Symbol	Device	Symbol	Device	Symbol	Device
or	Switch		Wires joined	G or`	galvanometer
	Cell		Wires crossed	A	ammeter
	Battery		Fixed resistor	V	Voltmeter
	D .c . power` supply		variable resistor` (rheostat)		Two-way switch
	A.c. power supply		fuse		Earth connector
	Light bulb		Coil of wire		capacitor
	Potentiometer		transformer		thermistor
	light-depemdent resistor (LDR)		Semiconductor diode		bell

Table 2.1 Common symbols in electrical circuits

2.3.2 Different electrical circuits

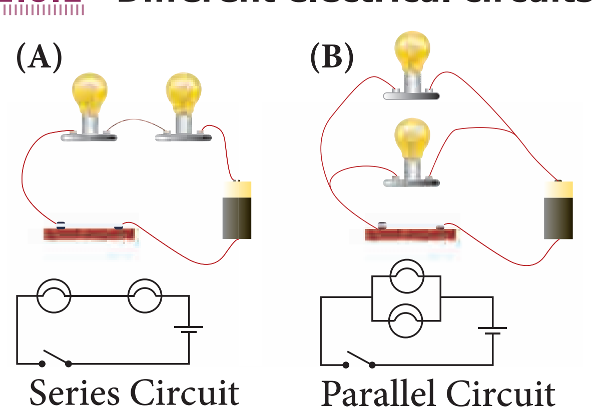


Figure 2.15 Series and parallel connections

Look at the two circuits, shown in Figure 2.15. In Figure A two bulbs are connected in series and in Figure B they are connected in parallel. Let us look at each of these separately.

Series circuits

Let us first look at the current in a series circuit. In a series circuit the components are connected one after another in a single loop. In a series circuit there is only one pathway through which the electric charge flow. From the above we can know that the current I all along the series circuit remain same. That is in a series circuit the current in each point of the circuit is same.

Now, for example, let us consider three resistors of resistances R_1, R_2 and R_3 that are connected in series. When resistors are connected in series, same current is flowing through each resistor as they are in a single loop. If the potential difference applied between the ends of the combination of resistors is V, then the potential differences across each resistor R_1, R_2 and R_3 are V_1, V_2 and V_3 respectively as shown in Figure 2.16.

The net potential difference, $V = V_1 + V_2 + V_3$

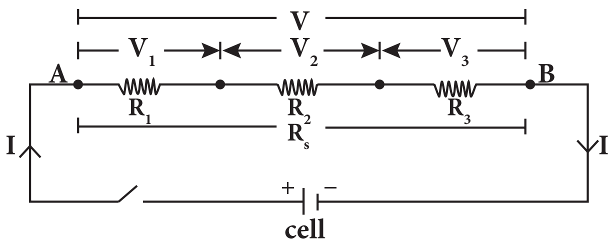


Figure 2.16 Resistors in series

By Ohm's law, $V_1 = IxR_1$; $V_2 = IxR_2$; $V_3 = IxR_3$; and $V = IxR_S$

where R_3 is the equivalent or effective resistance of the series combination.

Hence, $(IxR_s) = (IxR_1) + (IxR_2) + (IxR_3) = Ix(R_1 + R_2 + R_3)$

$$R_S = R_1 + R_2 + R_3$$

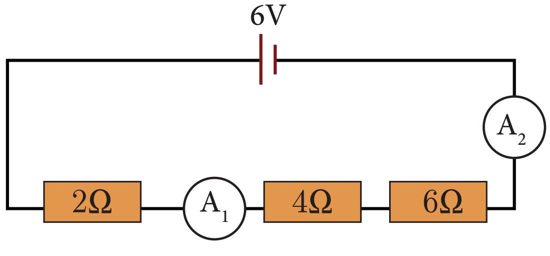
Thus, the equivalent resistance of a number of resistors in series connection is equal to the sum of the resistance of individual resistors.

Suppose, n resistors are connected in series, then the equivalent resistor is,

$$R_S = R_1 + R_2 + R_3 + \ldots\ldots + R_n$$

Exercise 2.7

Look at the series circuit below.



a. What is the effective resistance of the three resistors?

b. What is the current measured by ammeter A_1 and ammeter A_2?

c. What is the potential difference across each resister?

Solution:

a) Effective resistance $R = R_1 + R_2 + R_3$
$= 2 + 4 + 6 = 12\Omega$

b) Since, V= 6 V and effective resistance is 12Ω

$I = V/R = 6V/12\Omega = 0.5A$

As the same current flows through both the resistors, both the ammeters A_1 and A_2 will show the same current of 0.5A.

c) Let V1, V2 and V3 be the potential difference across the 2Ω, 4Ω, 6Ω resisters respectively, then

$V_1 = I \times R_1 = 0.5A \times 2\Omega = 1V$

$V_2 = I \times R_2 = 0.5A \times 4\Omega = 2\ V$

$V_3 = I \times R_3 = 0.5A \times 6\Omega = 3\ V$

Now, we can see that V = V1+V2+V3 = 6 V

Parallel circuits

In parallel circuits, the components are connected to the e.m.f source in two or more loops. In a parallel circuit there is more than one path for the electric charge to flow. In a parallel circuit the sum of the individual current in each of the parallel branches is equal to the main current flowing into or out of the parallel branches. Also, in a parallel circuit the potential difference across separate parallel branches are same.

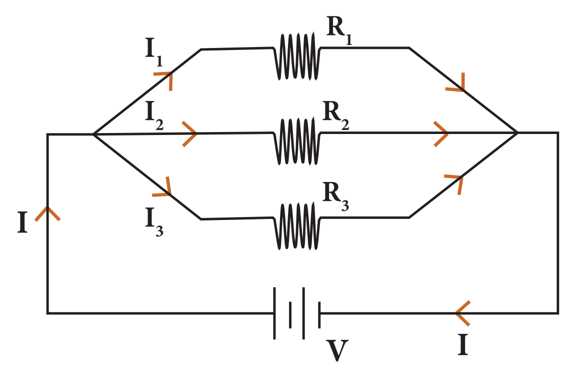


Figure 2.17 Resistors in parallel

Consider three resistors of resistances R_1, R_2 and R_3 connected in parallel. A source of e.m.f with voltage V is connected to the parallel combination of resistors. A current I entering the combination gets divided into I_1, I_2 and I_3 through R_1, R_2 and R_3 respectively as shown in Fig. 2.17.

The total current I is, $I = I_1 + I_2 + I_3$

By Ohm's law, $I_1 = V/R_1$; $I_2 = V/R_2$; $I_3 = V/R_3$; and $I = V/R_P$

where R_P is the equivalent or effective resistance of the parallel combination.

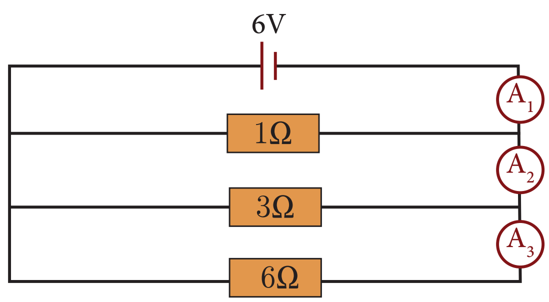
$(V/R_P) = (V/R_1) + (V/R_2) + (V/R_3) = V x(1/R_1 + 1/R_2 + 1/R_2)$

$1/R_P = 1/R_1 + 1/R_2 + 1/R_2$

Thus, the reciprocal of the effective resistance of resisters in parallel ($1/R_P$) is equal to the sum of the reciprocal of all the individual resistance.

Exercise 2.8

Figure shows three resistors of values 1 Ω, 3 Ω, and 6 Ω connected in parallel to a 6 V dry cell.



(a) What is the effective resistance of the three resistors?

(b) What is the p.d. across each resistor?

(c) What is the current measured by ammeters A_1, A_2 and A_3?

Solution:

(a) $1/R_p = 1/R_1 + 1/R_2 + 1/R_3$

$1/R_p = 1/1 + 1/3 + 1/6$

$1/R_p = 9/6$

$\therefore R_p = 0.667\ \Omega$

(b) As the resistors are in parallel, the p.d. across each resistor is equal, ∴ p.d. = 6V

(c) (i) $I = V/R = 6\ V/6\ \Omega = 1\ A$

Current measured by ammeter A_1 is 1 A

(ii) Current through 3 Ω resistor

$= 6\ V/3\ \Omega = 2\ A$

Current measured by ammeter A_2

$= 1\ A + 2\ A = 3\ A$

(iii) Current through the 1 Ω resistor

$= 6\ V/1\ \Omega = 6\ A$

Current measured by ammeter A_3

$= 6\ A + 3\ A = 9\ A$

Alternatively, since V = 6 V and effective resistence R = 0.667 Ω, current measured by ammeter

$A_3 = 6\ V / 0.667\ \Omega = 9\ A$

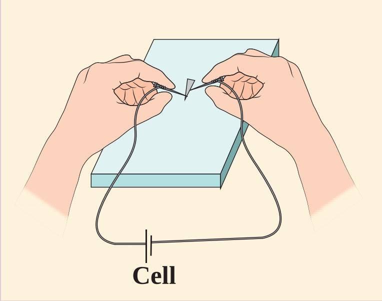
2.4 Effects of electric current

When current flows in a circuit it exhibits various effects. The main effects are heating, chemical and magnetic effects.

2.4.1 Heating effect

Activity 3

Cut an arrow shaped strip from aluminium foil. Ensure that the head is a fine point. Remove any paper backing it may have. Keep the arrow shaped foil on a wooden board. Connect a thin pin to two lengths of wire. Connect the wires to the terminals of electric cell, may be of 9V. Press one pin onto the pointed tip and other pin at a point about one or two mm away. Can you see that the tip of aluminium foil starts melting?



When the flow of current is 'resisted' generally heat is produced. This is because the electrons while moving in the wire or resistor suffer resistance. Work has to be done to overcome the resistance which is converted in to heat energy. **This conversion of electrical energy in to heating energy is called 'Joule heating'** as this effect was extensively studied by the scientist Joule. This forms the principle of all electric heating appliances like iron box, water heater, toaster etc. Even connecting wires offer a small resistance to the flow of current. That is why almost all electrical appliances including the connecting wires feel warm when used in an electric circuit.

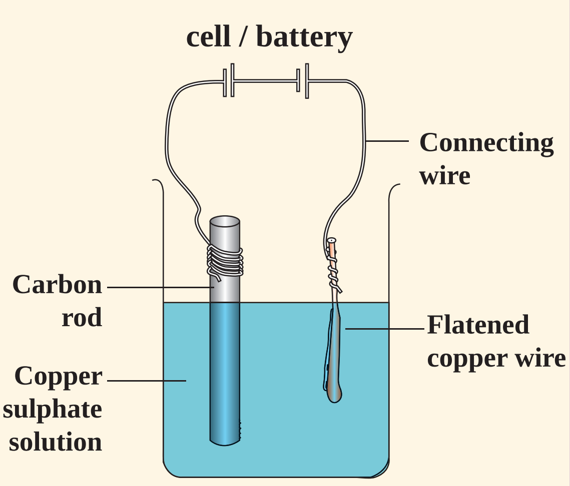
Caution:

The heating effect and the chemical effect experiments have to be performed only with a dc cell of around 9V. The 9V dc cell will not give any electrical shock.

Students at any cost **should not use** the main domestic electric supply which is a 220V ac voltage. If it is used it will give a heavy electric shock leading to a severe damage to our body.

2.4.2 Chemical effect

Activity 4



Take a beaker half filled with copper sulphate solution. Take a carbon rod from a used dry cell. Wind a wire on its upper end. Take a thick copper wire, clean it well and flatten it with a hammer. Immerse both the copper wire and carbon rod in the copper sulphate solution. Connect the carbon rod to the negative terminal of an electric cell and copper wire to the positive terminal of the cell. Also ensure that the copper and the carbon rod do not touch each other, but are close enough. Wait and watch. After some time you would find fine copper deposited over the carbon rod. This is called as electroplating. This is due to the chemical effect of current.

So far we have come across the cases in which only the electrons can conduct electricity. But, here when current passes through electrolyte like copper sulphate solution, both the electron and the positive copper ion conduct electricity. **The process of conduction of electric current through solutions is called 'electrolysis'. The solution through which the electricity passes is called 'electrolyte'.** The positive terminal inserted in to the solution is called 'anode' and the negative terminal 'cathode'. In the above experiment, copper wire is anode and carbon rod is cathode.

DO YOU KNOW?

Extremely weak electric current is produced in the human body by the movement of charged particles. These are called synaptic signals. These signals are produced by electro-chemical process. They travel between brain and the organs through nervous system.

2.4.3 Magnetic effect of electricity

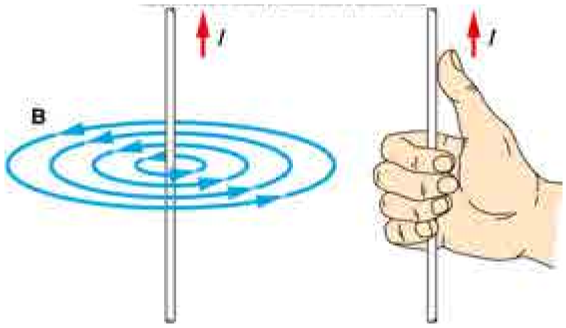


Figure 2.18 Direction of current and magnetic field

A wire or a conductor carrying current develops a magnetic field perpendicular to the direction of the flow of current. This is called magnetic effect of current. The discovery of the scientist Oersted and the 'right hand thumb rule' are detailed in the chapter on Magnetism and Electromagnetism in this book.

Direction of current is shown by the right hand thumb and the direction of magnetic field is shown by other fingers of the same right hand (Fig. 2.18).

2.5 Types of current

There are two distinct types of electric currents that we encounter in our everyday life: direct current (dc) and alternating current (ac).

2.5.1 Direct current

We know current in electrical circuits is due to the motion of positive charge from higher potential to lower potential or electron from lower to higher electrical potential. Electrons move from negative terminal of the battery to positive of the battery. Battery is used to maintain a potential difference between the two ends of the wire. Battery is one of the sources for dc current. The dc is due to the unidirectional flow of electric charges. Some other sources of dc are solar cells, thermocouples etc. The graph depicting the direct current is shown in Fig. 2.19.

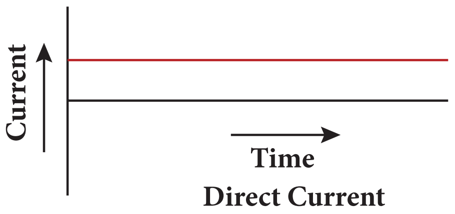


Figure 2.19 Wave form of dc

Many electronic circuits use dc. Some examples of devices which work on dc are cell phones, radio, electric keyboard, electric vehicles etc.

2.5.2 Alternating current

If the direction of the current in a resistor or in any other element changes its direction alternately, the current is called an alternating current. The alternating current varies sinusoidally with time. This variation is characterised by a term called as frequency. **Frequency is the number of complete cycle of variation, gone through by the ac in one second.** In ac, the electrons do not flow in one direction because the potential of the terminals vary between high and low alternately. Thus, the electrons move to and fro in the wire carrying alternating current. It is diagrammatically represented in Fig. 2.20.

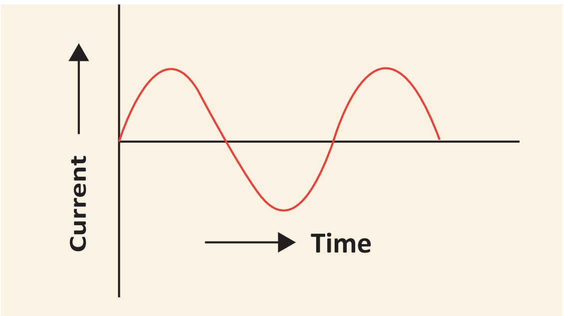


Figure 2.20 Wave form of ac

Domestic supply is in the form of ac. When we want to use an electrical device in dc, then we have to use a device to convert ac to dc. **The device used to convert ac to dc is called rectifier.** Colloquially it is called with several names like battery eliminator, dc adaptor and so on. The device used to convert dc in to ac is called inverter. The symbols used in ac and dc circuits are shown in Fig. 2.21.

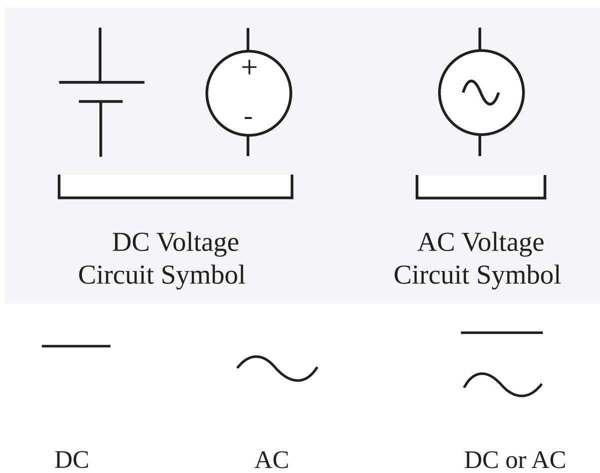


Figure 2.21 The symbol used in ac and dc circuit diagrams

> **DO YOU KNOW?**
> Joule's heating effect of current is common to both direct and alternating current.

2.5.3 Advantages of ac over dc

The voltage of ac can be varied easily using a device called transformer. The ac can be carried over long distances using step up transformers. The loss of energy while distributing current in the form of ac is negligible. Direct current cannot be transmitted as such. The ac can be easily converted into dc. Generating ac is easier than dc. The ac can produce electromagnetic induction which is useful in several ways.

2.5.4 Advantage of dc over ac

Electroplating, Electro refining, electrotyping can be done only using dc. Electricity can be stored only in the form of dc.

> **DO YOU KNOW?**
> In India, the voltage and frequency of ac used for domestic purpose is 220V and 50Hz respectively where as in United States of America it is 110V and 60 Hz respectively.

2.6 Safe handling of electrical energy

Electricity is to be handled with much precaution because the passage of electricity causes heavy damage to human body. As electric current produces heat, several safety aspects are to be strictly adhered while handling electric current.

2.6.1 Dangers of electricity and precautions to be taken

The following are the possible dangers as for as electric current is concerned.

i. Damaged insulation – Do not touch the bare wire, use safety glows and stand on insulating stool or rubber slippers while handling electricity.

ii. Overheating of cables – use quality ISI certified cable wires for domestic wiring

iii. Overload of power sockets – Do not connect too many electrical devices to a single electrical socket.

iv. Inappropriate use of electrical appliances – Always use the electrical appliances according to the power rating of the device like ac point, TV point, microwave oven point etc.

v. Environment with moisture and dampness – Keep the place where there is electricity out of moisture and wetness as it will lead to leakage of electric current.

vi. Beyond the reach of children – The electrical sockets are to be kept away from the reach of little children who do not know the dangers of electricity.

2.6.2 Safety features

There are many safety features to be followed while handling electricity. Some of them are given below.

Ground connection

The metal bodies of all the electrical appliances are to be connected to the ground by means of a third wire apart from the two wires used for electrical connection. Normally the ground connection wire will be green in colour while the main wire is in red and the return wire is in black. This ground connection provides an easy path for the current avoiding it from flowing through our body. All the ground wires from various electrical sockets are connected together finally to a thick copper wire that is buried deep in to the ground so that the excess current could directly pass in to the ground without passing in to our body.

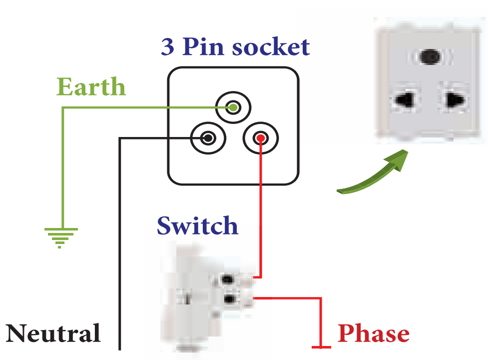


Figure 2.22 Earth and other connections given to a three pin socket

DO YOU KNOW? Resistance of a dry human body is about 1,00,000 ohm. Because of the presence of water in our body the resistance is reduced to few hundred ohm. Thus, a normal human body is a good conductor of electricity. Hence, precautions are required while handling with electricity.

Trip switch

It is an electromechanical device which does not allow a current beyond a particular value by automatically switching off the connection. We have trip switches of various current ratings used for specific purposes. It works on relay principle. A set of the trip switches used in electrical connections is shown in Figure 2.23.

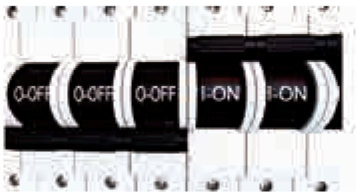


Figure 2.23 Set of trip switches

Fuse

A fuse is another safety mechanism which works on joule heating principle. Fuse is a wire made up of a Nickel and Chromium alloy which has a definite melting point. If current passes through the fuse beyond a particular desired value, the excess heat produced melts the fuse wire, thus the electrical connection is cut-off. Fuse has to be kept in tight a ceramic enclosure to avoid the melting heat from producing fire accidents.

Figure 2.24 Fuse with ceramic carrier

Points to remember

- Electric charge is a fundamental property of all matter.
- The unit of electric charge is coulomb with a symbol C.
- The charge of an electron is negative of 1.6×10-19 C (represented as e). This is the fundamental unit of charge.
- Like charges repel and unlike charges attract.
- Electric field (E) is represented by lines and arrowheads indicating the direction of the electric filed.
- Electric current flows from higher electric potential to lower electric potential.
- The movement of the positive charge is called as 'conventional current'. The flow of electrons is termed as 'electron current'.
- The standard SI unit for current is the ampere with the symbol A.
- The SI unit for both e.m.f and potential difference is the same in volt (V).
- The opposition to the flow of current is called resistance.
- Metals like copper, aluminium etc., have very much negligible resistance. Thus they are good conductors.
- The SI unit of resistance is ohm with the symbol Ω.
- The four main components of any circuit are: cell, connecting wire, switch and resistor.
- In a parallel circuit there is more than one path for the electric charge to flow.
- The main effects when current flows in a circuit are heating, chemical and magnetic effects.
- There are two distinct types of electric currents that we encounter in our everyday life: direct current (dc) and alternating current (ac).
- Dangers of electricity are: damaged insulation, overheating of cables, overload of power sockets, inappropriate use of electrical appliances and environment with moisture and dampness.
- Safety features to be followed are: Ground connection, Trip switch, Fuse

A-Z GLOSSARY

Electric charge	It is the fundamental property of matter.
Electric field	The region around a charge in which another charge experiences electric force.
Electric lines of force	The electric lines of force are straight or curved paths along which a unit positive charge tends to move in the electric field.
Electric potential	It is a measure of the work done on unit positive charge to bring it to that point against all electrical forces.
Electric current	Current is the rate at which charges flow across a conductor in a circuit.
Ammeter	An instrument used for measuring the amount of electric current.

e.m.f	It is the work done by the electrical energy source in driving a unit charge around the complete circuit.
Voltmeter	It is an instrument used to measure the potential difference.
Resistance	The measure of opposition offered by the component to the flow of electric current through it.
Resistors	Components used for providing resistance are called as resistors.
Electrolyte	The solution through which electric current flows.
Anode	The positive terminal in the electrolyte.
Cathode	The negative terminal in the electrolyte.
Alternating current	If the direction of the current in a resistor or in any other element changes its direction alternately, the current is called an alternating current.

TEXT BOOK EXERCISES

I. Choose the correct answer

1. In current electricity, a positive charge refers to,
   a) presence of electron
   b) presence of proton
   c) absence of electron
   d) absence of proton

2. Rubbing of comb with hair
   a) creates electric charge
   b) transfers electric charge
   c) either (a) or (b)
   d) neither (a) nor (b)

3. Electric field lines ________ from positive charge and ________ in negative charge.
   a) start; start   b) start; end
   c) start: end   d) end; end

4. Potential near a charge is the measure of its ________ to bring a positive charge at that point.
   a) force   b) abiility
   c) tendency   d) work

5. In an electrolyte the current is due to the flow of,
   a) electrons
   b) positive ions
   c) both (a) and (b)
   d) neither (a) nor (b)

6. Heating effect of current is called,
   a) Joule heating
   b) Coulomb heating

c) voltage heating

d) Ampere heating

7. The following is not a safety device.

a) fuse b) trip switch

c) ground connection d) wire

8. Electroplating is an example for

a) heating effect b) chemical effect

c) flowing effect d) magnetic effect

9. Resistance of a wire depends on,

a) temperature b) geometry

c) nature of material d) all the above

10. In India the frequency of alternating current is,

a) 220 Hz b) 50 Hz

c) 5 Hz d) 100 Hz

II. Match the following

1. Electric Charge	(a) ohm
2. Potential difference	(b) ampere
3. Electric field	(c) coulomb
4. Resistance	(d) newton per coulomb
5. Electric current	(e) volt

III. True or False

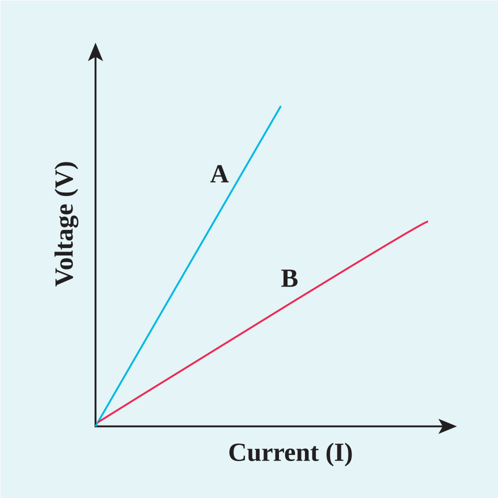
1. Electrically neutral means it is either zero or equal positive and negative charges.
2. Ammeter is connected in parallel in any electric circuit.
3. The anode in electrolyte is negative.
4. Current can produce magnetic field.
5. Electric fuse works on Joule heating principle.

IV. Fill in the blanks

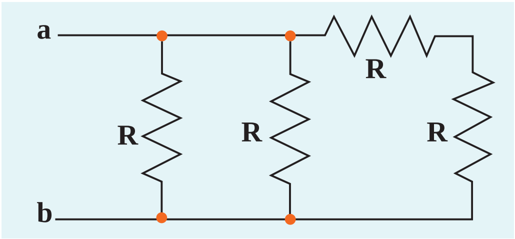
1. Electrons move from ________ potential to ________ potential.
2. The direction opposite to the movement of electron is called ________ current.
3. The e.m.f of a cell is analogues to ________ of a pipe line.
4. The domestic electricity in India is an ac with a frequency of ________ Hz.
5. Trip switch is a ________ safety device.

V. Conceptual questions

1. A bird sitting on a high power electric line is still safe. How?
2. Two resistors 12Ω and 6Ω are first connected in series and then in parallel. The current-voltage graph for the two connections will be represented by which lines in the graph?



3. Does a solar cell always maintain the potential across its terminals constant? Discuss.
4. What is the effective resistance across the terminals a and b of the arrangement of resistors?



5. Can electroplating be possible with alternating current?

VI. Answer the following

1. On what factors does the electrostatic force between two charges depend?
2. What are electric lines of force?
3. Define electric field.
4. Define electric current and give its unit.
5. State Ohm's law.
6. On what factor does the resistance of a wire depend at a particular temperature?
7. Name any two appliances which work under the principle of heating effect of current.
8. Draw a circuit with a 2Ω and 5Ω resistors in series. Connect another 3Ω resistor parallel to the above connection.
9. How are the home appliances connected in general, in series or parallel. Give reasons.
10. List the safety features while handling with electricity.

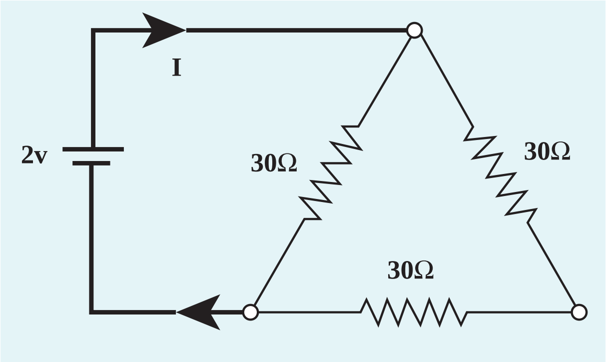
VII. Exercises

1. Rubbing a comb on hair makes the comb get – 0.4C. (a) Find which material has lost electron and which one gained it. (b) Find how many electrons are transferred in this process.
2. Calculate the amount of charge that would flow in 2 hours through an element of an electric bulb drawing a current of 2.5A.
3. The values of current I flowing through a resistor for various potential differences V across the resistor are given below. What is the value of resistor?

I (ampere)	0.5	1.0	2.0	3.0	4.0
V (volt)	1.6	3.4	6.7	10.2	13.2

   [Hint: plot V-I a graph and take slope]

4. Find the value of current in the circuit.



5. A wire of resistance 10 Ω is bent in the form of a circle .Find the effective resistance between the points A and B which lies on the diameter.

REFERENCE BOOKS

Fundamentals of Physics by K.L Gomber and K. L.Gogia

Concepts of Physics by H.C Verma

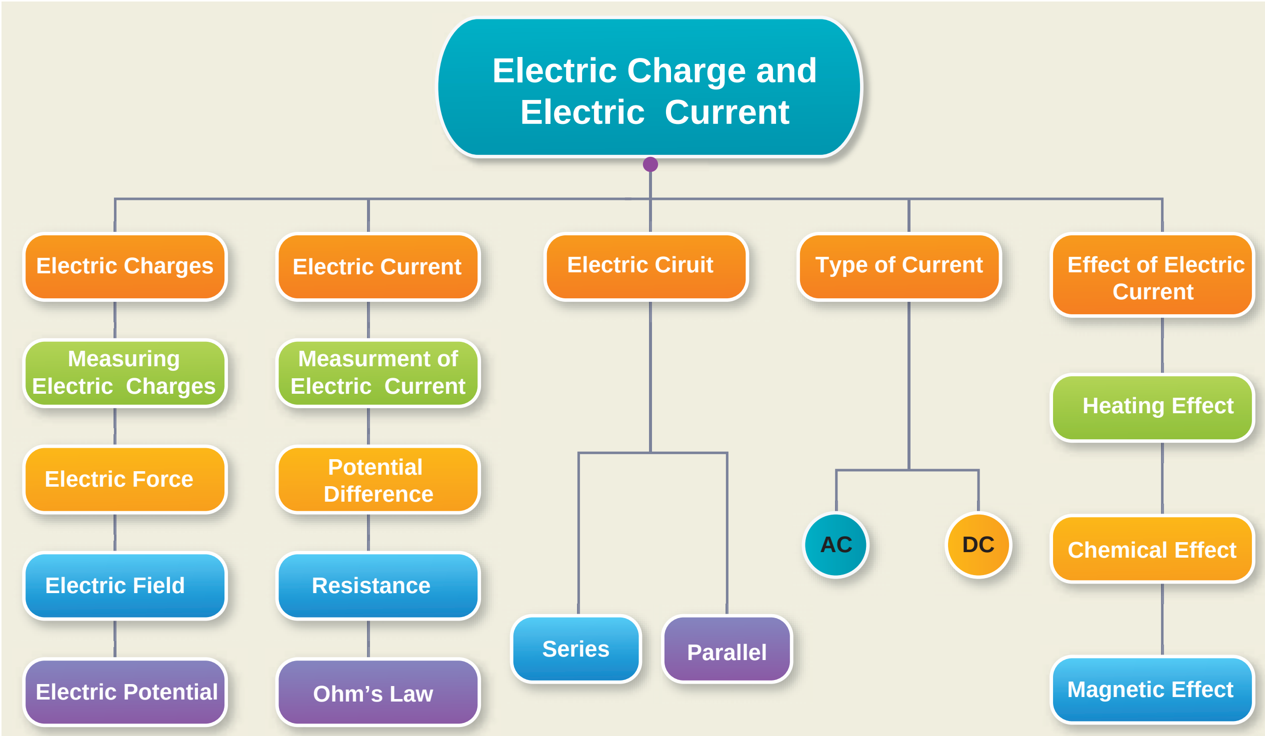
General Physics by W.L. Whiteley

INTERNET RESOURCES

http://www.qrg.northwestern.edu/projects/vss/docs/propulsion/1-what-is-an-ion.html

https://www.explainthatstuff.com/batteries.html

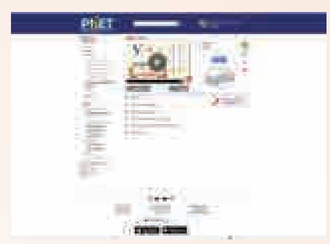
https://www.woodies.ie/tips-n-advice/how-the-fusebox-works-in-the-home-new



ICT CORNER

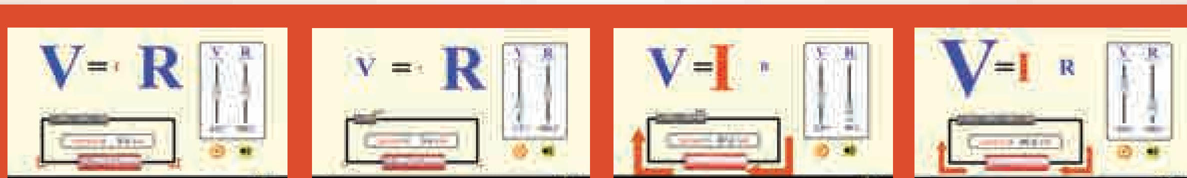
Ohm's Law Verification

This activity enables to learn the relationship between current and potential difference.



Step 1

- Type the URL link given below in the browser OR scan the QR code.
- You can vary the value of **V** and **R** to know the change the **current flowing across the conductor**
- On the right you can do the changes in V and R to learn the variations.



Step1 Step2 Step3 Step4

Browse in the link:

URL: https://phet.colorado.edu/en/simulation/ohms-law

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*Pictures are indicative only

UNIT 3

Magnetism and Electromagnetism

BH6RTD

Learning Objectives

After studying this chapter, students will be able to

- understand the concept of magnetic field
- know the properties of magnetic field lines
- calculate the force exerted on a current carrying conductor in a magnetic field
- understand the force between two parallel current carrying conductors
- know the concept of electromagnetic induction and apply it in the case of generators.
- appreciate how voltage can be increased or decreased using transformers
- understand the applications of electromagnet and apply the knowledge in constructing devices using electromagnets

Introduction

Have you ever played with magnets? Do you wonder why it attracts iron? Magnets are always very attractive objects for the humans. In fact famous scientist Einstein mentioned that he was always attracted by magnets in his childhood. In the olden days magnets were used in the ships. Captains of the ships effectively used the magnets to identify the direction of the ship in the sea.

There are two kinds of magnets that we can see around us: Natural magnet and Artificial magnet. Natural magnets exist in the nature. These kind of magnets can be found in rocks and sandy deposits in various parts of the world. The strangest natural magnet is lodestone magnetite (Fig. 3.1)

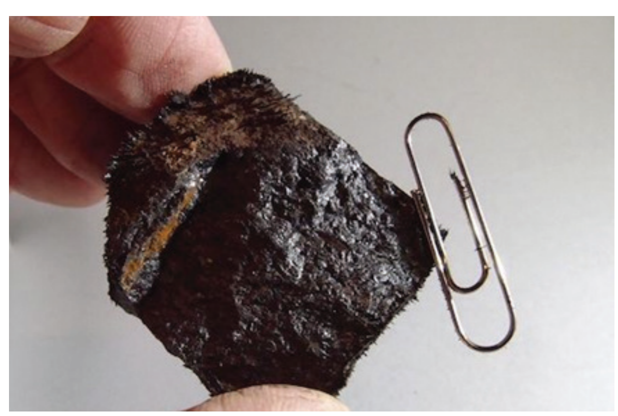


Figure 3.1 Natural magnets

The magnetic property in the natural magnets is permanent. It never gets destroyed. The lodestone are used to make compasses in the olden days. Artificial magnets are made by us. The magnets available in the shops are basically artificial magnets (Fig. 3.2) In this lesson we shall study about magnetic properties and how it is effectively used in day to day life.

Figure 3.2 Artificial magnets

3.1 Magnetic field (B)

Activity 1

Put a magnet on a table and place some paper clips nearby. If you push the magnet slowly towards the paper clips, there will be a point at which the paper clips jump across and stick to the magnet. What do you understand from this?

The interesting question is how the magnet attracts the paper clip? From the above activity we notice that magnets have an invisible field all around them which attracts magnetic materials. In this space we can feel the force of attraction or repulsion due to the magnet. Thus, magnetic field is the region around the magnet where its magnetic influence can be felt. It is denoted by B and its unit is Tesla.

DO YOU KNOW?

The broad spectrum of magnetic-field strengths is very interesting to know:

Human Brain's magnetic field
= 1 pT = 1 pico tesla

Magnetic field in a galaxy
= 0.5 nT = 0.5 nano tesla

Magnetic field due to microwave oven (at 1 foot distance)
= 8 μT = 8 micro tesla

Earth's magnetic field at Chennai (13^{o} latitude) = 42 μT = 42 micro tesla

Magnetic field of MRI scanner = 2 T

The direction of the magnetic field around a magnet can be found by placing a small compass in the magnetic field as shown in the Fig 3.3

Figure 3.3 Compass showing direction of magnetic field

Magnetic field can penetrate through all kinds of materials, not just air. The Earth produces its own magnetic field, which shields the earth's ozone layer from the solar wind and is important in navigation using a compass.

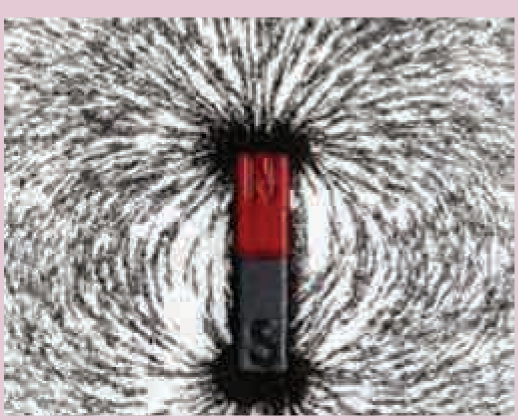
DO YOU KNOW?

Some sea turtles (loggerhead sea turtle) return to their birth beach many decades after they were born, to nest and lay eggs. In a research, it is suggested that the turtles learnt their home beach's location through what is called "geomagnetic imprinting". The turtles, it seems, can perceive variations in magnetic parameters of Earth such as magnetic field intensity and remember them. This memory is what helps them in returning to their homeland.

3.2 Magnetic Field Lines

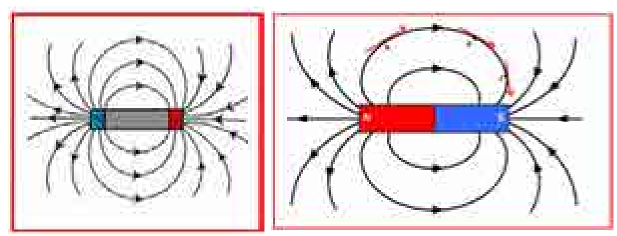
Activity 2

Place a magnet over a cardboard. Sprinkle some iron-filings on the cardboard. Tap the card board gently. We observe that the iron filings align themselves in definite pattern. These patterns are called magnetic lines of force.



Activity 2 shows that magnets have some curved lines around them and these lines are called magnetic field lines. This can also be inferred by placing a test magnet in the magnetic field of another magnet. Through the direction the test magnet moves, magnetic field lines can be identified. The magnetic field lines start at north pole and ends at south pole as shown in the Figure 3.4(a)

A magnetic field line is defined as a curve drawn in the magnetic field in such a way that the tangent to the curve at any point gives the direction of the magnetic field as shown in the Figure 3.4 (b). In the Figure 3.4 (b), the arrow mark indicates the direction of magnetic field at points A, B and C. Note carefully that the magnetic field at a point is tangential to the magnetic field lines.



a b

Figure 3.4 Magnetic field lines

We all know that earth also behaves like a magnet and the magnetic field lines of earth's is shown in the figure 3.5

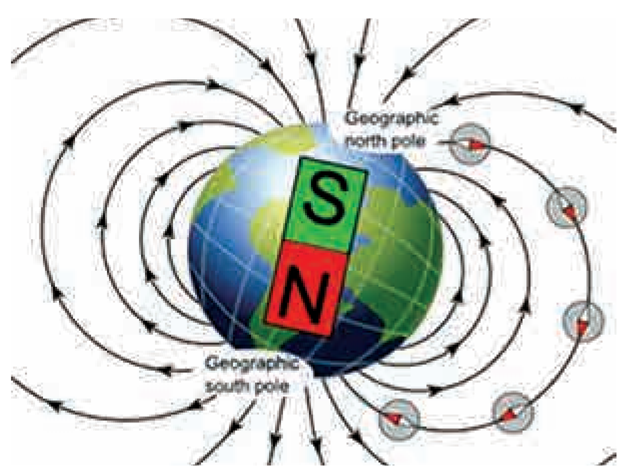


Figure 3.5 Earth's magnetic field lines

3.2.1 Magnetic flux

Magnetic flux is the number of magnetic field lines passing through a given area as shown in the figure 3.6. It is denoted by ϕ and its unit is weber (Wb).

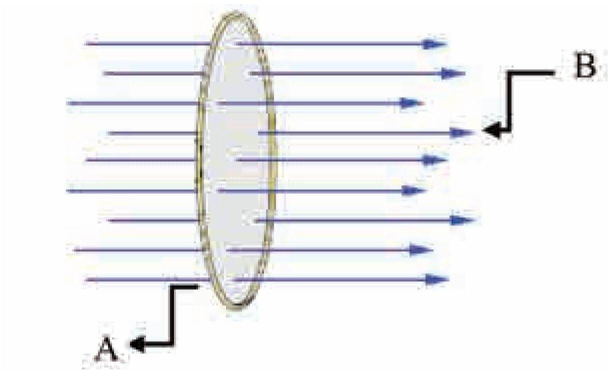


Figure 3.6 Magnetic flux

The number of magnetic field lines crossing unit area kept normal to the direction of field lines is called magnetic flux density. It is shown in the figure 3.7. Its unit is Wb/m2

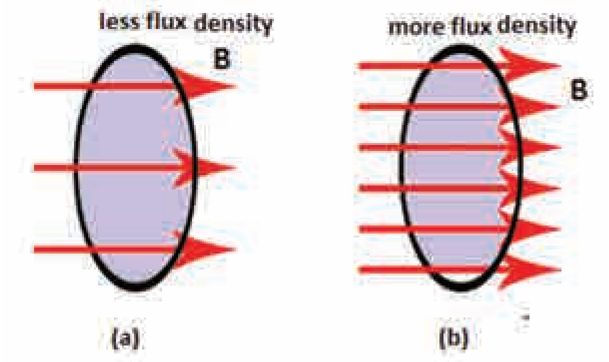


Figure 3.7 Magnetic flux density

3.2.2 Properties of magnetic lines of force

- Magnetic lines of force are closed continuous curves, extending through the body of the magnet.
- Magnetic lines of force start from the North Pole and end at the South Pole.
- Magnetic lines of force never intersect.
- They will be maximum at the poles than at the equator.
- The tangent drawn at any point on the curved line gives the direction of magnetic field.

More to Know

Magnetic Shielding

The computer hard disk stores information using magnetism. Therefore if the hard disk comes near a powerful magnet the data may get corrupted because of the strong magnetic field. Hence we may have to shield computer hard disk, MRI and other such sensitive equipments from such magnetic effects. Stopping the magnetic field from entering into a region is called magnetic shielding. It is known that soft magnetic materials like iron or nickel-iron alloy have the ability to choke up magnetic lines. Magnetic lines coming out of a magnet prefer to pass within the soft metals rather than through air.

3.2.3 Magnetic field lines between two magnets

What does happen when two magnets are placed near each other? There are four ways we can keep them. They are shown in Fig 3.8

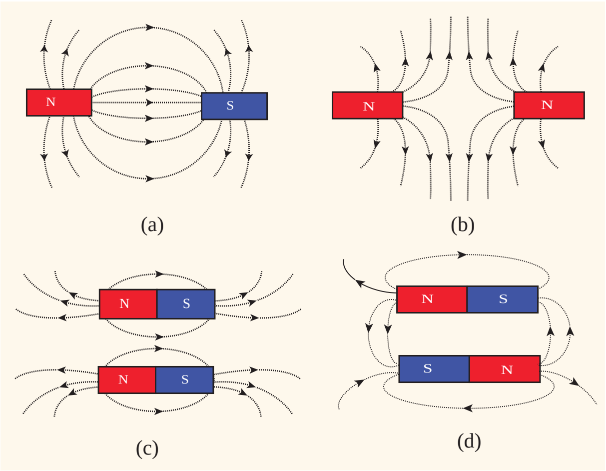


Figure 3.8 Magnets placed together in different directions

(a) two unlike poles facing each other, (b) two like poles facing each other, (c) parallel magnets with same poles facing same side and (d) parallel magnets with opposite poles facing same side. All these positions are.

3.3 Magnetic effect of current

It was on 21st April 1820, Hans Christian Oersted, a Danish Physicist was giving a lecture. He was demonstrating electrical circuits in that class. He had to often switch on and off the circuit during the lecture. Accidentally, he noticed the needle of the magnetic compass that was on the table. It deflected whenever he switched on and the current was flowing through the wire. The compass needle moved only slightly, so that the audience didn't even notice. But it was clear to Oersted that something significant was happening. Intrigued, he conducted experiments to find out a startling effect, the magnetic effect of current.

Oersted aligned a wire XY such that they were exactly along the North-South direction. He kept one magnetic compass above the wire at A and another under the wire at B. When the circuit was open and no current was flowing through it, the needle of both the compass was pointing to north. Once the circuit was closed and electric current was flowing, the needle at A pointed to east and the needle at B to the west as shown in Figure 3.9. This showed that current carrying conductor produces magnetic field around it.

The direction of the magnetic lines around a current carrying conductor can be easily understood using the right hand thumb rule. Hold the wire with four fingers of your right hand with thumbs-up position. If the direction of the current is towards the thumb then the magnetic lines curl in the same direction as your other four fingers as shown in Figure 3.10. This shows that the magnetic field is always perpendicular to the direction of current.

The strength of the magnetic field at a point due to current carrying wire depends on: (i) the current in the wire, (ii) distance of the point from the wire, (iii) the orientation of the point from the wire and (iv) the magnetic nature of the medium. The magnetic field lines are stronger near the current carrying wire and it diminishes as you go away from it. This is represented by drawing magnetic field lines closer together near the wire and farther away from the wire.

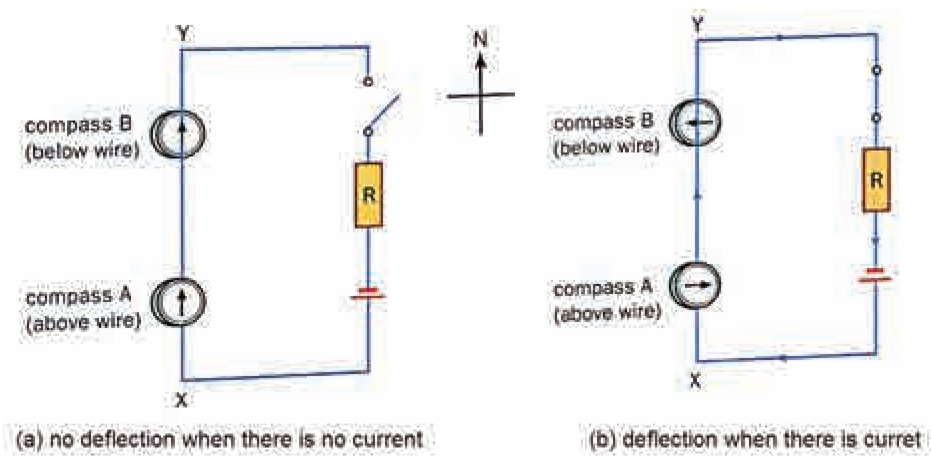


Figure 3.9 Current produces magnetic field

Know Your Scientist

Hans Christian Oersted, (14th August 1777 – 9th March 1851) was a Danish Physicist and Chemist who discovered that electric currents create magnetic fields, which was the first connection found between electricity and magnetism. In 1824, Oersted founded Selskabet for Naturlærens Udbredelse (SNU), a society to disseminate knowledge of the natural sciences.

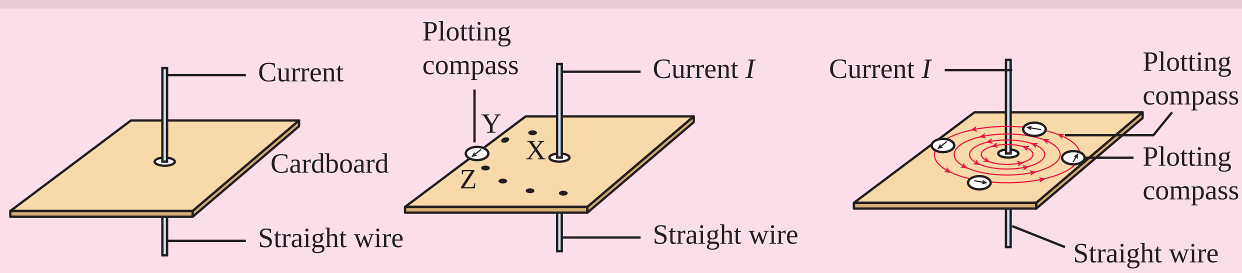
3.4 Force on a current carrying conductor in a magnetic field

H.A.Lorentz found that a charge moving in a magnetic field, in a direction other than the direction of magnetic field, experiences a force. It is called the magnetic Lorentz force. Since charge in motion constitutes a current, a conductor carrying moving charges, placed in magnetic field other than the direction of magnetic field, will also experience a force and can produce motion in the conductor.

In activity 3, we saw that a current carrying wire has a magnetic field perpendicular to the

Activity 3

Take a cardboard and thread a wire perpendicular through it. Connect the wire such that current flows up the wire. Switch on the circuit. Let the current flow. Place a magnetic compass on the cardboard. Mark S and N point of the compass as X and Y respectively on the cardboard. Move the compass such that S end touches Y. Now mark the N end as Z. In the next step move the compass such that S end touch Z. Repeat the steps. Now if you join all the points you will find that it is a circle. Start again, but now keep the compass away from the center or towards the center. If you follow the above steps, you can see that you can draw another magnetic line and the magnetic lines are concentric circles. Also you will find the magnetic lines are anti-clockwise.



Reverse the direction of the current, you will find the magnetic circles are clockwise. Note: The flow of current here means conventional current and not the direction of the flow of electrons.

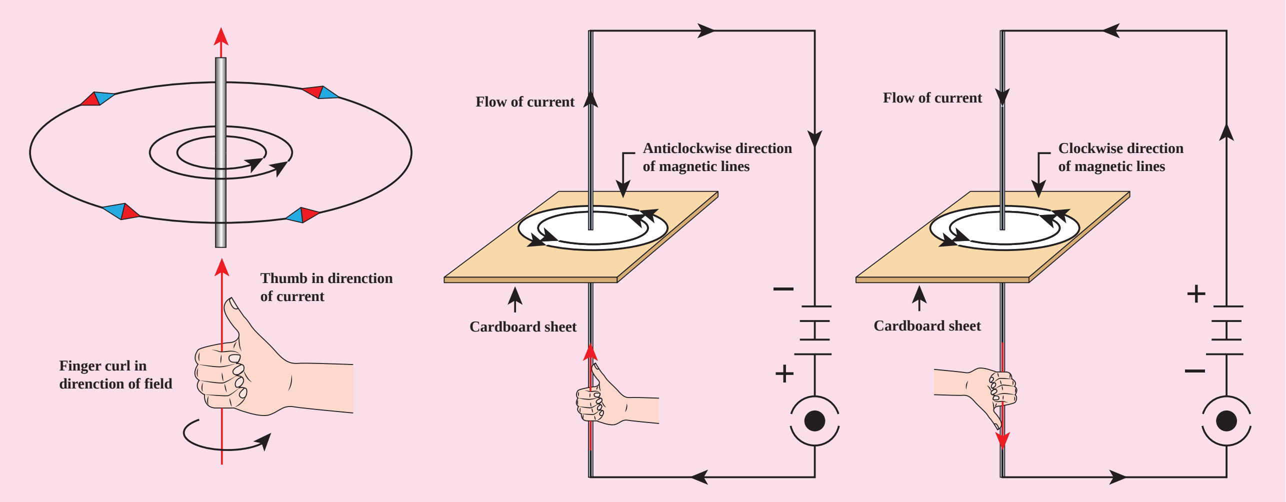


Figure 3.10 Right hand thumb rule

wire, by looking at the deflection of the compass needle in the vicinity of a current carrying conductor. The deflection of the needle implies that the current carrying conductor exerts a force on the compass needle. In 1821, Michael Faraday discovered that a current carrying conductor also gets deflected when it is placed in a magnetic field. In Figure 3.11, we can see that the magnetic field of the permanent magnet and the magnetic field produced by the current carrying conductor interact and produce a force on the conductor. The view perpendicular to the direction of current is shown in Figure 3.12.

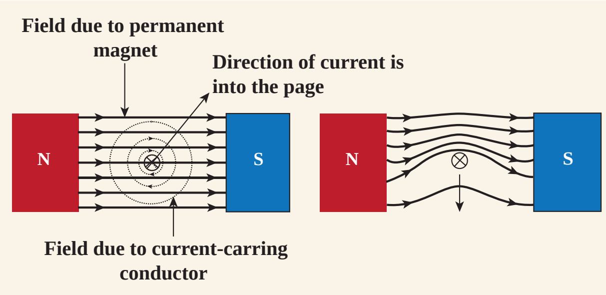


Figure 3.12 Force on current carrying conductor kept in magnetic field

If a current I is flowing through a conductor of length L kept perpendicular to the magnetic field B, then the force F experienced by it is given by the equation,

Activity 4

Stand near the TV screen (The old CRT type TV). Do you feel any sensation on your skin? Take a bar magnet and bring it near the TV Screen. What do you observe? You can observe that the picture on the screen is distorted. Move the bar magnet away from the screen. Now you will get a clear picture. Repeat this to confirm that the motion of electrons is affected by the field produced by the bar magnet. This must be due to the fact that the magnetic field exerts force on the moving charges. This force is called magnetic force.

$$F = I\,L\,B$$

The above equation indicates that the force is proportional to current through the conductor, length of the conductor and the magnetic field in which the current carrying conductor is kept.

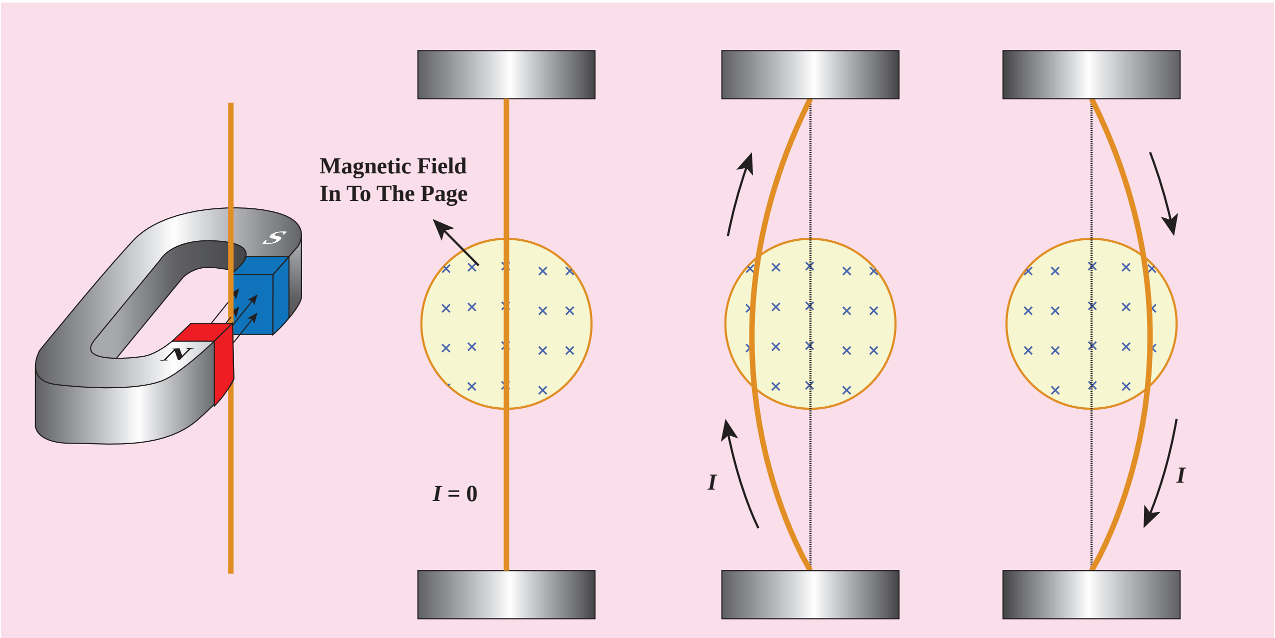


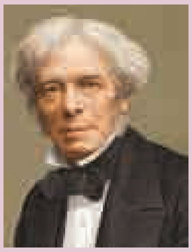
Figure 3.11 Deflection of current carrying wire in magnetic field

Note : The angle of inclination between the current and magnetic field also affects the magnetic force. When the conductor is perpendicular to the magnetic field, the force will be the maximum (=BIL). When it is parallel to the magnetic field, the force will be zero.

The force is always a vector quantity. A vector quantity has both magnitude and direction. It means we should know the direction in which the force would act. The direction is often found using what is known as Fleming's Left hand Rule (formulated by the scientist John Ambrose Fleming).

The law states that while stretching the three fingers of left hand in perpendicular manner with each other, if the direction of the current is denoted by middle finger of the left hand and the second finger is for direction of the magnetic field then the thumb of the left hand denotes the direction of the force or movement of the conductor (Fig. 3.13)

Know Your Scientist



Michael Faraday (22 September 1791 – 25 August 1867) was a British Scientist who contributed to the study of electromagnetism and electrochemistry. His main discoveries include the principles underlying electromagnetic induction, diamagnetism and electrolysis.

Although Faraday received little formal education, he was one of the most influential scientists in history. Faraday was an excellent experimentalist who conveyed his ideas in clear and simple language. The SI unit of capacitance is named in his honour: the farad. Albert Einstein kept a picture of Faraday on his study wall, alongside pictures of Isaac Newton and James Clerk Maxwell. Faraday is one of the greatest scientific discoverers of all time.

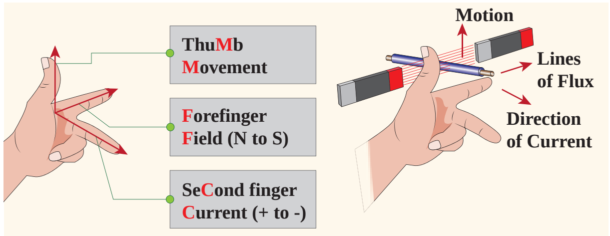


Figure 3.13 Fleming's left hand rule

Exercise 1

A conductor of length 50 cm carrying a current of 5 A is placed perpendicular to a magnetic field of induction 2×10^{-3} T. Find the force on the conductor.

Solution:

Force on the conductor = ILB

$$= 5\times50\times10^{-2}\times2\times10^{-3}$$

$$= 5\times10^{-3}\ \text{N}$$

Exercise 2

A current carrying conductor of certain length, kept perpendicular to the magnetic field experiences a force F. What will be the force if the current is increased four times, length is halved and magnetic field is tripled?

Solution:

Let the current be I, length be L, and magnetic field be B. Therefore, F = I L B.

When current is increased four times, length is halved and magnetic field tripled then, force, $F_1 = (4I) \times (L/2) \times (3B)$

$F_1 = 6F$

Therefore, the force increases six times.

3.5 Force on parallel current carrying conductors

We have seen that a current carrying conductor has a magnetic field around it. If we place another conductor carrying current parallel to the first one, the second conductor will experience a force due to the magnetic field of the first conductor. Similarly, the first conductor will experience a force due to the magnetic field of the second conductor. These two forces will be equal in magnitude and opposite in direction. This is shown in Fig. 3.14.

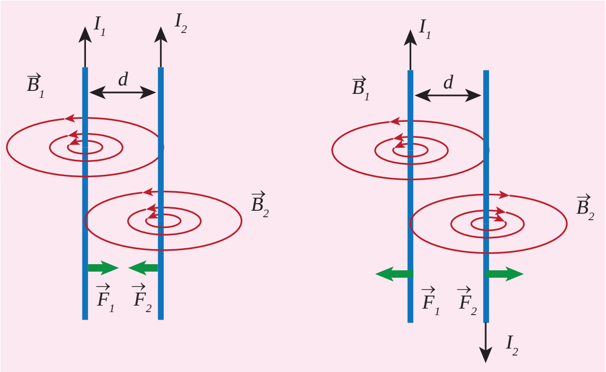


Figure 3.14 Attractive and repulsive force on current carrying wires

Using Fleming's left hand rule we can find that the direction of the force on each wire would be towards each other when the current in both of them are flowing in the same direction. That is the wires would experience an attractive force. However, if the direction of the flow of current is in opposite direction, then the force on each of the wire will also be in opposite direction. These are shown in Figure 3.14. The perpendicular view of the same is shown in Figure 3.15.

Connection between Electricity and magnetism:

Before 18th century people thought that magnetism and electricity were separate subjects of study. After Oersted experiment the electricity and magnetism were united and became a single subject called "Electromagnetism".

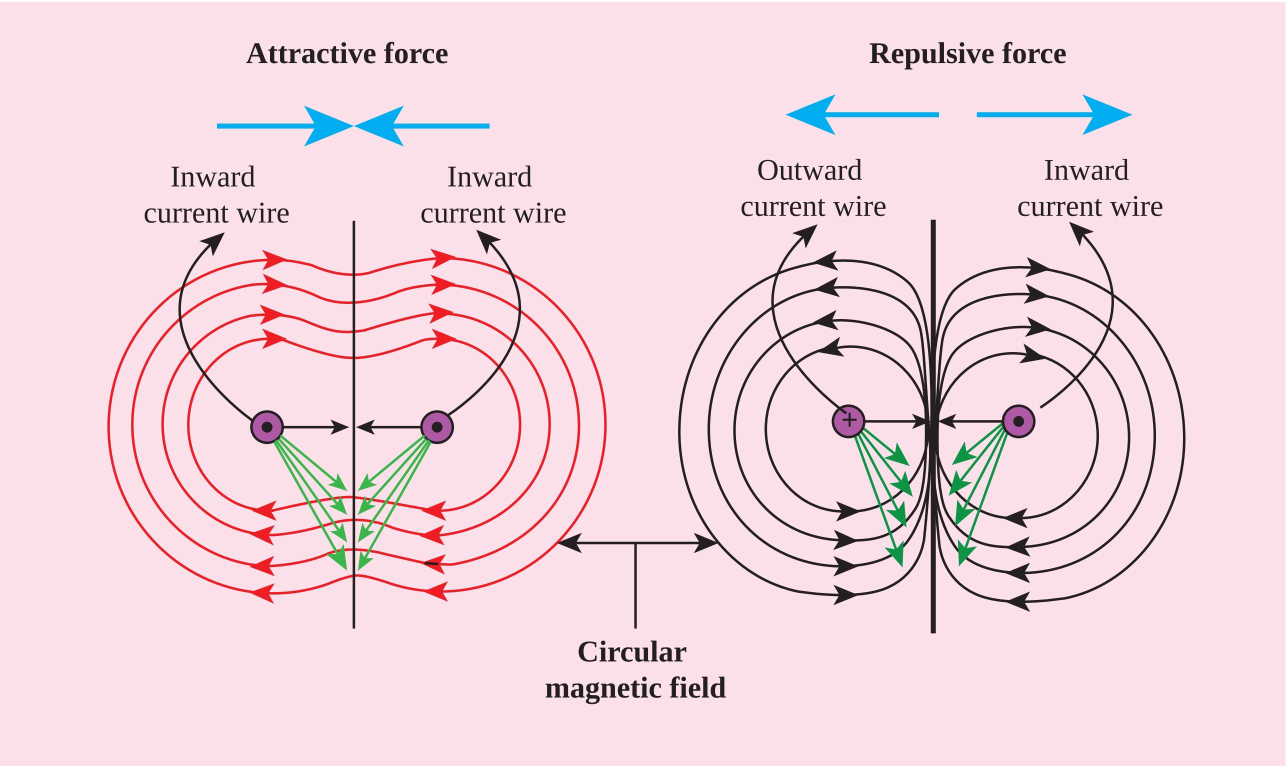


Figure 3.15 Force on current carrying conductors when viewed perpendicular to the direction of current

When there is current, the magnetic field is produced and the current carrying conductor behaves like a magnet. You may now wonder how was it possible for a lodestone to behave like a magnet when there was no current passing through it. In the twentieth century only we understood that the magnetic property arises due to the motion of electrons in the lodestone. In the circuit the electrons flow from negative of the battery to positive of the battery and constitutes current. As a result it produces magnetic field. In natural magnets and artificial magnets we buy in shops, the electrons move around the nucleus constitutes current which leads to magnetic property. Here, every orbiting electron in its orbit is like a current carrying loop. Even though in all materials the electron orbits around the nucleus, only for certain special type of material called magnetic material the motion of electrons around the nucleus gets added up and as a result we have permanent magnetic field.

3.6 Electric motor

BMFMV1

An electric motor is a device which converts electrical energy into mechanical energy. Electric motors are crucial in modern life. They are used in water pump, fan, washing machine, juicer, mixer, grinder etc. We have already seen that when electric current is passed through a conductor placed normally in a magnetic field, a force is acting on the conductor and this force makes the conductor to move. This is harnessed to construct an electric motor.

To understand how a motor works, we need to understand how a current carrying coil experiences a turning effect when placed inside a permanent magnetic field and it is shown in Figure 3.16.

In Fig. 3.16, a simple coil is placed inside two poles of a magnet. Now look at the current carrying conductor segment AB. The direction of the current is towards B, whereas in the conductor segment CD the direction is opposite. As the current is flowing in opposite directions in the segments AB and CD, the direction of the motion of the segments would be in opposite directions according to Fleming's left hand rule. When two ends of the coil experience force in opposite direction, they rotate.

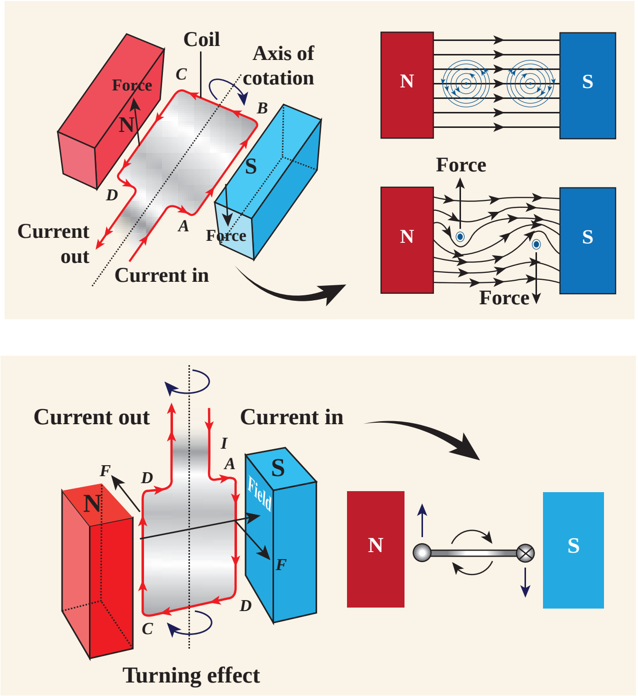


Figure 3.16 Turning effect in a coil

If the current flow is along the line ABCD, then the coil will rotate in clockwise direction first and then in anticlockwise direction. If we want to make the coil rotate in any one

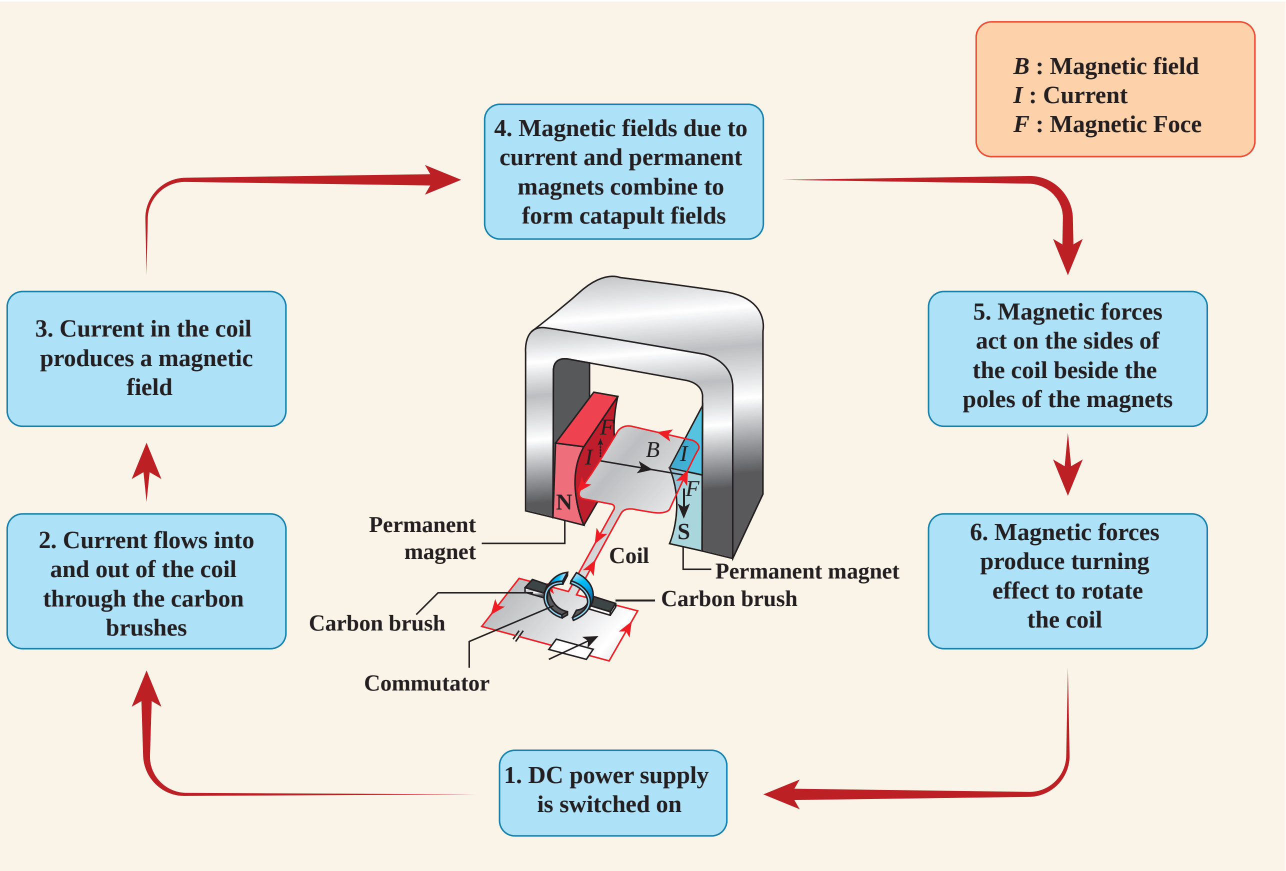


Figure 3.17 Principle of electric motor

direction, say clockwise, then the direction of the current should be along ABCD in the first half of the rotation and along DCBA in the second half of the rotation. To change the direction of the current, a small device called split ring commutator is used (Fig. 3.18).

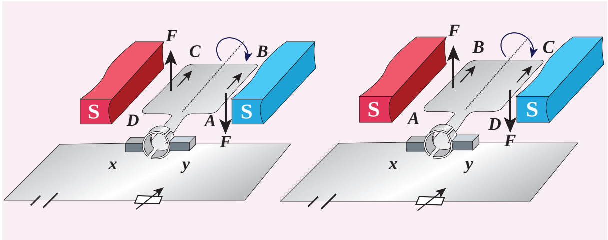


Figure 3.18 Split ring as commutator to produce rotation in same direction.

When the gap in the split ring commutator is aligned with terminals X and Y there is no flow of current in the coil. But, as the coil is moving, it continues to move forward bringing one of the split ring commutator in contact with the carbon brushes X and Y. The reversing of the current is repeated at each half rotation, giving rise to a continuous rotation of the coil.

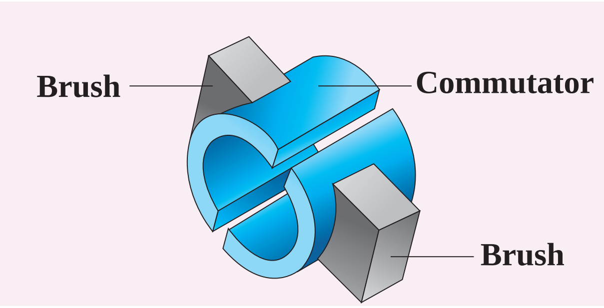


Figure 3.19 Close view of split ring and carbon brushes

The speed of rotation of coil can be increased by:

i. increasing the strength of current in the coil.
ii. increasing the number of turns in the coil.
iii. increasing the area of the coil and
iv. increasing the strength of the magnetic field.

3.7 Electromagnetic Induction

When it was shown by Oersted that magnetic field is produced around a conductor carrying current, the reverse effect was also attempted. In 1831, Michael Faraday explained the possibility of producing an e.m.f across the conductor when the magnetic flux linked with the conductor is changed. In order to demonstrate this Faraday conducted the following experiments.

3.7.1 Faraday's experiments

Experiment 1

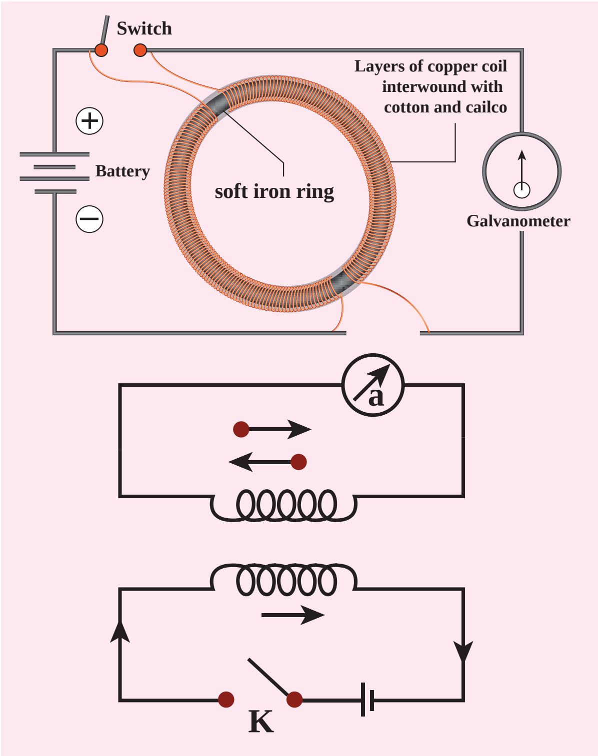


Figure 3.20 Faraday's experiment

In this experiment, two coils were wound on a soft iron ring (separated from each other). The coil on the left is connected to a battery and a switch K. A galvanometer is attached to the coil on the right. When the switch is put 'on', at that instant, there is a deflection in the galvanometer. Likewise, when the switch is put 'off', again there is a deflection – but in the opposite direction. This proves the generation of current.

Experiment 2

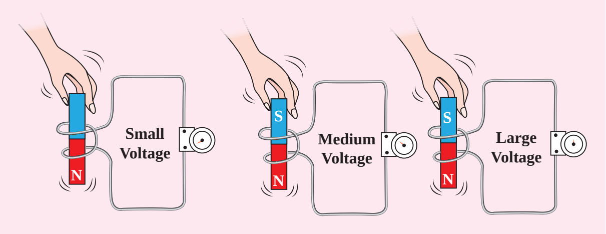


Figure 3.21 Electromagnetic induction by moving the magnet

In this experiment, current (or voltage) is generated by the movement of the magnet in and out of the coil. The greater the number of turns, the higher is the voltage generated.

Experiment 3

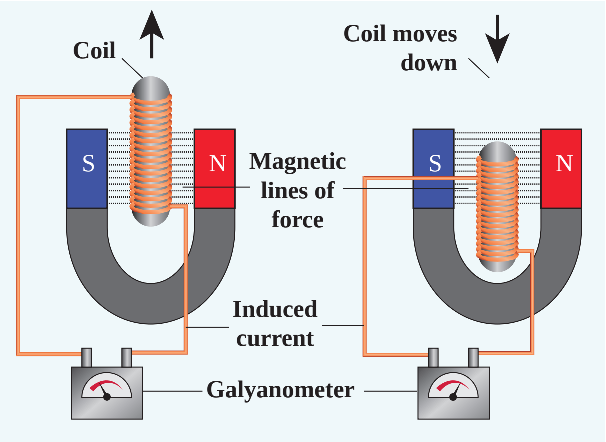


Figure 3.22 Electromagnetic induction by moving the coil

In this experiment, the magnet is stationary, but the coil is moved in and out of the magnetic field (indicated by the magnetic lines of force). Here also, current is induced.

All these observations made Faraday to conclude that whenever there is a change in the magnetic flux linked with a closed circuit an emf is produced and the amount of emf induced varies directly as the rate at which the flux changes. This emf is known as induced emf and the phenomenon of producing an induced emf due to change in the magnetic flux linked with a closed circuit is known as electromagnetic induction.

Note:

The direction of the induced current was given by Lenz's law, which states that the induced current in the coil flows in such a direction as to oppose the change that causes it. The direction of induced current can also be given by another rule called Fleming's Right Hand Rule.

Activity 5

Create your own electromagnet

You are given with a long iron nail, insulation coated copper wire and a battery. Can you make your own electromagnet?

3.7.2 Fleming's Right Hand Rule

Fleming formulated Right Hand Rule to find the direction of flow of current when a conductor is placed in a changing magnetic field as he formulated Left Hand Rule to find the direction of the force in a current carrying conductor placed in a magnetic field.

Stretch the thumb, fore finger and middle finger of your right hand mutually perpendicular to each other. If the fore finger indicates the direction of magnetic field and the thumb indicates the direction of motion of the conductor, then the middle finger will indicate the direction of induced current. Fleming's Right hand rule is also called "generator rule".

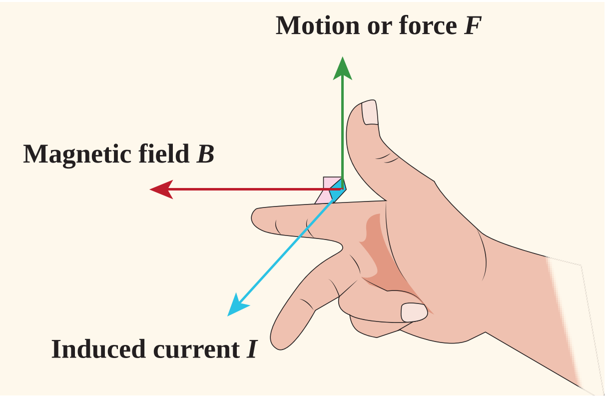


Figure 3.23 Fleming's right hand rule

3.8 Electric generator

An alternating current (AC) generator, as shown in Figure 3.24, consists of a rotating rectangular coil ABCD called armature placed between the two poles of a permanent magnet. The two ends of this coil are connected to the two slip rings S_1 and S_2. The inner sides of these rings are insulated. Two conducting stationary brushes B_1 and B_2 are kept separately on the rings S_1 and S_2 respectively. The two rings S_1 and S_2 are internally attached to an axle. The axle may be mechanically rotated from outside to rotate the coil inside the magnetic field. Outer ends of the two brushes are connected to the external circuit.

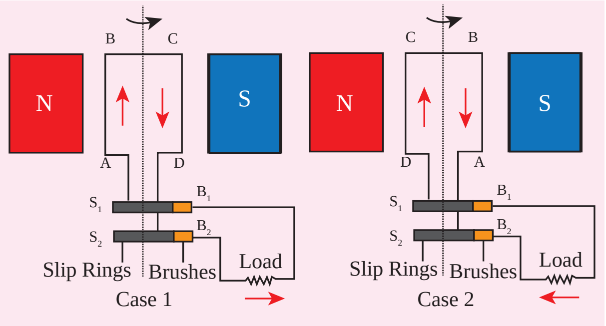


Figure 3.24 AC generator

When the coil is rotated, the magnetic flux linked with the coil changes. This change in magnetic flux will lead to generation of induced current. The direction of the induced current, as given by Fleming's Right Hand Rule, is along ABCD in the coil and in the outer circuit it flows from B_2 to B_1. During the second half of rotation, the direction of current is along DCBA in the coil and in the outer circuit it flows from B1 to B2. As the rotation of the coil continues, the induced current in the external circuit is changing its direction for every half a rotation of the coil.

To get a direct current (DC), a split ring type commutator must be used. With this arrangement, one brush is at all times in contact with the arm moving up in the field while the other is in contact with the arm moving down. Thus a unidirectional current is produced. The generator is thus called a DC generator (Figure 3.25).

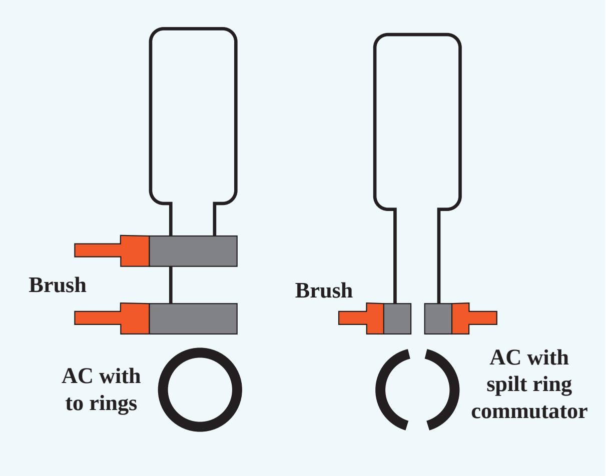


Figure 3.25 Comparison of AC and DC generators

3.9 Transformer

Transformer is a device used for converting low voltage into high voltage and high voltage into low voltage. It works on the principle of electromagnetic induction. It consists of primary and secondary coil insulated from each other. In Figure 3.26, the alternating current flowing through the primary coil induces magnetic field in the iron ring. The magnetic field of the iron ring induces a varying emf in the secondary coil.

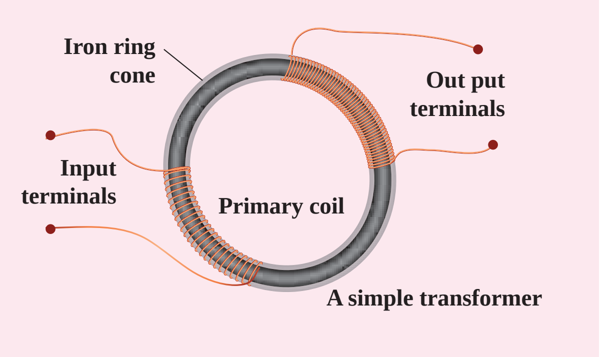


Figure 3.26 Principle of transformer

Depending upon the number of turns in the primary and secondary coils, we can step-up or step-down the voltage in the secondary coil as shown in Figure 3.27.

Step up transformer: The transformer used to change a low alternative voltage to a high alternating voltage is called a step up transformer. ie (Vs > Vp) . In a step up transformer, the number of turns in the secondary coil is more than the number of turns in the primary coil (Ns > Np).

Step down transformer: The transformer used to change a high alternating voltage to a low alternating voltage is called a step down transformer (Vs < Vp). In a step down transformer, the number of turns in the secondary coils are less than the number of turns in the primary coil (Ns < Np).

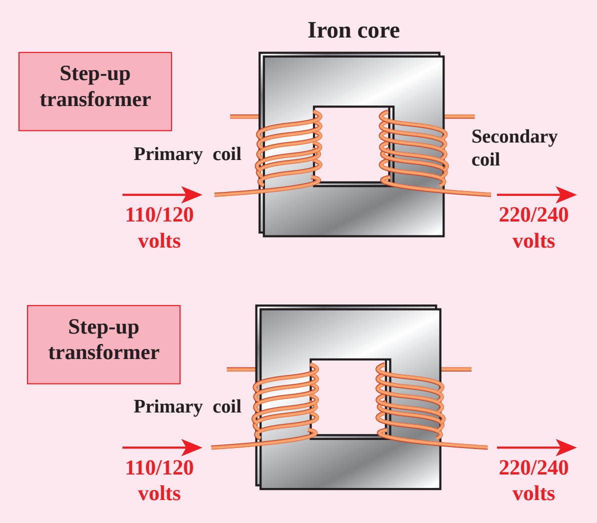


Figure 3.27 Step up and Step down transformers

DO YOU KNOW?

A step up transformer increases the voltage but it decreases the current and vice versa. Basically there will be loss of energy in a transformer in the form of heat, sound etc.

The formulae pertaining to the transformers are given in the following equations.

$$\frac{\text{The number of primary turns } N_p}{\text{The number of secondary turns } N_s} = \frac{\text{The primary voltage } V_p}{\text{The secondary voltage } V_s}$$

$$\frac{\text{The number of secondary turns } N_s}{\text{The number of primary turns } N_p} = \frac{\text{The primary current } I_p}{\text{The secondary current } I_s}$$

A transformer cannot be used with the direct current (DC) source because of current in primary coil is constant (ie. DC). Then there will be no change in the number of magnetic field lines linked with the secondary coil and hence no emf will be induced in the secondary coil.

Exercise 3

The primary coil of a transformer has 800 turns and the secondary coil has 8 turns. It is connected to a 220 V ac supply. What will be the output voltage?

Solution:

In a transformer, $E_s / E_p = N_s / N_p$

$E_s = N_s / N_p \times E_p$

$= 8/800 \times 220$

$= 220/100$

$E_s = 2.2$ volt

Exercise 4

A transformer is designed to give a supply of 8 V to ring a house bell from 240 V ac mains. The primary coil has 4800 turns. How many turns will be in the secondary coil.

Solution:

In a transformer, $E_s / E_p = N_s / N_p$

$N_s = E_s / E_p \times N_p$

$= 8/240 \times 4800$

$N_s = 4800/30 = 160$ turns

3.10 Applications of Electromagnets

Electromagnetism has created a great revolution in the field of engineering applications. In addition, this has caused a great impact on various fields such as medicine, industries, space etc.

3.10.1 Speaker

Inside the speaker, the electromagnet is placed in front of a permanent magnet. The permanent magnet is fixed firmly in position whereas the electromagnet is mobile. As pulses of electricity pass through the coil of the electromagnet, the direction of its magnetic field is rapidly changed. This means that it is in turn attracted to and repelled from the permanent magnet vibrating back and forth. The electromagnet is attached to a cone made of a flexible material such as paper or plastic which amplifies these vibrations, pumping sound waves into the surrounding air towards our ears.

DO YOU KNOW?

An electric bell contains an electromagnet, consisting of coils of insulated wire wound around iron rods. When an electric current flows though the coils, the rods become magnetic and attract a piece of iron attached to a clapper. The clapper hits the bell and makes it ring.

3.10.2 Magnetic Levitation Trains

Magnetic levitation (Maglev) is a method by which an object is suspended with no support other than magnetic fields. In maglev trains two sets of magnets are used, one set to repel and push the train up off the track, then another set to move the floating train ahead at great speed without friction. In this technology, there is no moving part. The train travels along a guideway of magnets which controls the train's stability and speed using the basic principles of magnets.

3.10.3 Medical System

Nowadays electromagnetic fields play a key role in advanced medical equipments such as hyperthermia treatments for cancer, implants and magnetic resonance imaging (MRI). In a, sophisticated equipments working based on the electromagnetism can scan minute details of the human body.


MRI Scanner

Many of the medical equipments such as scanners, x-ray equipments and other equipments also use principle of electromagnetism for their functioning.

Points to Remember:

- When current passes through a wire a magnetic field is set up around the wire. This effect of current is called magnetic effect of current.
- The space surrounding a bar magnet in which its influence in the form of magnetic force can be detected, is called magnetic field.
- The path along which a free magnetic north pole will move in a magnetic field is called magnetic field lines.
- Magnetic field lines do not intersect.
- The magnetic field set up by a current carrying conductor is always at right angles to the direction of flow of current.
- Two parallel wires carrying current in the same directions attract each other.
- Two parallel wires carrying current in the opposite directions repel each other.
- Direction of the force in a current carrying conductor is determined by Fleming's Left Hand Rule.
- Electric motor is a device which converts electrical energy into mechanical energy.
- The phenomenon of producing induced current in a closed circuit due to the change in magnetic field in the circuit is known as electromagnetic induction.
- Direction of induced current in a conductor is determined by Fleming's Right Hand Rule.
- Electric generator is a device used to convert mechanical energy into electrical energy.
- Electric generator works on the principle of electromagnetic induction.
- Transformer is a device which converts low alternating current to high alternating current and vice versa.
- Transformer transfers electric power from one circuit to another.

A-Z GLOSSARY

Magnetic field	The region surrounding a magnet in which the force of the magnet can be detected.
Magnetic line of force	The path followed by a magnetic needle in a magnetic field.
Dynamo	Device which converts mechanical energy into electrical energy.
Motor	Device which converts electrical energy into mechanical energy.
Electromagnetic induction	The phenomenon of producing an induced emf due to the changes in the magnetic lines of forces associated with a conductor.
Transformer	Device which converts low alternating current to high alternating current and vice versa.
MRI	Magnetic Resonance Imaging which is used to obtain images of the internal parts of our body.

TEXT BOOK EXERCISES

I. Choose the correct answer.

1. Which of the following converts electrical energy into mechanical energy.
   a) motor b) battery
   c) generator d) switch

2. An electric generator converts
   a) electrical energy into mechanical energy
   b) mechanical energy into heat energy
   c) electrical energy into electrical energy
   d) mechanical energy into electrical energy.

3. The part of the AC generator that passes the current from the armature coil to the external circuit is
   a) field magnet b) split rings
   c) slip rings d) brushes

4. Transformer works on
   a) AC only
   b) DC only
   c) both AC and DC
   d) Ac nor effectively than DC

5. The unit of magnetic flux density is
   a) Weber b) weber/metre
   c) weber/meter^2 d) weber . meter^2

II. Fill in the blanks.

1. The SI Unit of magnetic field induction is ________.

2. No force acts in a current carrying conductor when it is ________ to the magnetic field.

3. Devices which is used to convert high alternating current to low alternating current ________.
4. An electric motor converts ________.
5. A device for producing electric current is ________.

III. Match the following.

1.	Magnetic material	(a) Oersted
2.	Non-magnetic material	(b) iron
3.	Current and magnetism	(c) induction
4.	Electromagnetic induction	(d) wood
5.	Electric generator	(e) Faraday

IV. True or False:

1. A generator converts mechanical energy into electrical energy.
2. Magnetic field lines always repels each other and do not intersect.
3. Fleming's Left hand rule is also known as Dynamo rule.
4. The speed of rotation of an electric motor can be increased by decreasing the area of the coil.
5. A transformer can step up direct current.
6. In a step down transformer the number turns in primary coil is greater than that of the number of turns in the secondary coil.

V. Answer in brief.

1. State Fleming's Left Hand Rule.
2. Define magnetic flux density.
3. List the main parts of an electric motor.
4. Draw and label the diagram of an AC generator.
5. State an important advantage of ac over dc.
6. Differentiate step up and step down transformer.
7. A portable radio has a built in transformer so that if can work from the mains instead of batteries. Is this a step up or step down transformer?
8. Two coils A and B of insulated wire are kept close to each other. Coil A is connected to a galvanometer. While coil B is connected to a battery through a key. What would happen if
   (i) a current is passed through coil B by plugging the key?
   (ii) the current is stopped by removing the plug from the key?
9. State Faraday's laws of electromagnetic induction.

VI. Answer in detail.

1. Explain the principle, construction and working of a dc motor.
2. Explain two types of transformer.
3. Draw a neat diagram of an AC generator.

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Principles of physics (Extended) – Halliday Resnick and Walker. Wiley publication, New Delhi.

Fundamental University Physics – M. Alonso, E. J. Finn Addimon Wesley (1967)

INTERNET RESOURCES

www.physicsabout.com

https://science.howstuffworks.com

http://arvindguptatoys.com/films.html

UNIT 1

Fluids

G8JNLI

Learning Objectives

After completing this lesson, students will be able to

- define pressure in terms of weight.
- explain the variation of pressure with respect to depth in a fluid.
- learn the fact that water exerts an upward force on objects immersed in it.
- recall and state the Archimedes' principle.
- calculate density when pressure and altitude are given.
- learn the formula for finding the relative density of an object and apply the same.
- understand the behaviour of floating bodies.

Introduction

A small iron nail sinks in water, whereas a huge ship of heavy mass floats on sea water. Astronauts have to wear a special suit while traveling in space. All these have a common reason called 'pressure'. The intermolecular forces in solids are strong, so that the shape and size of solids do not easily change. But this force is less in liquids and gases (together known as fluids) so that their shape is easily changed. If the pressure increases in a solid, based on its inherent properties it experiences tension and ultimately deforms or breaks. In the case of fluids it however causes it to flow rather than to deform. Although liquids and gases share some common characteristics, they have many distinctive characteristics on their own. It is easy to compress a gas whereas liquids are incompressible. Learning of all these facts helps us to understand pressure better. In this lesson you will study about the pressure in fluids, density of fluids and their application in practical life.

1.1 Thrust and Pressure

Try to fix a paper with the help of a drawing pin. Push the pin into the board by its head. Did you succeed? Try now to push the pin by the pointed end. Could you do it this time? Have you ever wondered why a camel can run in a desert easily? Why a truck or a motorbus has wider tyre? Why cutting tools have sharp edges? In order to answer these questions and understand the phenomena involved, we need to learn about two interrelated physical concepts called thrust and pressure.

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Activity 1

Stand on loose sand. Your feet go deep into the sand. Now, lie down on the sand. What happens? You will find that your body will not go that deep into the sand.

In both the cases of the above activity, the force exerted on the sand is the weight of your body which is the same. This force acting perpendicular to the surface is called thrust. When you stand on loose sand, the force is acting on an area equal to the area of your feet. When you lie down, the same force acts on an area of your whole body, which is larger than the area of your feet. Therefore the effect of thrust, that is, pressure depends on the area on which it acts. The effect of thrust on sand is larger while standing than lying.

The net force in a particular direction is called thrust. The force per unit area acting on an object concerned is called pressure. Thus, we can say thrust on an unit area is pressure.

$$\text{Pressure} = \frac{\text{Thrust}}{\text{Area of contact}}$$

For the same given force, if the area is large pressure is low and vice versa. This is shown in Figure 1.1.

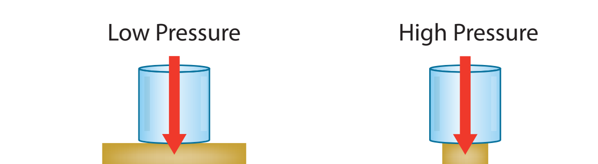


Figure 1.1 Pressure depends on area of application

DO YOU KNOW?

Bed of nail

If a single nail pricks our body it is very painful. How is it possible for people to lie down on a bed of nails, still remain unhurt?

In SI units, the unit of thrust is newton denoted as N. The unit of pressure is newton per square metre or newton metre^{-2} denoted as Nm^{-2}. In the honour of the great French scientist, Blaise Pascal, 1 newton per square metre is called as 1 pascal denoted as Pa. 1 Pa = 1 N m^{-2}

In CGS system force is measured in dyne and area in square cm. Thus the unit of pressure in CGS system is dyne per square cm (dyne cm^{-2}). The relation between the two units is,

$$1\ \text{N m}^{-2} = 10\ \text{dyne cm}^{-2}.$$

Example 1.1

A man whose mass is 90 kg stands on his feet on a floor. The total area of contact of his two feet with the floor is 0.036 m^2. (Take, g = 10 ms^{-2})

a. How much is the pressure exerted by him on the floor?

b. What pressure will he exert on the floor if he stands on one foot?

Solution

The weight of the man (thrust),

$F = mg = 90\ \text{kg} \times 10\ \text{m s}^{-2} = 900\ \text{N}$

a) Pressure, $P = \frac{F}{A} = \frac{900\ \text{N}}{0.036\ \text{m}^2} = 25000\ \text{Pa}$

b) Area of one foot, $A_{1foot} = \frac{A}{2} = 0.018\ \text{m}^2$

Pressure, exerted by 1foot

$$= \frac{F}{A_{1foot}} = \frac{900\ \text{N}}{0.018\ \text{m}^2} = 50000\ \text{Pa}$$

- Cutting edges of knife and axes are sharpened, because as the area decreases the pressure increases. Hence, small force is enough to cut an object.
- Heavy trucks are fitted with six to eight wheels. As area increases pressure decreases. So weight of the truck exerts less pressure on the road.
- Animals' jaws can exert a pressure of more than 750 pounds per square inch as they are very sharp.

1.2 Pressure in fluids

All the flowing substances, both liquids and gases are called fluids. Like solids, fluids also have weight and therefore exert pressure. When filled in a container, the pressure of the fluid is exerted in all directions and at all points of the fluid. Since the molecules of a fluid are in constant, rapid motion, particles are likely to move equally in any direction. Therefore the pressure exerted by the fluid acts on an object from all directions. It is shown in Figure 1.2. Pressure in fluids is calculated as shown below.

$$\text{Fluid Pressure} = \frac{\text{Total force exerted by the fluid}}{\text{Area over which the force is exerted}} = \frac{F}{A}$$

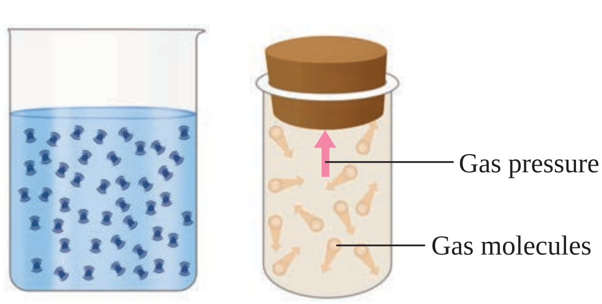


Figure 1.2 Collision of molecules gives rise to pressure

We shall first learn about the pressure exerted by liquids and then learn about the pressure exerted by gases.

1.2.1 Pressure due to liquids

The force exerted due to the pressure of a liquid on a body submerged in it and on the walls of the container is always perpendicular to the surface. In Figure 1.3, we can see the pressure acting on all sides of the vessel.

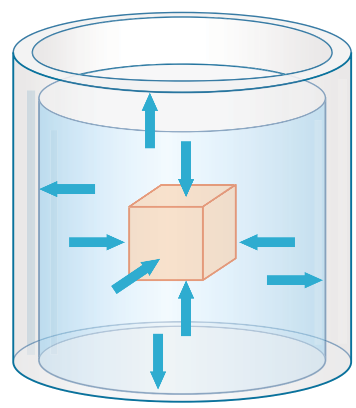
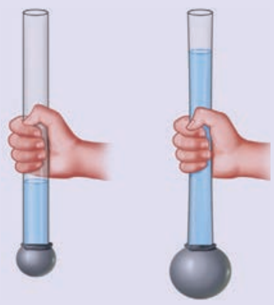


Figure 1.3 Force due to pressure of a liquid

When an air filled balloon is immersed inside the water in a vessel it immediately comes up and floats on water. This shows that water (or liquid) exerts pressure in the upward direction. It is shown in Figure 1.4.

Figure 1.4 Liquid pressure exerts force upwards

Activity 2



Take a transparent plastic pipe. Also take a balloon and tie it tightly over one end of the plastic pipe. Keep the pipe in a vertical position with its closed end at the bottom. Pour some water in the pipe from the top. What happens?

We will find that on pouring water in the pipe, the balloon tied at the bottom stretches and bulges out. The bulging out of balloon demonstrates that the water poured in the pipe exerts a pressure on the bottom of its container.

Similarly, liquid pressure acts in lateral sides also. When a bottle having water is pierced on the sides we can see water coming out with a speed as in Figure 1.5. This is because liquid exerts lateral pressure on the walls the container.

Figure 1.5 Liquid pressures on lateral sides of the container

1.2.2 Factors determining liquid pressure in liquids

Pressure exerted by a liquid at a point is determined by,

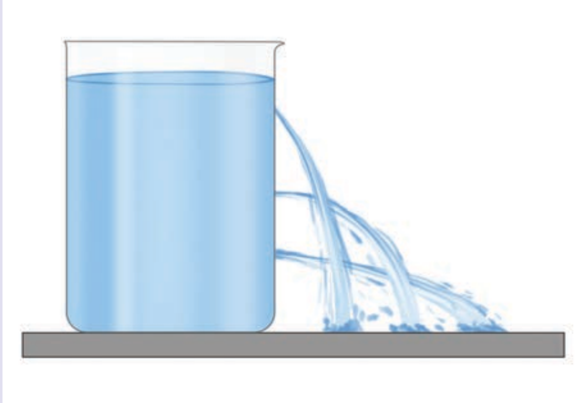
(i) depth (h)

(ii) density of the liquid (ρ)

(iii) acceleration due to gravity (g).

Activity 3

Take a large plastic can. Punch holes with a nail in a vertical line on the side of the can as shown in figure. Then fill the can with water. The water may just dribble out from the top hole, but with increased speed at the bottom holes as depth causes the water to squirt out with more pressure.



From this activity we can see that pressure varies as depth increases. But, it is same at a particular depth independent of the direction. In Figure 1.6, we see the gauge reads the same value because the pressure is being measured at the same depth (red line).

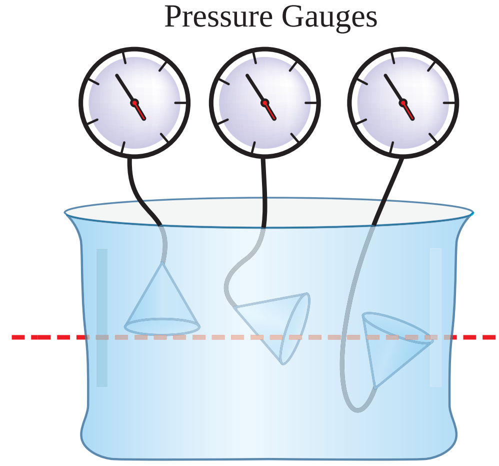


Figure 1.6 Pressure at a depth is same independent of directions

Activity 4

Take two liquids of different densities say water and oil to a same level in two plastic containers. Make holes in the two containers at the same level. What do you see? It is seen that water is squirting out with more pressure than that of oil. This indicates that pressure depends on density of the liquid.

Water Cooking oil

1.2.3 Pressure due to a liquid column

A tall beaker is filled with liquid so that it forms a liquid column. The area of cross section at the bottom is A. The density of the liquid is ρ. The height of the liquid column is h. In other words the depth of the water from the top level surface is 'h' as shown in Figure 1.7.

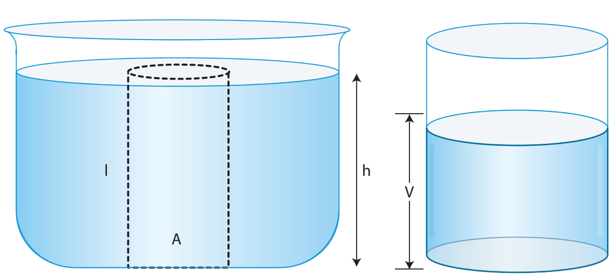


Figure 1.7 Pressure due to a liquid column

We know that thrust at the bottom of the column (F) = weight of the liquid.

Therefore, F = mg (1)

We can get the mass of the liquid by multiplying the volume of the liquid and its density.

Mass, m = ρ V (2)

Volume of the liquid column, V = Area of cross section (A) × Height (h) = Ah (3)

Substituting (3) in (2)

Hence, mass, m = ρAh (4)

Substituting (4) in (1)

Force = mg = ρAhg

$$\text{Pressure, } P = \frac{\text{Thrust (F)}}{\text{Area (A)}} = \frac{mg}{A} = \frac{\rho(Ah)g}{A} = \rho hg$$

∴ Pressure due to a liquid column, P = hρg

This expression shows that pressure in a liquid column is determined by depth, density of the liquid and the acceleration due to gravity. Interestingly, the final expression for pressure does not have the term area A in it. Thus pressure at a given depth does not depend upon the shape of the vessel containing the liquid or the amount of liquid in the vessel. It only depends on the depth. In Figure 1.8, the pressure is the same even though the containers have different amounts of liquid in them, and are of different shapes.

Figure 1.8 Pressure does not depend on shape and size of the container

Example 1.2

Calculate the pressure exerted by a column of water of height 0.85 m (density of water, ρ_w = 1000 kg m^{-3}) and kerosene of same height (density of kerosene, ρ_k = 800 kg m^{-3})

Solution:

Pressure due to water

= $h\rho_w g$ = 0.85 m × 1000 kg m^{-3} × 10 m s^{-2}

= 8500 Pa.

Pressure due to kerosene

= $h\rho_k g$ = 0.85 m × 800 kg m^{-3} × 10 ms^{-2}

= 6800 Pa.

1.3 Atmospheric pressure

Earth is surrounded by a layer of air up to certain height (nearly 300 km) and this layer of air around the earth is called atmosphere of the earth. Since air occupies space and has weight, it also exerts pressure (Fig. 1.9). This pressure is called atmospheric pressure. The atmospheric pressure we normally refer is the air pressure at sea level.

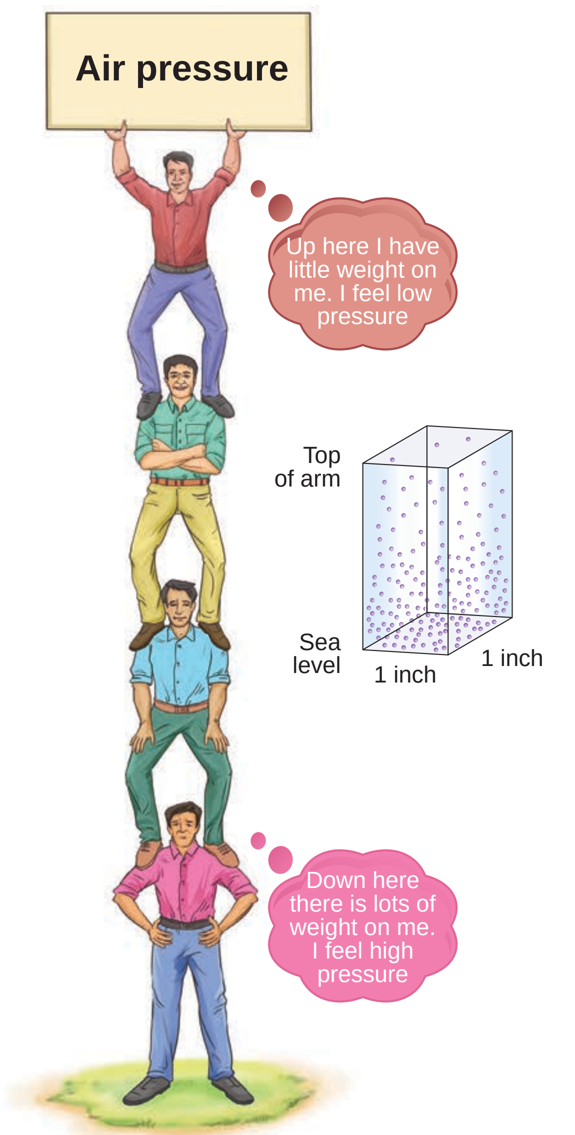


Figure 1.9 Atmospheric pressure

Figure 1.10 shows that air gets 'thinner' with increasing altitude. Hence, the atmospheric pressure decreases as we go up in mountains. On the other hand air gets heavier as we go down below sea level like mines. Table 1.1 gives the value of atmospheric pressure at some places above and below sea level.

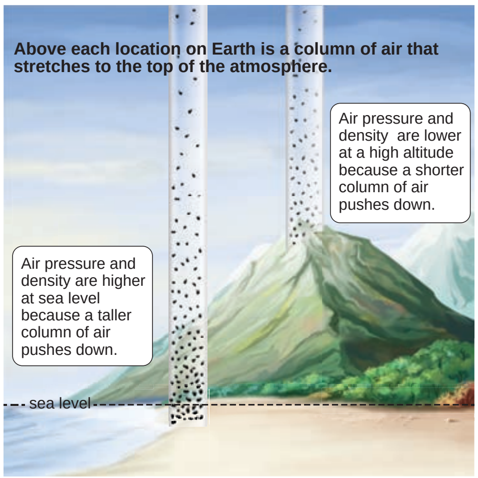


Figure 1.10 Atmospheric pressure acts like a column

DO YOU KNOW?

Human lung is well adapted to breathe at a pressure of sea level (101.3 k Pa). As the pressure falls at greater altitudes, mountain climbers need special breathing equipments with oxygen cylinders.

Similar special equipments are used by people who work in mines where the pressure is greater than that of sea level.

Table 1.1 Atmospheric pressure at different places

Atmospheric pressure	k Pa
Mount Everest summit	33.7
Earth sea level	101.3
Dead sea (below sea level)	*106.7*

1.3.1 Measurement of atmospheric pressure

The instrument used to measure atmospheric pressure is called barometer. A mercury barometer, first designed by an Italian Physicist Torricelli, consists of a long glass tube (closed at one end, open at the other) filled with mercury and turned upside down into a container of mercury. This is done by closing the open end of the mercury filled tube with the thumb and then opening it after immersing it in to a trough of mercury (Fig. 1.11). The barometer works by balancing the mercury in the glass tube against the outside air pressure. If the air pressure increases, it pushes more of the mercury up into the tub and if the air pressure decreases, more of the mercury drains from the tube. As there is no air trapped in the space between mercury and the closed end, there is vacuum in that space. Vacuum cannot exert any pressure. So the level of mercury in the tube provides a precise measure of air pressure which is called atmospheric pressure. This type of instrument can be used in a lab or weather station.

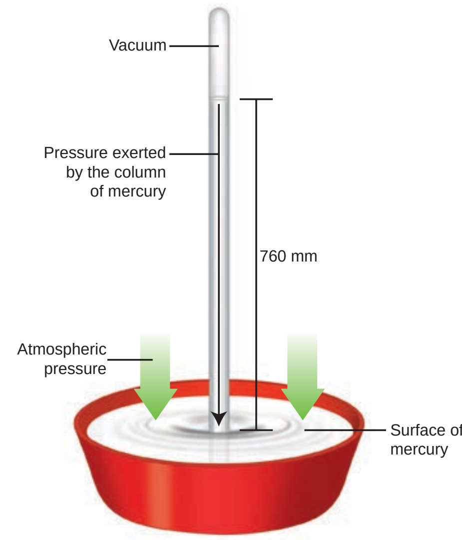


Figure 1.11 Mercury barometer

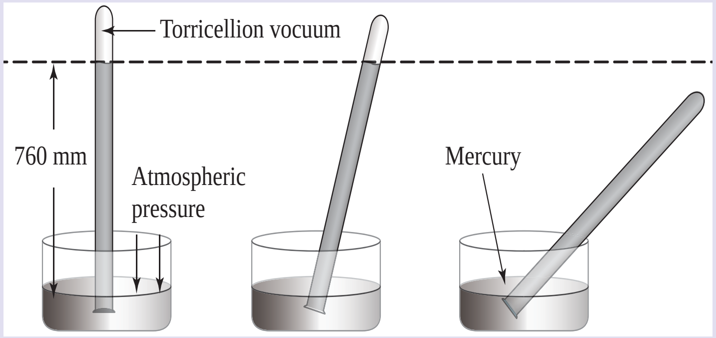
More to Know

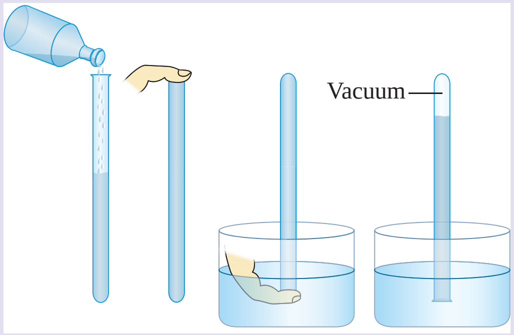
Two puzzling questions accidentally led to the discovery of the idea of air pressure and an instrument barometer, to measure it. During the time of Galileo, in Italy many were perplexed that a suction pump could not pump water from rivers and wells if the depth of the water was more than 11 meter. Another question that troubled philosophers in Europe was if there is an actual vacuum.

Galileo incorrectly suggested that the limit of the suction pump was imposed by the weight of water. The idea was put to test by Gasparo Berti around 1640. He took a glass tube of about 12 metres in length. He placed it vertically. Then he covered the bottom of the tube. Filled it with water and he sealed the top. Now he opened the top at the bottom. The water fell down and when it reached the level of 11 meter high the flow stopped. There was an empty space at the top above the water column. Was it really empty? Vacuum? Without examining the question, Berti died soon. The dramatic demonstration caught the attention of another Italian scientist, Evangelista Torricelli.

Torricelli took several glass tubes, each with different diameters, but all about one meter length, sealed at one end. He filled them with mercury. After placing a finger over the opening, they were upturned into a basin containing more mercury. When the finger was removed and the mercury was released, the level fell and stopping at the height of about 76 centimetre. This occurred irrespective of the diameter of the tube.

Above the 76 cm level the glass tube looked empty. Was it really empty? Torricelli tilted the tubes. As the tubes were tilted the mercury rushed into the empty space. If that space was filled with say air, bubbles should come out. None came. Therefore Torricelli reasoned that the empty space above the mercury column is real vacuum. But why the column remained at 76 cm?





In 1647, Marin Mersenne and Blaise Pascal, two scientists from France performed an interesting experiment. They made two identical barometers and placed them parallel at the base of a mountain in France, the Puy de Dôme. Both of them showed the same level of mercury. They carried one to the summit of the mountain. To their astonishment as they climbed the mountain, the level of the mercury dropped. They reasoned that air exerts pressure and as we go higher the air column above our head, the air pressure drops. The barometer helps to measure the invisible air pressure.

On a typical day at sea level, the height of the mercury column is 760 mm. Let us calculate the pressure due to the mercury column of 760 mm which is equal to the atmospheric pressure. The density of mercury is 13600 kg m^{-3}.

Pressure, $P = h\rho g$

$= (760 \times 10^{-3} m) \times (13600\ kgm^{-3}) \times (9.8\ ms^{-2})$

$= 1.013 \times 10^5$ Pa.

This pressure is called one atmospheric pressure (atm). There is also another unit called (bar) that is also used to express such high values of pressure.

1 atm = 1.013×10^5 Pa.

1 bar = 1×10^5 Pa.

Hence, 1 atm = 1.013 bar.

Expressing the value in kilopascal gives 101.3 k Pa. This means that, on each 1 m^2 of surface, the force acting is 1.013 k N.

1.3.2 Types of barometers

As the mercury is not in a closed vessel in the mercury barometer, moving the instrument without spilling the mercury is difficult. Hence, we have other sophisticated instruments which are handy. They also work on the same principle like a mercury barometer but instead of mercury they use diaphragms and other precise components which respond for variation in atmospheric pressure. Table 1.2 shows some of the barometers used frequently.

Example 1.3

A mercury barometer in a physics laboratory shows a 732 mm vertical column of mercury. Calculate the atmospheric pressure in pascal. [Given density of mercury, $\rho = 1.36 \times 10^4$ kg m^{-3}, $g = 9.8$ m s^{-2}]

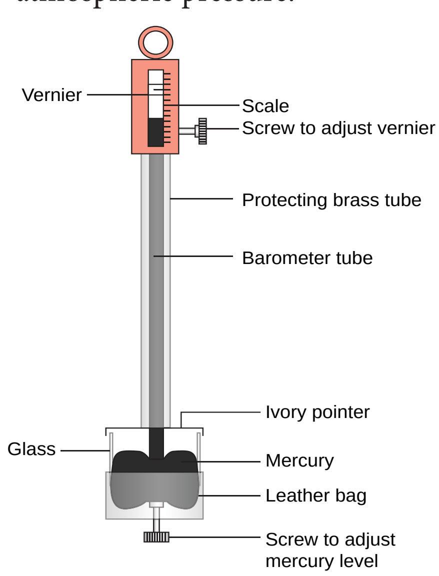
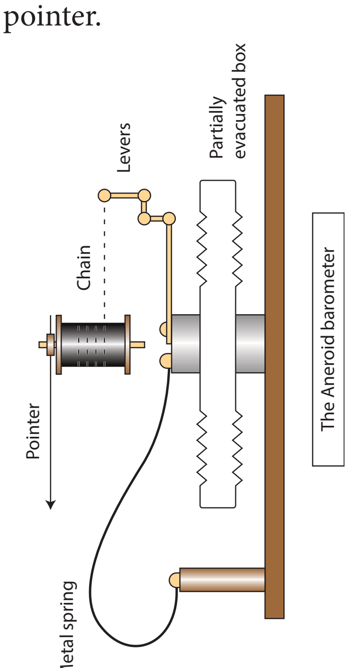
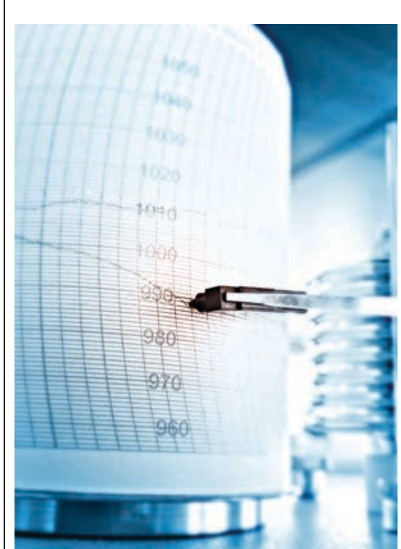
Solution:

Atmospheric pressure in the laboratory,

$P = h\rho g = 732 \times 10^{-3} \times 1.36 \times 10^4 \times 9.8$

$= 9.76 \times 10^4$ Pa (or) 0.976×10^5 Pa

Table 1.2 Types of barometers

Fortin's barometer	Aneroid barometer	Barograph
It is a mercury barometer in which the mercury bath along with mercury and barometer tube is covered with a flexible leather case so that spilling of mercury during transport is averted. The amount of movement of a screw at the bottom to maintain the mercury level same is a measure of the atmospheric pressure.	It is a device for measuring atmospheric pressure without the use of liquids. It consists of a partially evacuated metal chamber and a thin corrugated lid which is displaced by variations in the external air pressure. A lever connected to the diaphragm of the chamber moves a pointer.	It is a barometer that records the atmospheric pressure variations over time. One or more aneroid cells sense the pressure changes. The variations are recorded through a lever and pen arrangement on a moving graph sheet attached to a rotating drum.
 Fortin barometer		

1.3.3 Gauge pressure and absolute pressure

Our daily activities are happening in the atmospheric pressure. We are so used to it that we do not even realise. When tyre pressure and blood pressure are measured using instruments (gauges) they show the pressure over the atmospheric pressure. Hence, absolute pressure is zero-referenced against a perfect vacuum and gauge pressure is zero-referenced against atmospheric pressure.

For pressures higher than atmospheric pressure,
absolute pressure = atmospheric pressure + gauge pressure

For pressures lower than atmospheric pressure,
absolute pressure = atmospheric pressure – gauge pressure

Example 1.4

Find the absolute pressure on a scuba diver (deep sea diver) when the diver is 12 metres below the surface of the ocean. Assume standard atmospheric conditions. [Take density of water as 1030 kg m^{-3}, g = 9.8 m s^{-2}]

Solution:

Pressure due to sea water, $P_{water} = h\rho g$

$= (12\text{ m}) \times (1.03 \times 10^3\text{ kgm}^{-3}) \times (9.8\text{ m s}^{-2})$

$= 1.21 \times 10^5$ Pa

$P_{absolute} = P_{atmosphere} + P_{water}$

$= (1.01 \times 10^5) + (1.21 \times 10^5)$

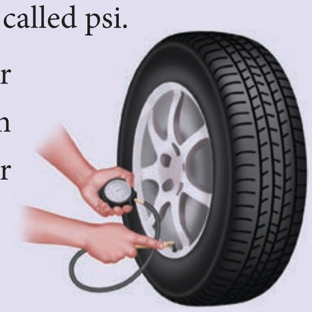
$P_{absolute} = 2.22 \times 10^5$ Pa

This is more than twice the atmospheric pressure. Parts of our body, especially blood vessels and soft tissues cannot withstand such high pressure. Hence, scuba divers always wear special suits and equipment to protect them (Fig. 1.12).

Figure 1.12 Scuba divers with special protecting equipment

DO YOU KNOW?

In petrol bunks, the tyre pressure of vehicles is measured in a unit called psi.



It stands for pascal per inch, an old system of unit for measuring pressure.

1 psi = 6895 Pa

1 psi = 0.06895×10^5 Pa

A tire pressure of 30 psi means 2.0685×10^5 Pa. It is almost twice the atmospheric pressure.

More to Know

Mass of the Atmosphere

The global mean pressure at the surface of the Earth (P_S = 984 hPa) is slightly less than the mean sea-level pressure because of the elevation of land. We can deduce the total mass of the atmosphere (m_a) as shown below.

$$Pa = \frac{F}{A} = \frac{(m_a g)}{4\pi R^2};\ m_a = \frac{(P_a 4\pi R^2)}{g} = 5.2 \times 10^{18}\text{ kg}$$

where R = 6400 km is the radius of the Earth.

Activity 5

Press a good quality rubber sucker hard on a plane smooth surface. It sticks to the surface. Now pull it off the surface. When you press the sucker, most of the air between its cup and the plane surface escapes out. The sucker sticks to the plane surface since the pressure due to the atmosphere pushes on it. The sucker can be removed off the plane surface by applying a large external force that overcomes the atmospheric pressure. By this principle only, lizards and monitor lizards (udumbu) are able to get good grip over surfaces.

1.4 Pascal's Law

Pascal's principle is named after Blaise Pascal (1623-1662), a French mathematician and physicist. The law states that the external pressure applied on an incompressible liquid is transmitted uniformly throughout the liquid. Pascal's law can be demonstrated with the help of the glass vessel having holes all over its surface. Fill it with water. Push the piston. The water rushes out of the holes in the vessel with the same pressure. The force applied on the piston exerts pressure on water. This pressure is transmitted equally throughout the liquid in all directions (Fig. 1.13). This principle is applied in various machines used in our daily life.

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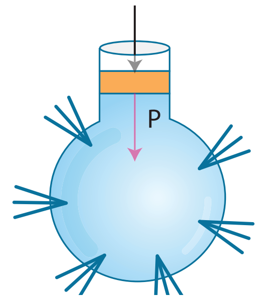


Figure 1.13 Demonstration of Pascal's Law

Activity 6

Take a tooth paste available in your home. Squeeze it. What happens? When any part of the tube is squeezed toothpaste squirts out through the open end. The pressure applied at one part of the tooth paste (through tube) is transmitted equally throughout the toothpaste. When the pressure reaches the open end, it forces toothpaste out through the opening.

1.4.1 Hydraulic press

Pascal's law became the basis for one of the important machines ever developed, the hydraulic press. It consists of two cylinders of different cross-sectional areas as shown in Figure 1.14. They are fitted with pistons of cross-sectional areas "a" and "A". The object to be compressed is placed over the piston of large

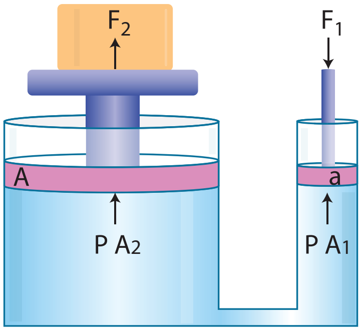


Figure 1.14 Hydraulic press

cross-sectional area A. The force F_1 is applied on the piston of small cross-sectional area a. The pressure P produced by small piston is transmitted equally to large piston and a force F_2 acts on A which is much larger than F_1. Pressure on piston of small area 'a' is given by,

$$P = \frac{F_1}{A_1} \quad (1)$$

Applying Pascal's law, the pressure on large piston of area A will be the same as that on small piston. Therefore, $P = \frac{F_2}{A_2}$ (2)

Comparing equations (1) and (2),we get $\frac{F_1}{A_1} = \frac{F_2}{A_2}$. or $F_2 = F_1 \times \frac{A_2}{A_1}$

Since, the ratio $\frac{A_2}{A_1}$ is greater than 1, the force F_2 that acts on the larger piston is greater than the force F_1 acting on the smaller piston. Hydraulic systems working in this way are known as *force multipliers*.

Example 1.5

A hydraulic system is used to lift a 2000 kg vehicle in an auto garage. If the vehicle sits on a piston of area 0.5 m², and a force is applied to a piston of area 0.03 m², what is the minimum force that must be applied to lift the vehicle?

Given: Area covered by the vehicle on the piston $A_1 = 0.5$ m²

Weight of the vehicle, $F_1 = 2000 \text{ kg} \times 9.8 \text{ m s}^{-2}$

Area on which force F_2 is applied, $A_2 = 0.03$ m²

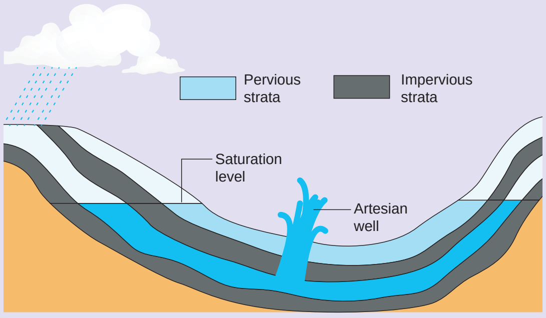
Solution:

$$P_1 = P_2; \ \frac{F_1}{A_1} = \frac{F_2}{A_2} \text{ and } F_2 = \frac{F_1}{A_1} A_2;$$

$$F_2 = (2000 \times 9.8)\frac{0.03}{0.5} = 1176 \text{ N}$$

Info bits

An artesian aquifer is a confined aquifer containing groundwater that will flow upwards out of a well without the need for pumping. In recharging aquifers, this happens because the water table at its recharge zone is at a higher elevation than the head of the well.



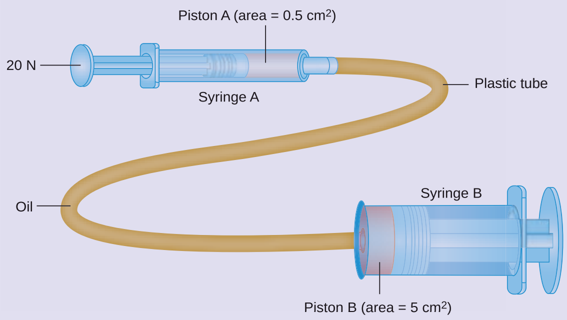
Example 1.6

Two syringes are connected together as shown in the diagram below.

A force of 20 N is applied to the piston in syringe A.

(a) Calculate the pressure that the piston in syringe A exerts on the oil.

(b) Calculate the force needed to just prevent the piston in syringe B from moving out.



Solution:

(a) A force of 20 N is applied to the piston in syringe A.

The pressure that the piston in syringe A exerts on the oil,

$$P = \frac{F}{A} = \frac{20\text{N}}{0.5 \text{ cm}^2} = 40 \text{ N cm}^{-2}$$

(b) $P = \frac{F}{A}$. So $F = PA$

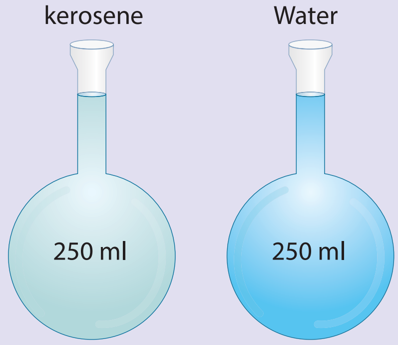
The force needed to just prevent the piston in syringe B from moving out,

$F = 40\ N\ cm^{-2} \times 5\ cm^2 = 200\ N$

1.5 Density

Activity 7

Take two identical flasks and fill one flask with water to 250 cm^3 mark and the other with kerosene to the same 250 cm^3 mark. Measure them in a balance. The flask filled with water will be heavier than the one filled with kerosene. Why? The answer is in finding the mass per unit volume of kerosene and water in respective flasks.



To understand density better, let us assume that the mass of the flask be 80g. So, the mass of the flask filled with water is 330g and the mass of flask filled with kerosene is 280g. Mass of water only is 250g and kerosene only is 200g. Mass per unit volume of water is 250/250cm^3. This is 1g/cm^3. Mass per unit volume of kerosene is 200g/250cm^3. This is 0.8g/cm^3. The result 1g/cm^3 and 0.8gcm^3 are the densities of water and kerosene respectively. *Therefore the density of a substance is the mass per unit volume of a given substance.*

The SI unit of density is kilogram per meter cubic (kg/m^3) also gram per centimeter cubic (g/cm^3). The symbol for density is rho (ρ).

Example 1.7

A silver cylindrical rod has a length of 0.5 m and radius of 0.4 m. Find the density of the rod if its mass is 2640 kg.

Solution:

Mass of the cylinder = 2640 kg

Volume of the cylinder = $\pi r^2 h = 3.14 \times (0.4)^2 \times 0.5 = 0.2512\ m^3$

Density = mass/volume = 2640 kg/0.2512 m^3 = 10509 kg m^{-3}

1.5.1 Relative Density

We can compare the densities of two substances by finding their masses. But generally density of a substance is compared with the density of water at 4°C because density of water at that temperature is 1g/cm^3. Density of any other substance with respect to the density of water at 4°C is called the relative density. Thus relative density of a substance is defined as ratio of density of the substance to density of water at 4°C. Mathematically, relative density (R.D)

$$= \frac{\text{Density of the substance}}{\text{Density of water at 4°C}}$$

We know that, Density $= \frac{\text{Mass}}{\text{Volume}}$

∴ Relative density

$$= \frac{\text{Mass of the substance/Volume of the substance}}{\text{Mass of water/Volume of water}}$$

Since the volume of the substance is equal to the volume of water,

Relative density

$$= \frac{\text{Mass of certain volume of substance}}{\text{Mass of equal volume of water}}$$

Thus, the ratio of the mass of a given volume of a substance to the mass of an equal volume of water at 4°C also denotes relative density.

1.5.2 Measurement of relative density

Relative density can be measured using Pycnometer (Fig. 1.15) also called density bottle. It consists of ground glass stopper with a fine hole through it. The function of the hole in a stopper is that, when the bottle is filled and the stopper is inserted, the excess liquid rises through the hole and runs down outside the bottle. By this way the bottle will always contain the same volume of whatever the liquid is filled in, provided the temperature remains constant. Thus the density of a given volume of a substance to the density of equal volume of referenced substance is called relative density or specific gravity of the given substance. If the referenced substance is water then the term specific gravity is used.

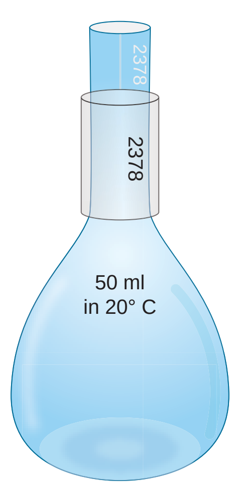


Figure 1.15 Specific gravity bottle

1.5.3 Floating and sinking

Whether an object will sink or float in a liquid is determined by the density of the object compared to the density of the liquid. If the density of a substance is less than the density of the liquid it will float. For example a piece of wood which is less dense than water will float on it. Any substance having more density than water (for example, a stone), will sink into water.

Example 1.8

You have a block of a mystery material, 12 cm long, 11 cm wide and 3.5 cm thick. Its mass is 1155 grams. (a) What is its density? (b) Will it float in a tank of water, or sink?

Solution:

(a) $\text{Density} = \dfrac{\text{Mass}}{\text{Volume}} = \dfrac{1155\text{g}}{12\text{ cm} \times 11\text{ cm} \times 3.5\text{ cm}}$

$= \dfrac{1155\text{ g}}{462\text{ cm}^3} = 2.5\text{ g cm}^{-3}$

(b) The mystery material is denser than the water, so it sinks.

1.5.4 Application of principle of flotation

Hydrometer

A direct-reading instrument used for measuring the density or relative density of the liquid is called hydrometer. Hydrometer is based on the principle of flotation, i.e., the weight of the liquid displaced by the immersed portion of the hydrometer is equal to the weight of the hydrometer.

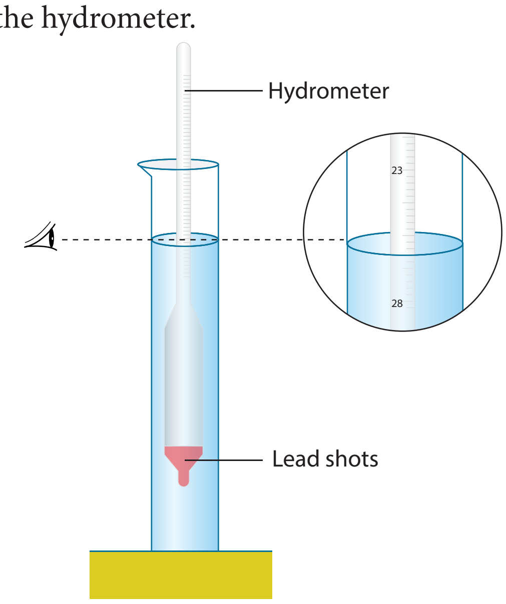


Figure 1.16 Hydrometer

Hydrometer consists of a cylindrical stem having a spherical bulb at its lower end and a narrow tube at is upper end. The lower spherical bulb is partially filled with lead shots or mercury. This helps hydrometer to float or stand vertically in liquids. The narrow tube has markings so that relative density of a liquid can be read directly.

The liquid to be tested is poured into the glass jar. The hydrometer is gently lowered in to the liquid until it floats freely. The reading against the level of liquid touching the tube gives the relative density of the liquid.

Hydrometers may be calibrated for different uses such as lactometers for measuring the density (creaminess) of milk, saccharometer for measuring the density of sugar in a liquid and alcoholometer for measuring higher levels of alcohol in spirits.

Lactometer

One form of hydrometer is a lactometer, an instrument used to check the purity of milk. The lactometer works on the principle of gravity of milk.

The lactometer consists of a long graduated test tube with a cylindrical bulb with the graduation ranging from 15 at the top to 45 at the bottom. The test tube is filled with air. This air chamber causes the instrument to float. The spherical bulb is filled with mercury to cause the lactometer to sink up to the proper level and to float in an upright position in the milk.

Inside the lactometer there may be a thermometer extending from the bulb up into the upper part of the test tube where the scale is located. The correct lactometer reading is obtained only at the temperature of 60°C. A lactometer measures the cream content of milk. More the cream, lower the lactometer floats in the milk. The average reading of normal milk is 32. The lactometers are used highly at milk processing units and at dairies.

1.6 Buoyancy

We already saw that a body experiences an upward force due to the fluid surrounding, when it is partially or fully immersed in to it. We also saw that pressure is more at the bottom and less at the top of the liquid. This pressure difference causes a force on the object and pushes it upward. This force is called buoyant force and the phenomenon is called buoyancy (Fig.1.17).

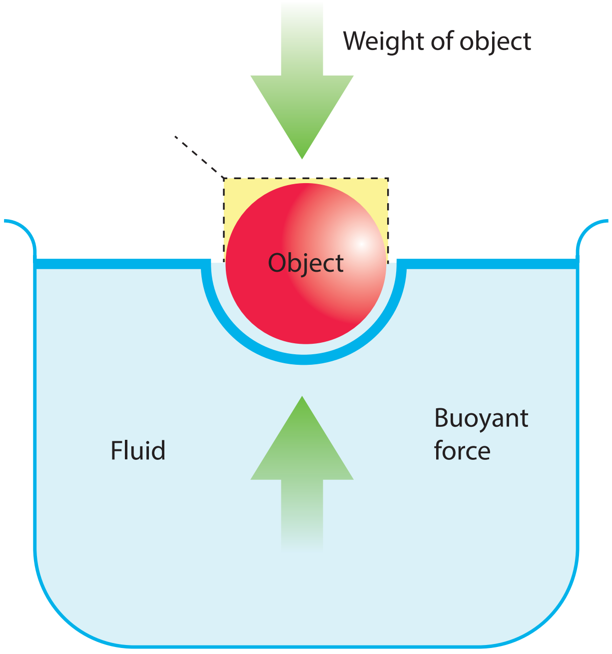


Figure 1.17 Buoyant force

Most buoyant objects are those with a relatively high volume and low density. If the object weighs less than the amount of water it has displaced (density is less), buoyant force will be more and it will float (such object is known as positively buoyant). But if the object weighs more than the amount of water it has displaced (density is more), buoyant force is less and the object will sink (such object is known as negatively buoyant).

More to Know

- ✓ Salt water provides more buoyant force than fresh water. Because buoyant force depends as much on the density of fluids as on the volume displaced.
- ✓ Hydrogen, helium and hot air are much less dense than ordinary air and this gives them buoyancy.

Cartesian diver

Cartesian diver is an experiment that demonstrates the principle of buoyancy. It is a pen cap with clay. The Cartesian diver contains just enough liquid that it barely floats in a bath of the liquid; its remaining volume is filled with air. When pressing the bath, the additional water enters the diver, thus increasing the average density of the diver, and thus it sinks.

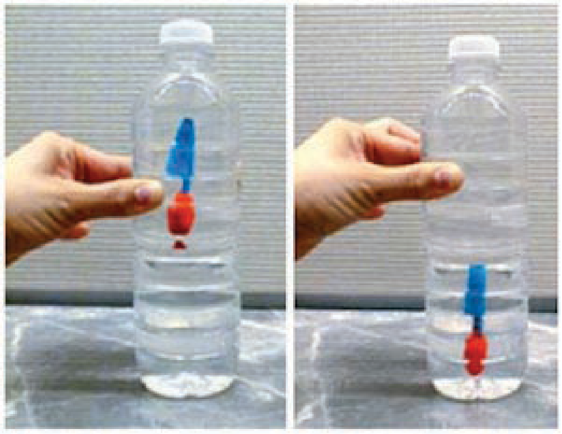
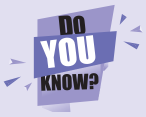


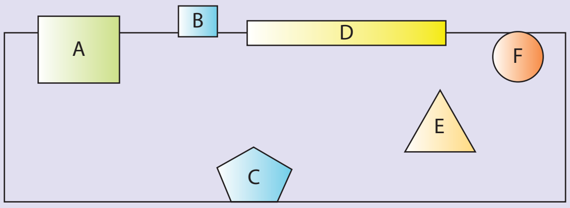
Figure 1.18 Cartesian diver



- Fish has an internal swim bladder which is filled with gas. When it needs to rise or descend, it changes the volume and its density.
- Human swimmers, icebergs and ships stay afloat due to buoyancy.
- Petroleum-based products typically float on the surface of water, because their specific gravity is low.

Examples 1.9

Six objects (A-F) are in a liquid, as shown below. None of them are moving. Arrange them in order of density, from lowest to highest.



Solution:

The more of an object's volume is above the water surface, the less dense it is. Object B must therefore be the least dense, followed by D, A, and F. Object E is next, because it is neutrally buoyant and equal in density to the liquid. Object C is negatively buoyant because it is denser than the fluid.

Therefore the order of density from lowest to highest is B,D,A,F, E,C.

1.6.1 Mathematical representation of Buoyant force

For an object submerged in a fluid, there is a net force on the object, because the pressure at the top and bottom of it are different.

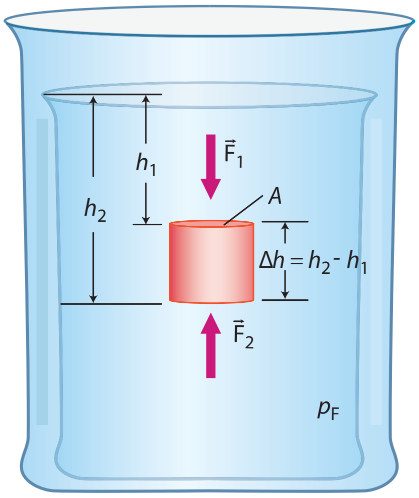


Figure 1.19 Net force acting on an object

We know that pressure, $P = \frac{F}{A}$

$$F = P\,A$$

$$F_{buoyancy} = F_2 - F_1 = P_2A_2 - P_1A_1$$

Since area is same, $A_2 = A_1 = A$

Therefore,

$$F_{buoyancy} = P_2A - P_1A$$
$$= A(P_2 - P_1)$$

Since, $P = h\rho g$,

$$F_{buoyancy} = A(\rho g h_2 - \rho g h_1)$$
$$= A\rho g(h_2 - h_1) = \rho g A(h_2 - h_1)$$
$$F_{buoyancy} = \rho g(A\Delta h) = (\rho_{fluid})\ g\ (V_{displaced})$$

Example 1.10

A golden crown has been placed in a tub of water. The volume of water displaced is measured to be 1.50 liters. The density of water is 1000 kg m^{-3}, or 1.000 kg L^{-1}. What is the buoyant force acting on the crown?

Solution:

The buoyant force is, $F_b = \rho g V$

First, we ensure that the units used for volume are the same.

If 1 m^3 = 1000 L, then 1.50 L = 0.00150 m^3.

$F_b = (1000\ kg\ m^{-3})(9.80\ m\ s^{-2})(0.00150\ m^3)$

$= 14.7\ kg\ m\ s^{-2} = 14.7\ N$

The buoyant force acting on the golden crown is 14.7 N.

1.7 Archimedes' Principle

Archimedes principle is the consequence of Pascal's law. According to legend, Archimedes devised the principle of the "hydrostatic balance" after he noticed his own apparent loss in weight while sitting in his bath. The story goes that he was so enthused with his discovery that he jumped out of his bath and ran through the town, shouting "eureka". Archimedes principle states that 'a body immersed in a fluid experiences a vertical upward buoyant force equal to the weight of the fluid it displaces'.

Figure 1.20 Archimedes and eureka

When a body is partially or completely immersed in a fluid at rest, it experiences an upthrust which is equal to the weight of the fluid displaced by it. Due to the upthrust acting on the body, it apparently loses a part of its weight and the apparent loss of weight is equal to the upthrust.

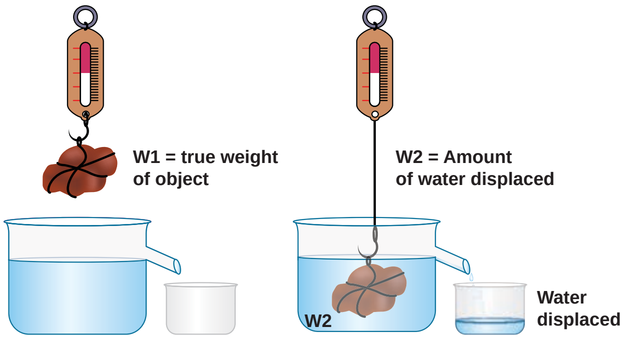


Figure 1.21 Upthrust is equal to the weight of the fluid displaced

Thus, for a body either partially or completely immersed in a fluid,

Upthrust = Weight of the fluid displaced

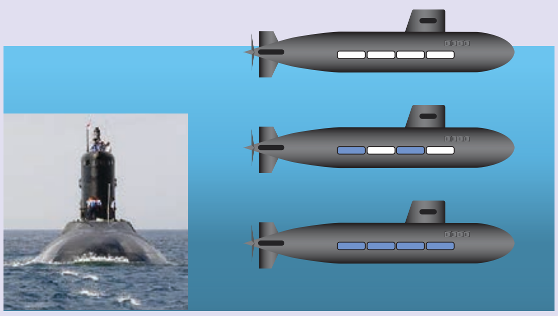
= Apparent loss of weight of the body.

Apparent weight of an object =

True weight of an object in air

– Upthrust (weight of water displaced)

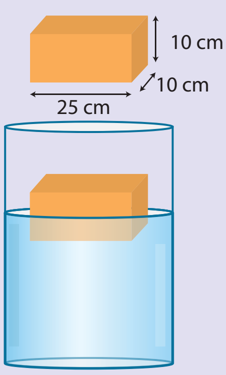
Info bits



Submarines change the level of floating by pumping in and pumping out water in to its compartments.

Example 1.11

What is the mass of the object floating in the given diagram?



Solution:

Weight of the object = Buoyant force

$\rho = 1000 \text{ kg m}^{-3}$

$V = (25\text{x}10\text{x}10)\ \text{cm}^3 = 2500 \text{ x } 10^{-6}\ \text{m}^3$

$m = \rho V = 1000 \text{ x } 2500 \text{ x } 10^{-6} = 2.5 \text{ kg}$

1.8 Laws of flotation

Laws of flotation are,

1. The weight of a floating body in a fluid is equal to the weight of the fluid displaced by the body.
2. The centre of gravity of the floating body and the centre of buoyancy are in the same vertical line.

The point through which the force of buoyancy is supposed to act is known as centre of buoyancy. It is shown in Figure 1.22.

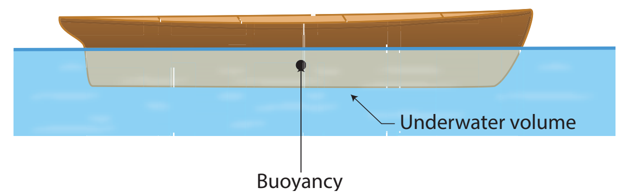


Figure 1.22 Centre of buoyancy

Info bits

Flotation therapy uses water that contains Epsom salts rich in magnesium. As a floater relaxes, he or she is absorbing this magnesium through the skin. Magnesium helps the body to process insulin, which lowers a person's risk of developing Type 2 Diabetes.

Points to Remember

- The force which produces compression is called thrust. Its S.I. unit is newton.
- Thrust acting normally to a unit area of a surface is called pressure. Its S.I. unit is pascal.
- The pressure exerted by the atmospheric gases on its surroundings and on the surface of the earth is called atmospheric pressure. 1 atm is the pressure exerted by a vertical column of mercury of 76 cm height.
- Barometer is an instrument used to measure atmospheric pressure.
- The upward force experienced by a body when partly or fully immersed in a fluid is called upthrust or buoyant force.
- Cartesian diver is an experiment which demonstrates the principle of buoyancy and the ideal gas law.
- Pascal's law states that an increase in pressure at any point inside a liquid at rest

is transmitted equally and without any change, in all directions to every other point in the liquid.

- Archimedes' Principle states that when a body is partially or wholly immersed in a fluid, it experiences an up thrust or apparent lose of weight, which is equal to the weight of the fluid displaced by the immersed part of the body.
- Density is known as mass per unit volume of a body. Its S.I. unit is kg m^{-3}.
- Relative density is the ratio between the density of a substance and density of water. Relative density of a body is a pure number and has no unit.
- Relative density of a liquid

$$= \frac{\text{Apparent loss of weight of a body in liquid}}{\text{Apparent loss of weight of the same body in water}}$$

- Hydrometer is a device used to measure the relative density of liquids based on the Archimedes' principle.
- Lactometer is a device used to check the purity of milk by measuring its density using Archimedes' Principle.
- Laws of flotation are given as: i) Weight of a floating body = Upthrust or buoyant force = Apparent loss of weight of the body in the fluid. ii) The centre of gravity and the centre of buoyancy lie in the same vertical line.

A-Z GLOSSARY

Altitude	Vertical distance in the up direction.
Astronaut	Person who is specially trained to travel into outer space.
Axes	Simple machine to cut, shape and split wood.
Deformation	Changes in an object's shape or form due to the application of a force or forces.
Fossils water	Preserved water.
Iceberg	Large piece of ice floating in water.
Hydraulic systems	Device that uses fluids and work under the fluid pressure to control valves.
Incompressible	No change in volume if a pressure is applied.
Meteorological	Weather condition.
Piston	Movable disc fitted inside a cylinder.
Propellers	Fan that transmits power in the form of thrust by rotation.
Syringe	Simple pump made of plastic or glass to inject or withdraw fluid.
Therapy	Treatment.
Velocity	Speed with direction.