pipe. The cause of the pressure difference is the friction between the liquid and the walls of the pipe.

**Experiment 10.3: To investigate the relationship between speed of water and the pressure it exerts**

*Apparatus*

Glass tube with varying cross-section area and fitted with vertical tubes at X, Y and Z, source of running water.

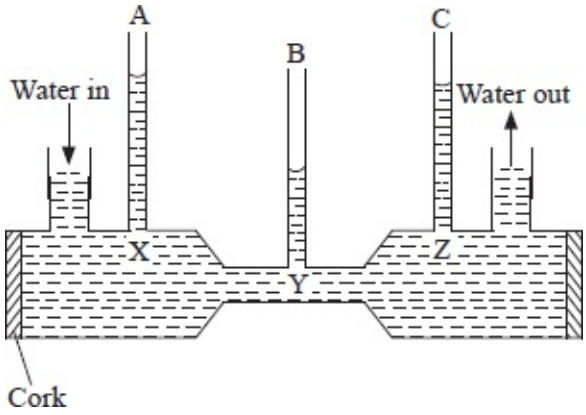



*Fig. 10.11: Investigating speed and pressure of moving water*

*Procedure*

- Fill the glass tube with water.
- Fill the vertical tubes (manometers) with water up to the same height.
- Open the outlet and supply the glass tube with water such that the amount of water entering the glass tube is the same as the amount flowing out. Note if there are changes in the heights of the water in the vertical tubes.

*Observation*

It is observed that the level in manometer B is lower than the level in the other tubes, see figure 10.12.

*Explanation*

Recall that pressure in stationary fluids is given by $P = h\rho g$ (where $\rho$ = density). Hence, the pressure being exerted by the fluid in the narrow constriction is lower than that of X and Z. It is also slightly lower at Z than at X. Recall also that the velocity of the fluid at the narrow constriction is higher than that at the wider sections. Thus, the higher the speed of the fluid, the lower the pressure it exerts. This relation is known as **Bernoulli's effect,** which can be stated as follows:

**Provided a fluid is non-viscous, incompressible and its flow streamline, an increase in its velocity produces a corresponding decrease in the pressure it exerts**.

(a) Some books are arranged on a table and a piece of paper placed on them, as shown in figure 10.12 (a).

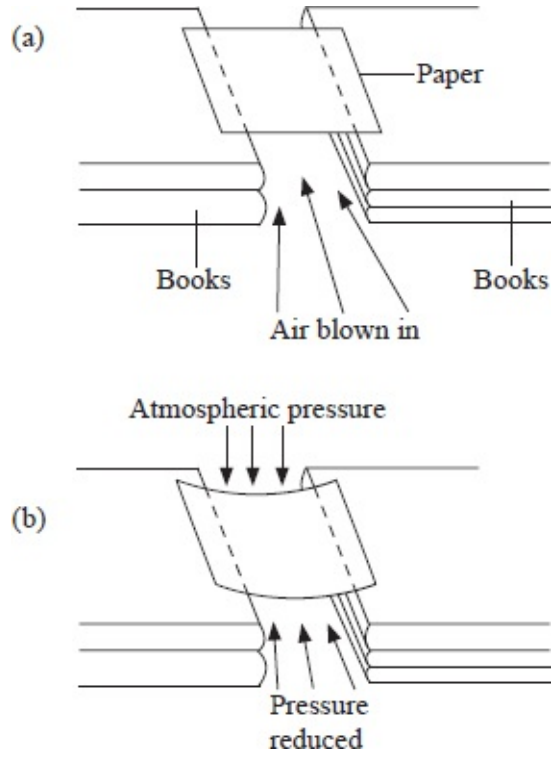



*Fig. 10.12: Bernoulli's effect*

When air is blown into the channel made by the books, the pressure under the paper decreases and the atmospheric pressure acting on top of the paper presses it down. The paper thus curves in as shown in figure 10.13 (b). The pressure in the channel decreases because the velocity of the air in the channel increases.

(b) If a light paper is held in front of the mouth and air blown horizontally over the paper, it will be observed that the paper gets lifted up.

Initially, part of the paper is suspended because its weight and the atmospheric pressure acting on the two surfaces balance. When air is blown over the paper, its velocity gets higher than at the initial state when air is stationary. Increase in velocity causes a corresponding decrease in the pressure being exerted on the top side of the paper. The atmospheric pressure acting underneath, therefore, becomes higher and produces the force that lifts up the paper, see Figure 10.13 (a).

(c) If two pieces of paper are placed close to each other and air blown between them as shown in figure 10.14 (a), the two papers close in towards each other. The moving air between the papers lowers the pressure it exerts on their inner surfaces. The higher atmospheric pressure acting on the outside surfaces causes the papers to move closer to each other. The same effect is observed when air is blown between two suspended pithballs, see figure

10.13 (b).

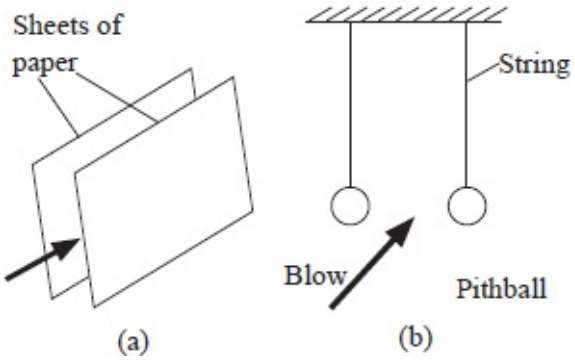



*Fig. 10.13: Bernoulli's effect*

(d) The Spinning Ball

When a tennis ball of negligible weight is moving through still air with a constant speed, the streamlines around it are uniformly spread, as shown in figure 10.14 (a). The direction of the streamlines is the direction of the relative motion between the ball and the air.

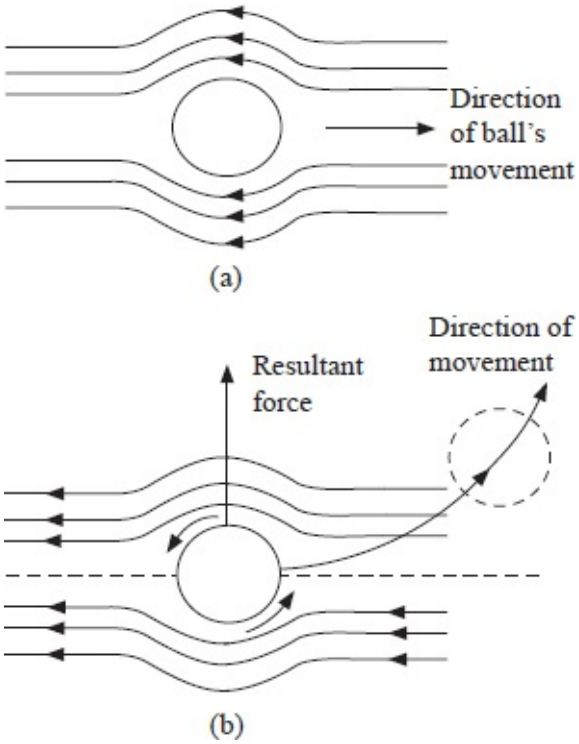



*Fig. 10.14: Spinning ball*

If the ball is now made to spin as it moves, it is observed to curve out of its initial path. As the ball spins, it drags air along with it, which opposes the relative motion on one side of the ball. This causes a reduction in the

relative speed and the streamlines are spread, see figure 10.14 (b). On the opposite side, the dragged air is in the direction of the relative motion, resulting in an increase in speed and consequential decrease in pressure in accordance with Bernoulli's effect. The pressure difference on the two sides of the ball produces a resultant force that causes the ball to curve out of its initial path.

(e) Lifting a light ball using a Funnel

The streamlines as air is blown down the narrow section of the funnel are very close to each other, signifying high velocity and therefore low pressure, see figure 10.16. However, when the streamlines emerge into the wider section, they spread, signifying reduced velocity and therefore high pressure. The high pressure below the ball (atmospheric pressure) lifts the ball up to the neck of the funnel.

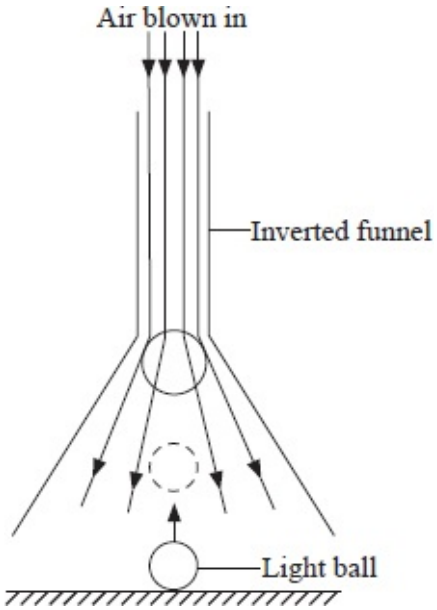



*Fig. 10.15: Lifting a light ball*

## Bernoulli's Equation

Bernoulli's principle can also be expressed as an equation. Consider liquid of mass m flowing through a pipe with velocity v. Let the pressure at a given point be p. Then, kinetic energy per unit volume

$$= \frac{\text{kinetic energy}}{\text{volume}} = \frac{mv^2}{2V}$$

But density $p = \frac{m}{V}$

Hence, kinetic energy per unit volume

$$= \frac{1}{2}\rho v^2$$

Similarly, potential energy per unit

$$\text{volume} = \frac{\text{potential energy}}{\text{volume}}$$

$$= \frac{mgh}{V}$$

$$= \rho gh$$

Bernoulli found that if the liquid is incompressible, non-viscous and its flow streamline;

$$p + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$$

That is, **the sum of pressure, kinetic energy per unit volume and the potential energy per unit volume is a constant. This is Bernoulli's principle**.

## Applications of Bernoulli's Principle

### *The Aerofoil*

This is a structure constructed in such a way that the fluid flowing above it moves with a higher speed than that flowing below, see figure 10.16.

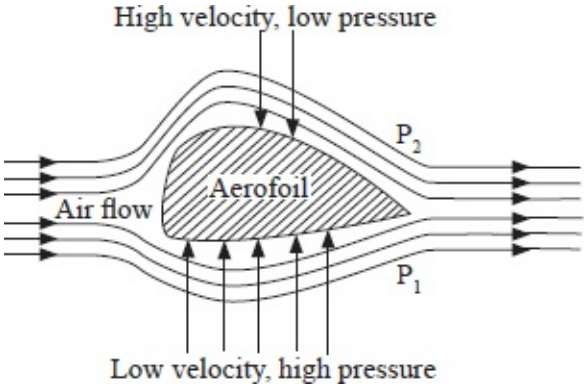



*Fig. 10.16: Aerofoil*

Aircraft wings and helicopter rotor blades are examples of aerofoils. Because the fluid flowing above the aerofoil has to travel a longer distance than that flowing below, it has to travel at a higher speed (low pressure) compared to the low speed (high pressure) underneath. The pressure $P_1$ is thus greater than pressure $P_2$. The pressure difference $(P_1 - P_2)$ gives rise to the lift of the aerofoil, called the dynamic lift. The force of the lift is given by $F = (P_1 - P_2)\,A$, where A is the area of the aerofoil.

*Bunsen Burner*

When gas is made to flow into the bunsen burner from the gas cylinder, its velocity is increased when it passes through the nozzle. This decreases the pressure above the nozzle. Because of the atmospheric pressure outside the barrel, air is then drawn in as shown in the diagram. The air and gas then mix as they rise up and when ignited, a flame is produced.

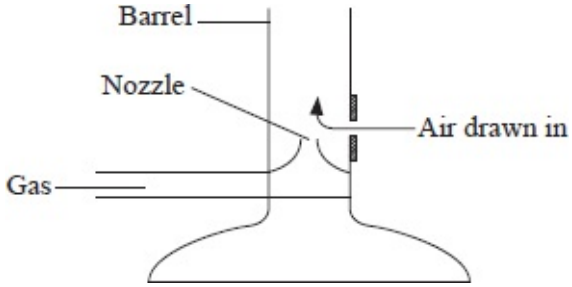



*Fig.10.17: Bunsen burner*

## *Spray gun*

Figure 10.19 shows a hand spray gun. When the piston is moved forward, air is made to flow through the barrel, some of it going down tube A and the remainder blowing past the mouth of tube B, where it causes low pressure. Because of increased pressure on the surface of the liquid, and reduced pressure at the mouth of B, the liquid is compelled to move up tube B and blown to the nozzle by the air from the barrel. The velocity of the liquid is increased as it passes through the nozzle because of the reduced cross-section area. The liquid thus emerges as a fine spray.

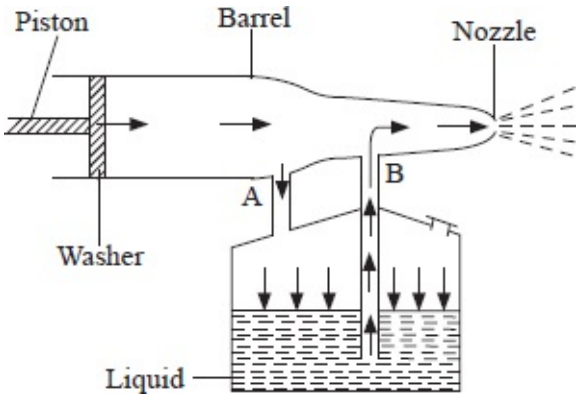



*Fig. 10.18: Spray gun*

## *The Carburettor*

Due to the action of the engine pistons, air is drawn into the venturi, see figure

10.20.

The fast-moving air causes low pressure above the petrol pipe. Petrol is drawn into the venturi due to low pressure in the venturi and atmospheric pressure in the float chamber. The mixture of air and petrol is thus drawn into the cylinders for combustion.

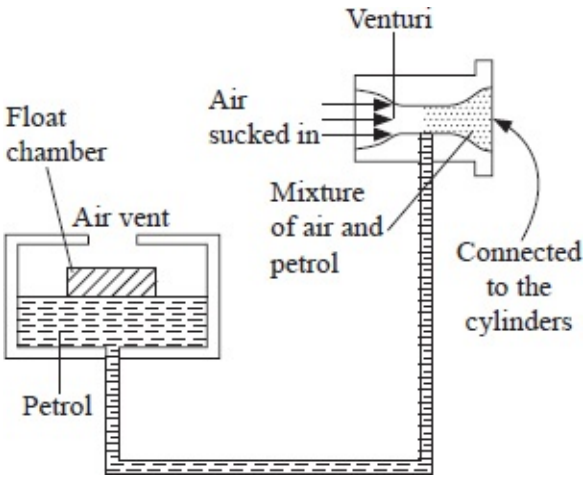



*Fig. 10.19: Carburettor*

## *Flow Meters*

### Venturi meter

This device is used in measuring the volume flux of a fluid.

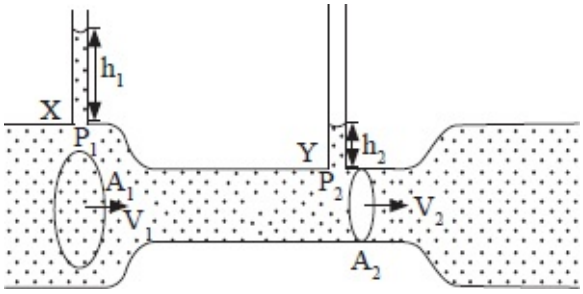



*Fig. 10.20: Venturi meter*

Let $P_1$ and $P_2$ be pressure and $v_1$ and $v_2$ the velocities of the fluid at X and Y respectively.

Since $P + \frac{1}{2} pv^2$ = constant (horizontal tube);

$$P_1 + \frac{1}{2}\rho v_1^2 = p_2 + \frac{1}{2}\rho v_2^2$$

$$\text{Hence, } P_1 - P_2 = \frac{1}{2} p\,(v_2^2 - v_1^2)$$

Applying the equation of continuity;

$A_1 v_1 = A_2 v_2$

$$v_2 = \frac{A_1 v_1}{A_2}$$

$$v_2^2 = \left(\frac{A_1}{A_2}\right)^2 v_1^2$$

$$\text{Thus, } P_1 - P_2 = \frac{1}{2} p \left[\left(\frac{A_1}{A_2}\right)^2 v_1^2 - v_1^2\right]$$

$$= \frac{1}{2} \rho v_1^2 \left[\left(\frac{A_1}{A_2}\right)^2 - 1\right]$$

From this, $v_1$ and hence $A_1 v_1$ can be calculated.

**Pitot-tube**

This device is used for measuring the velocity of moving fluid. The static pressure is measured by the static tube while the pitot tube measures the total pressure.

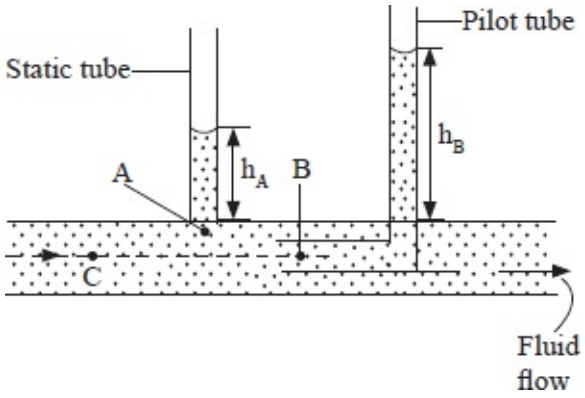



*Fig. 10.21: Pitot tube*

Pressure at C is given by:

$$P_C = P + \frac{1}{2} \rho v^2$$

Total pressure at B equal $P_C$

$$P_B = P + \frac{1}{2} \rho v^2$$

Pressure at A is given by;

$P_A = P$

$$\text{Now, } P_B - P_A = \frac{1}{2} \rho v^2$$

$$\text{So, } v^2 = \frac{2}{\rho} (P_B - P_A)$$

Therefore, $V = \sqrt{\frac{2}{\rho}(P_B - P_A)}$

Where $P_B$ is the total pressure and $P_A$ the static pressure.

But $P_B - P_A = (h_B - h_A)\,pg$

Hence, $v = \sqrt{2g(h_B - h_A)}$

## Hazards of Bernoulli's effect

### *Blowing off of Roof-tops*

The air flowing over a roof-top has a high velocity compared to the one flowing underneath, see figure 10.24. Consequently, the pressure acting on the roof from the underneath, $P_2$, will be higher than that acting from above, $P_1$. Hence, the roof may be blown off.

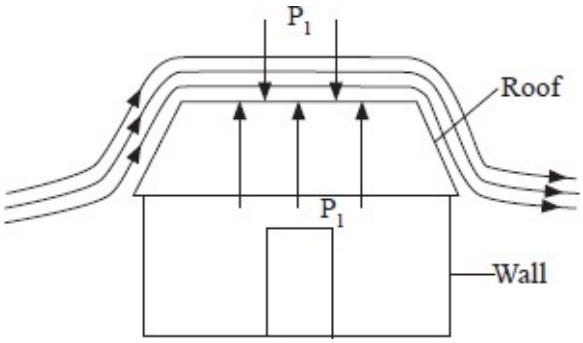



*Fig. 10.22: Wind driven air flow over a building roof*

### *Road Accidents*

A small car travelling at a very high speed is likely to be dragged into a long truck traveling in the opposite direction, also at a high speed. This is because the air in between them moves with a very high speed, reducing the pressure between them. The atmospheric pressure acting from the sides of two vehicles will push them closer together, increasing chances of an accident.

### *Example 4*

Water flows steadily through a horizontal pipe of varying cross-section area. At a point A of cross-section area 10 $cm^2$, the velocity is 0.2 $ms^{-1}$. Calculate the:

(a) Velocity at a point B, of cross-section area 2.5 $cm^2$

(b) Pressure difference between A and B, given that the density of water is

1,000 $Kgm^{-3}$ .

*Solution*

(a) From the equation of continuity;

$A_1v_1 = A_2v_2$

$10 \times 10^{-4} \times 0.2 = v_B \times 2.5 \times 10^{-4}$

$v_B = 0.8\ ms^{-1}$

(b) $P = \frac{1}{2}\rho (v_B^2 - v_A^2)$

$= \frac{1}{2} \times 10^3 (0.64 - 0.04)$

$= \frac{1}{2} \times 10^3 \times 0.6$

$= 3 \times 10^2\ Nm^{-2}$

## *Example 5*

Air flows over the upper surfaces of the wings of an aeroplane at a speed of 100 $ms^{-1}$ and past the lower surface of the wings at 90 $ms^{-1}$. Calculate the:

(a) Pressure difference on the wings.

(b) Lift force on the aeroplane, if it has a total area of 10 $m^2$ (take the density of air as 1.3 $Kgm^{-3}$).

*Solution*

(a) Pressure difference

$P = \frac{1}{2}\rho (v_1^2 - v_2^2)$

$= \frac{1}{2} \times 1.3 (10\ 000 - 8\ 100)$

$= 1235\ Nm^{-2}$

(b) Lift force = pressure difference × area

$= 1\ 235 \times 10$

$= 1.235 \times 10^4$ N

## *Example 6*

A liquid of density $8.75 \times 10^3$ gm is flowing through a horizontal pipe whose cross-section area changes from 40 $cm^2$, to 25 $cm^2$, with two open vertical tubes

at the two sections. The vertical tubes contain the same liquid. If there is a liquid level difference of 1.25 cm between the two tubes, calculate the rate of flow in mass per unit time.

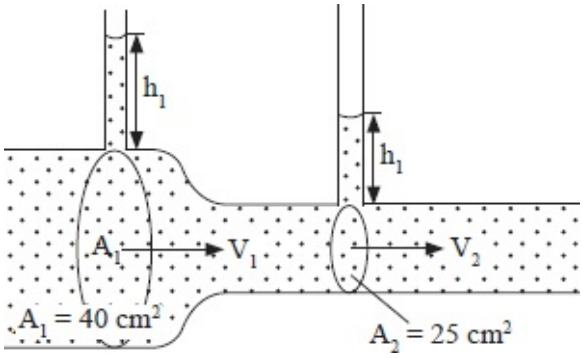



*Fig. 10.23*

From the equation of continuity,

$A_1v_1 = A_2v_2$

$40 \times 10^{-4} \times v_1 = 25 \times 10^{-4}v_2$

$$\frac{v_1}{v_2} = 0.625$$

So, $v_1 = 0.625v_2$ ms$^{-1}$

The change in pressure is responsible for the change in the kinetic energy per unit volume of the fluid. That is;

$$\Delta P = \frac{1}{2}p\,(v_2^2 - v_1^2)$$

$$\Delta P = \frac{1}{2} \times 8.75 \times 10^2(v_2^2 - 0.39v_2^2)$$

$$= 4.375 \times 10^2 \text{ x } 0.61\ v_2^2$$

$$= 266.9\ v_2^2$$

But P = hpg

Therefore $\Delta P = 1.25 \times 10^{-2} \times 8.75 \times 10$

$= 109.4$ Nm$^{-2}$

Hence, $266.9\ v_2^2 = 109.4$

$$v_2^2 = \frac{109.4}{266.9}$$

$$v_2 = \sqrt{\frac{109.4}{266.9}}$$

$v^2 = 0.64$ ms$^{-1}$

Mass flux = volume flux × density

= AV × density

$= 20 \times 10^{-4} \times 0.64 \times 8.75 \times 10^{2}$

$= 1.4\ kgs^{-1}$

### *Example 7*

Water flows steadily along a uniform flow tube of cross-section area 20 $cm^4$. The total pressure is $3 \times 10^4$ Pascal and the static pressure $2.5 \times 10^4$ Pa. Calculate the:

(a) Velocity of the fluid.

(b) Mass of water flowing past a section in two seconds (take density of water as $10^3\ kgm^{-3}$ )

*Solution*

(a) $V^2 = \frac{2}{\rho}(P_T - P_S)$, where $P_T$ is the total pressure and $P_S$ static pressure

$$V = \sqrt{\frac{2 \times 10^4 (3 - 2.5)}{10^3}}$$

$= 3.162\ ms^{-1}$

In two seconds, the mass of water flowing past a given section is;

$2 \times 6.324 = 12.64$ kg.

### *Example 8*

The depth of water in a tank of large cross-section area is maintained at 40 cm. Water emerges in a continuous stream out of a hole 2 mm in a diameter at the base

(a) Calculate:

(i) Speed at which the water emerges from the hole.

(ii) Mass flux (density of water = 1 000 $kgm^{-3}$)

(b) What assumptions have you made in part (a)?

*Solution*

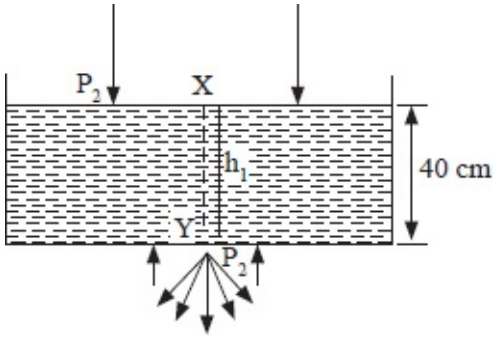



*Fig. 10.24*

At point X, $P_1$ = atmospheric pressure P

$h_1$ = 40 cm

Velocity $v_1 = 0$

At point Y, $P_2$ = atmospheric pressure P $h_2 = 0$

velocity = $v_2$

## Using Bernoulli's principle;

$P + hpg + \frac{1}{2} pv^2 = \text{constant}$

$P_1 + h_1pg + \frac{1}{2} pv_1^2 = P_2 + h_2pg + \frac{1}{2} pv_2^2$

Substituting, $P + (40 \times 10^{-2} \times 10^3 \times 10)$

$= P + (\frac{1}{2} \times 10^3 \times v_2^2)$

$4 \times 10^3 = \frac{1}{2} \times 10^3 \times v_2^2$

$v_2^2 = 8$

Therefore $v_2 = 2.828\ ms^{-1}$

Mass flux = volume flux x density

$= 3.142 \times 10^{-6} \times 2.828 \times 10^3$

$= 8.89 \times 10^{-3}\ kgs^{-1}$

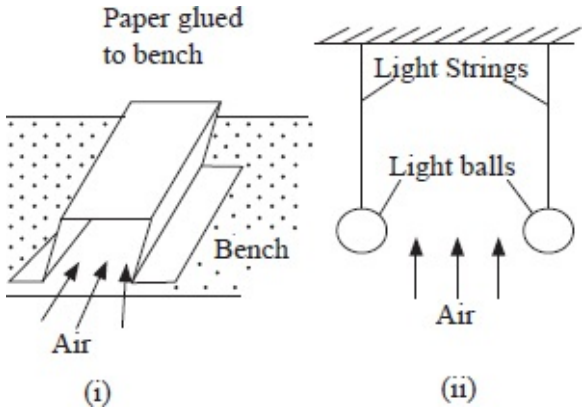
(b) Assumptions:

(i) The area of the hole is negligible compared to that of the tank.

(ii) The flow is streamline.

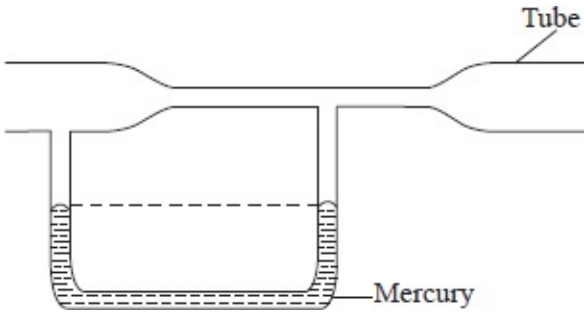
## Revision Exercise 10

1. The window and door of a house are both left open during a windy day. The door, which opens inwards, tends to slum shut when it is slightly ajar. Explain.
2. Explain your observation when air is blown:
   (a) Through the tunnel shown in diagram (i) below.
   (b) Between light balls suspended on light strings as shown in diagram (ii).




3. Explain the following:
   (a) A car travelling at high speed appears lighter.
   (b) It is dangerous to stand close to a railway line on which a fast moving train is passing.
   (c) An aeroplane is likely to take off much earlier than expected when the speed of the wind blowing in the opposite direction to its motion on the runway suddenly increases.
4. Explain using a diagram why a spinning baseball travels in a slightly curved path.
5. State Bernoulli's principle and write its equation. Define the physical quantities which appear in it and the conditions required for its validity.
6. Draw a cross-section of an airplane's wing and clearly indicate the two components of the resultant force of the air moving over the airplane. Which component is useful and which one acts as a retarding force?
7. A ship's captain, in an attempt to warn off another ship steered his ship, parallel and close to the intruder ship. The two ships finally collided. What could have caused the accident?
8. When a strong wind blew over a primary school with crowded buildings, the roofs were blown off and the walls that were close collapsed towards each other. Explain these observations. What physical modifications could be made on the buildings to minimise such hazards?
9. Redraw the diagram below, showing the new mercury levels when air is

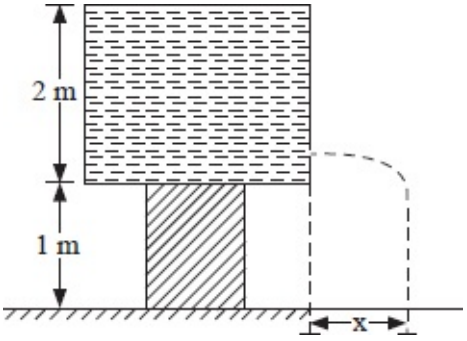
moving very fast through the tube.




10. A venture tube is used to measure the speed v of a fluid in a pipe by comparing the pressure in the wide and narrow sections, as in the diagram below. Fin v if the difference between the mercury level in h = 25 mm. The density of mercury is 13 600 $kgm^{-3}$

11. Water flows steadily through a horizontal pipe with varying cross-section area. At one point, the pressure is 130 kPa and the velocity is 1.20 m/s. Determine the pressure at a point in the pipe where the speed is 12.0 m/s.

12. A large tank contains water to a depth of 2 m. Water emerges from a small hole on the side of the tank 50 cm above the bottom of the tank as below.

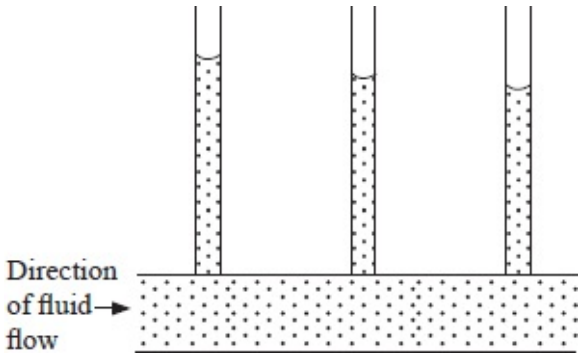



Calculate the:

(a) Speed (v) at which the water emerges from the hole.

(b) Distance marked (x).

13. (a) Explain why the levels of the liquid in the vertical tubes below are not the same.




(c) Using a diagram, explain how a filter pump works.

14. Water flows steadily along a horizontal pipe at a volume rate of $8 \times 10^{-3}$ $m^3$ $s^{-1}$. If the area of cross-section of the pipe is 20 $cm^2$:
    (a) Calculate the velocity of the fluid.
    (b) Find the total pressure in the pipe if the static pressure in the horizontal pipe is $1.0 \times 10^4$ Pa, assuming that water is incompressible, non-viscous and its density is $10^3$ $kgm^{-3}$.
    (c) What is the new flow velocity if the total pressure is $2 \times 10^4$ Pa?
15. Air flows over the upper surfaces of the wings of an aeroplane at a speed of 12.0 $ms^{-1}$. If the lift force on the aeroplane is $2.97 \times 10^4$ N, calculate the speed of the air past the lower surfaces of the wing (take the total wing area to be 20.0 $m^2$ and the density of air as 1.29 $kgm^{-3}$).

This book is the second title in the KLB Secondary Physics series. It comprehensively covers the Form Two syllabus as per the new curriculum.

The edition is rich in detail, has numerous worked-out examples and puts emphasis on a practical approach. This enables the learner to appreciate more the concepts under study.

Each title in the series is accompanied by a Teachers' Guide which, apart from providing the teacher with vital tips on methodology, gives answers to questions in the revision exercises.

**Cover photograph:** *Part of a grain handling plant. The horizontal conveyor (top) loads fresh grain into the system. The white pipes release hot air driven through the damp grain from a furnace underneath, while the smaller silvery tubes are fixed to a set-up which electrically sucks dust. The black conveyor belt is connected to a machinery which ultimately leads dry grain into the storage silos through the white vents.*

***Courtesy:*** *Lesiolo Grain Handlers, Nakuru.*

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