Arise with Physics

Students' BOOK 4

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Above all else, I thank Jehovah, God; for making sure that I remained healthy and strong.

Dedication

To Gift and Stephano, my sons and Sellina my wife

Contents

UNIT 1

It is generally known that matter expands when heated and contracts when cooled. This phenomenon can be useful as well as problematic. It is for this reason that in this unit you will learn to describe thermal expansion of matter and give its molecular explanation. In particular you will also learn about the unusual expansion of water and its effects. Lastly, you will learn the effects and applications of thermal expansion.

Thermal expansion

Thermal expansion in solids, liquids and gases

Why do balloons burst when placed near a hot electric bulb and water pipes burst in very cold weather? Why do over head cables for telephones and electricity sag more on hot summer day but stretch tightly on a cold day? Activity 1.1 will help you to confirm that matter expands when heated and contract when cooled. It will also show you that different states and different materials have different rates of expansion.

Activity 1.1

Defining temperature

Materials

- Burner
- Two 150ml beakers
- Tap Water
- Boiling water
- Two thermometers
- Stop watch
- Tripod stand and gauze wire
- Measuring cylinder

Method

1. Discuss and describe the meaning of temperature
2. Pour out 50ml and 100 ml of boiling water from the same source and using measure their temperatures immediately.
   a. How do the temperatures in the two beakers compare?
   b. How the amounts of heat energy in the two beakers compare?
3. Using a measuring cylinder put 50ml

of tap water into a beaker and put it on a tripod stand as shown in Figure 1.1. Heat the water for 2 minutes and using a thermometer measure its temperature at the end of the two minutes.

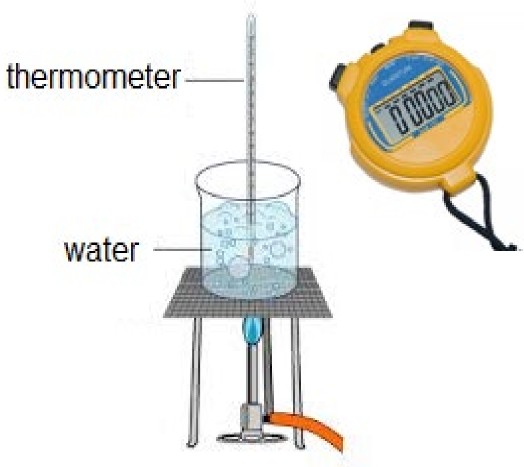

Figure 1.1 Investigating whether heat is same as temperature

4. Repeat step 3 using 100ml of tap water using another 150ml beaker
5. Discuss the following questions from your observations in step 3 and 4
   a. How do the temperatures in the two beakers compare?
   b. How the amounts of heat energy in the two beakers compare?
   c. Is temperature the same as heat?
   d. What is the relationship between heat and temperature?

Feedback

Remember that heat is a measure of energy and its units are joules. Since molecules in matter are in constant motion, it is right to say that all molecules contain some amount of kinetic energy. Temperature is associated with the kinetic energy of the molecules.

In step 2 of the Activity 1.1, the two beakers have same temperature but the larger beaker contain more heat energy. In other words the molecules in each of the two beakers have same average kinetic energy but the larger beaker has more heat energy since it has more molecules.
In steps 3 and 4, the two quantities of water received same amount of heat since they were heated using same source and within same period of time. However, the smaller water quantity attain a higher temperature than a larger quantity. The heat, which is the same for both beakers is more concentrated in the smaller quantity of water. Temperature is therefore a measure of concentration of heat.

Temperature is well known as hotness of a substance as measured by a thermometer. In actual sense, temperature is defined as a measure of the average kinetic energy of the molecules in a substance.
On the other hand, heat is the total energy of all molecular motion in an object. Heat is related to temperature in a sense that when molecules gain their kinetic energy, the temperature of substance also increases.

Key points
Temperature is commonly defined as a measure of hotness or coldness of a substance.

Temperature is actually a measure of average kinetic energy of the molecules in a substance.

Activity 1.2

Describing thermal expansions in solids, liquids and gases

A. **Expansion of solids**

Materials

- Different thick metal rods of same length
- Needle
- Two wood blocks
- Hard paper for paper scale
- straw
- Heat source (spirit or Bunsen burner)
- Stop watch.
- Graph paper

Method

1. Pierce a needle through a straw and place the needle on a wooden block as shown in figure 1.1. Lay one of the metal rods on the needle while the other end is on a wood block touching the wall. Stand a paper scale beside the wooden block and adjust the straw so that it is in line with the zero point on the scale.

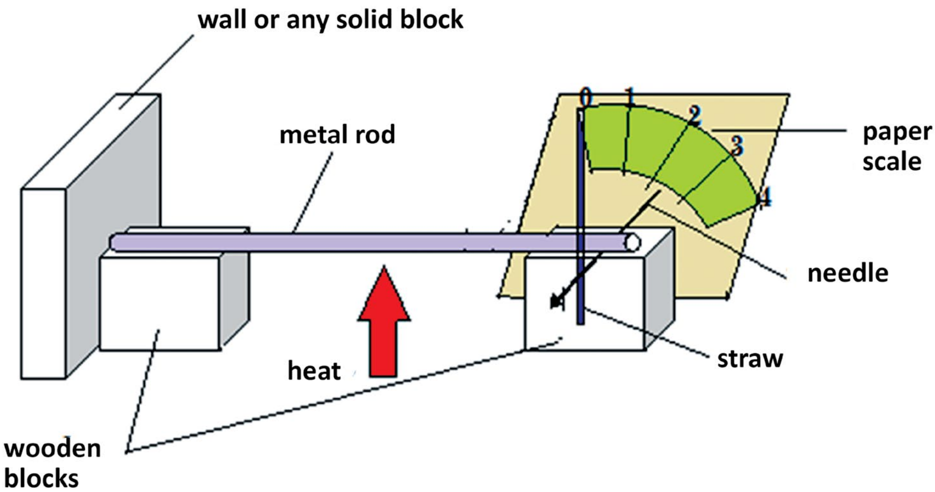

Figure 1.2: Expansion of solids

2. Light the heat source and heat the metal rod while observing the straw pointer. Remove the heat source and observe what happens as the rod cools.
a. Discuss and explain both heating and cooling observation of the metal rod.
3. Do step 1 and 2 using rods of different metals and using stopwatch estimate the position of the pointer at 30 seconds interval until the readings do not change anymore.
4. Using one graph paper plot graph lines of pointer reading against time for each metal rod.
   a. Discuss the graph lines.
   b. Explain the slopes of the graph lines.
5. Heat a bimetallic strip and make observation.
   a. Discuss and explain your observations
   b. What would happen when the hot bimetallic strip is cooled? Explain.

B. **Expansion of liquids.**
Materials
- Stop watch
- One glass tube
- Water
- Cooking oil
- Paraffin oil
- Food colour
- Flask
- Clamp stand

- Ruler
- Perforated bung
- Graph paper

Method

1. Fill a flask with water (coloured using food colour) and gently insert a tube in a bung into the flask so that the water level is seen in the tube as shown in figure 1.3
2. Mount a ruler in such a way that the water level in the tube is against the ruler scale.
3. Place a weak heat source (preferably spirit burner) below the water and make observations on the level of the water. Then remove the heat source and make observations.
    a. Discuss and explain both heating and cooling observation of the water level.
        1. Do step 1 and 2 using different liquids (cooking oil and paraffin oil or any other non flammable liquid) and using stopwatch estimate the position of the pointer at 30 seconds interval until the liquid is near top of tube.
        2. Using one graph paper plot graph lines of pointer reading against time for each kind of liquid.
            a. Discuss the graph lines.
            b. Explain the slope of the graph lines.

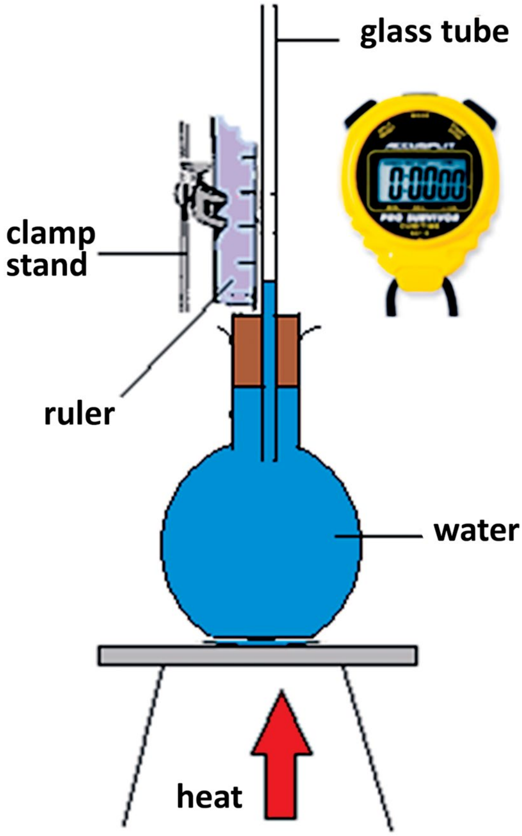

Figure 1.3: Observing expansion of liquids

C. **Expansion of gases**

Materials

- flask
- Glass tube perforated bung
- Coloured water

Method

1. Gently insert a tube in a bung (with coloured water as index in it) into an empty flask as shown in figure1. 3

2. Place you palms around the flask
    a. Explain the observation.
    b. Would different types of gases have same or different rates of expansion? Explain you answer.
3. Remove your palms to let the air inside cool. What happens to the water index? Explain why?

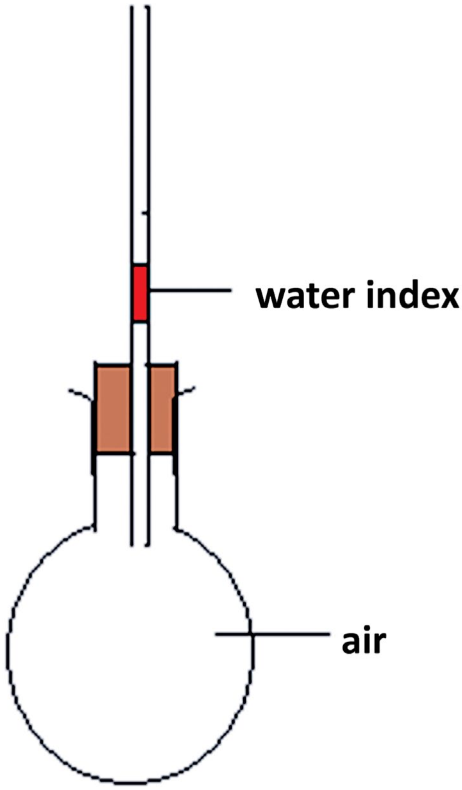

Figure 1.4: Observing expansion of gases

Feedback
The set of experiment in activity 1.2 confirm that in all cases matter expands when heated and contracts when cooled. For solids and liquids, different materials have different rates of expansion as can be deduced from the slopes of the graphs drawn. A bimetallic strip bends when heated because its two metals expand by different amounts. For each material, its ability to expand is equal to its contraction. This variation in rate of expansion is not present for gases. All gases expand by the same rate if equally heated. What makes substances expand when heated? Why do different solids and liquids have different rates of expansion? These questions can be answered by studying expansion of the substance at molecular level as discussed in the next section.

Key point
Matter, in all its three states, expand when heated and contact when cooled

Exercise 1.1
1. With the aid of a diagram, describe what happens to the size of a hole when a solid object is heated?
2. Draw a diagram of a bimetallic strip to show its shape when it is
    a. At room temperature
    b. Heated above room temperature
    c. Cooled below room temperature
3. Figure 1.5 shows a hot air balloon which can lift into space carrying a good value of load.

a. What is the use of burner in the hot air balloon?
b. Explain how hot air balloon lifts into space using the idea of expansion.

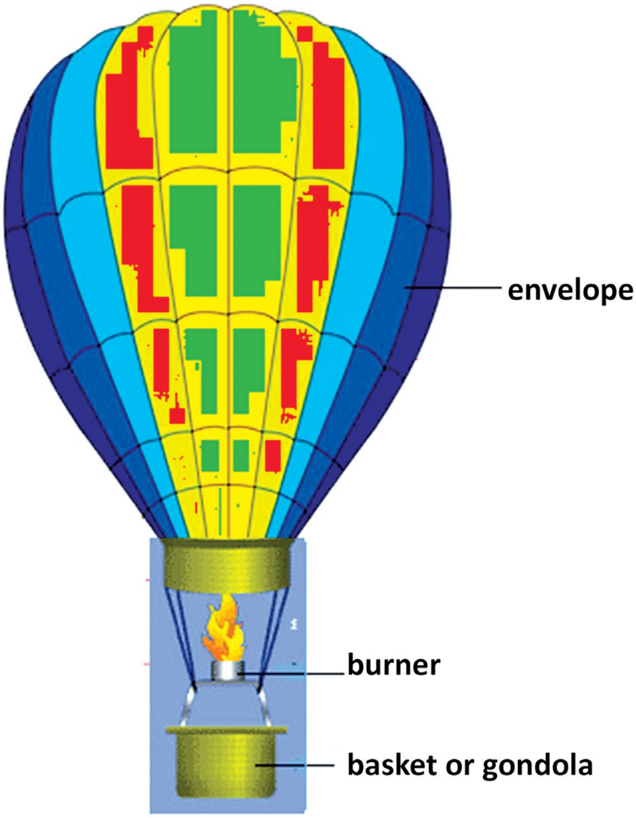

Figure 1.5: Hot air balloon

Expansion and particle behaviour

Thermal expansion can be explained by molecular behaviour of a substance as its temperature changes. Before you proceed, it is important that you do activity 1.2 to revise on kinetic theory.

Activity 1.1

Explaining expansion in terms of particle behaviour

Materials

- Note book
- Pens

Method.

1. In groups discuss and give answers to the following questions
   a. Kinetic theory says that substance particles are always in motion in all the states of matter.
      i. What happens to the speed of movement of the particles (molecules or atoms) when temperature of a substance is raised?
      ii. What happens to the intermolecular forces when temperature is raised?
      iii. What happens to the space between particles when the temperature is raised?
   b. Explain expansion of a material in terms of behaviour of particles.
   c. Explain contraction of a material in terms of behaviour of particles.
2. Using eight or more people, perform a role play to illustrate behaviour of molecules in all the three states when heated or cooled.

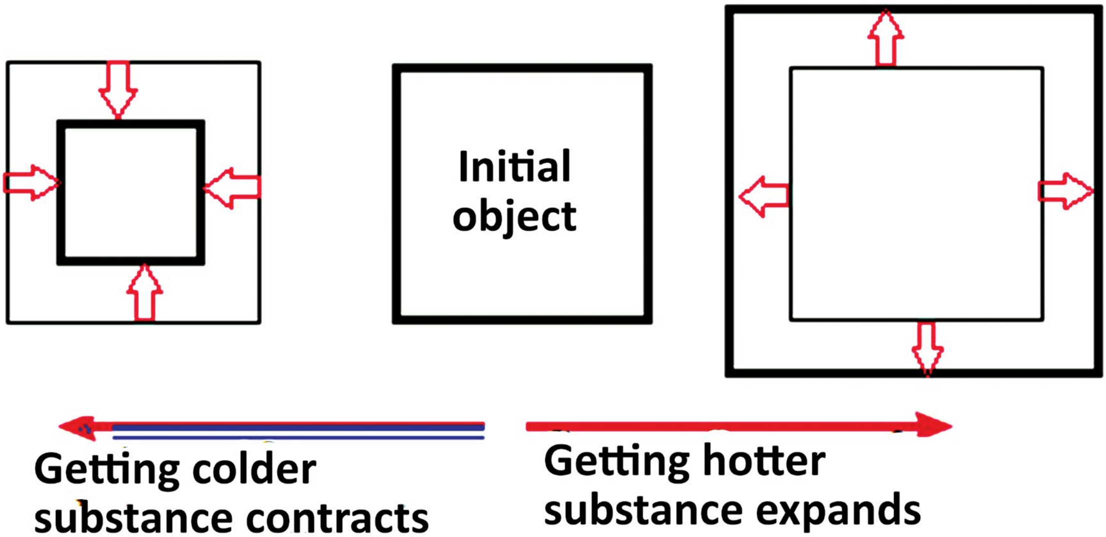

Figure 1.6: Expansion and contraction of a substance.

Feedback
Kinetic theory stipulates that particles in matter are always in motion, and that the motion of particles increases when heated. This is so because the heat energy gained increases the kinetic component of the internal energy. The increase in motion is always associated with a rise in temperature so that temperature itself can be used as a measure of molecular movement. It is this increase in motion that weakens the binding forces between molecules hence they move further apart thereby, occupying a larger volume in the process as seen in figure 1.6.

This is called expansion. The size of the object or substance increases but its mass remains the same. It should be noted that expansion causes decrease in density due to the increase in volume.

The rate of expansion is dependent on the strength of intermolecular forces. Materials with stronger binding forces have smaller rate of expansion. In all types of gases these binding forces are almost zero; hence they all expand at same rate. In conclusion expansion is a result of substance particles moving further apart as intermolecular forces are weakened by increasing molecular motion when heated.

Contraction would occur when a substance cools. The loss in heat energy make molecules slow down and intermolecular forces are strong enough to pull the particles closer together, hence occupying a small volume.

In the activity above, when you do a role play, people should move further apart during heating and they should move closer together when cooled. When a substance is heated enough, the increasing motion of particles may be too large so that the holding forces may no longer keep the particle arrangement. In this case the substance changes its state as illustrated in figure 1.7.

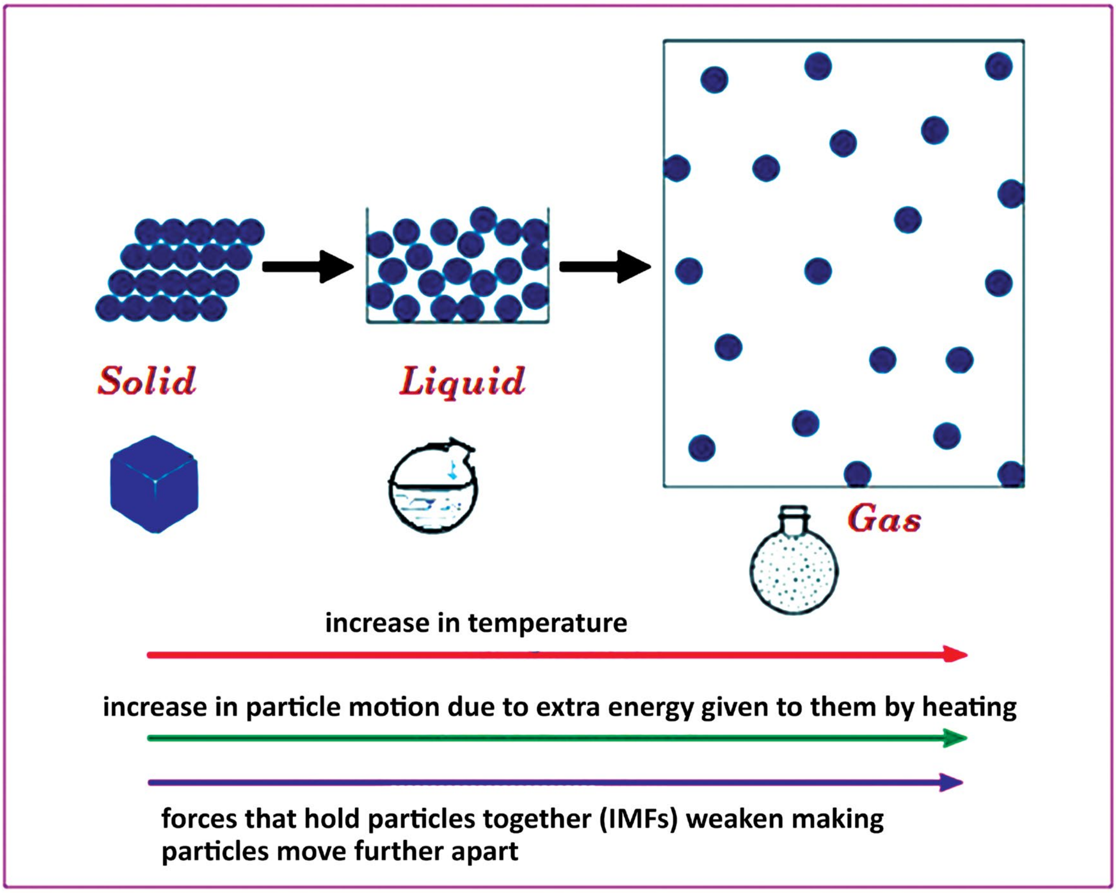

Figure 1.7 Change of state

Key point
Expansion is caused by molecules moving further apart due to weakening of intermolecular forces when there is increase in particle motion due to temperature rise.

Exercise 1.2

1. Explain what happens to molecules and atoms of substances when heated.
2. Give molecular explanation of how heating makes a substance expand.
3. Explain why
   a. Solids have lower expansion than liquids.
   b. Gases have very high expansion when heated.
   c. Why do different solids or liquids have different rates of expansion?

Expansion of water and its effects

In all cases, liquids contract when they freeze into solids, and indeed expand when heated. When something contracts its density increases due to decrease in volume. Conversely, density of a substance decreases as it expands. This is not the case with water at temperatures between 0 and 4°C.

Activity 1.4

Describing the unusual expansion of water and its effects

Method

In pairs discuss and explain the following observations.

1. When water is cooled from 4 to 0°C, it expands (its volume increases), instead of contracting.
2. Ice floats on water instead of sinking.

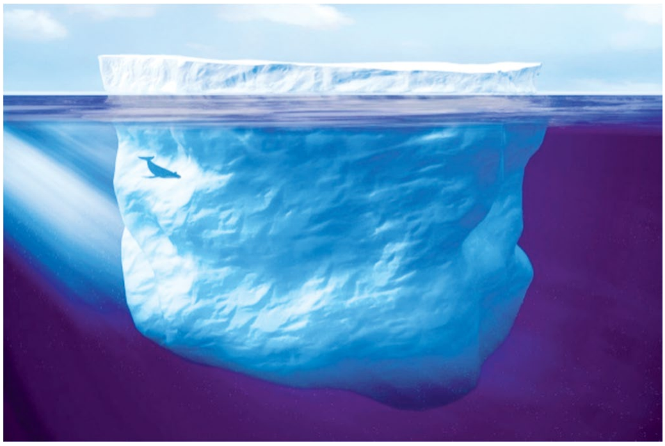

Figure 1.8: Huge block of iceberg floating on water

Feedback

All substances expand when their temperature rises and contract when temperature falls. This is always so regardless of state of the substance. However, this is not always the case with water. When water is heated, from 0 to 4°C, it contracts instead of expanding. Beyond 4°C the water behaves normally, expanding as temperature rises. When cooled water contracts but only up to 4°C. When the water is cooled between 4 and 0°C, the water expands instead of contracting. This is referred to as anomalous expansion of water. Cooling the water further below 0°C makes the ice expand so that the density of ice becomes lower than that of liquid water. It follows that water has largest density at that temperature where it has the smallest volume. The density of water at 4°C is 1g/cm^3 as shown in figure 1.9(b). For this reason ice floats on water because it has lower density than liquid water. In Polar Regions large icebergs floats on water as shown in figure 1.8.

Figure 1.8 (a) is a graph of volume against temperature. The graph shows that water has the smallest volume at 4°C. Notice that the water has the largest increase in volume at 0°C, as it freezes.

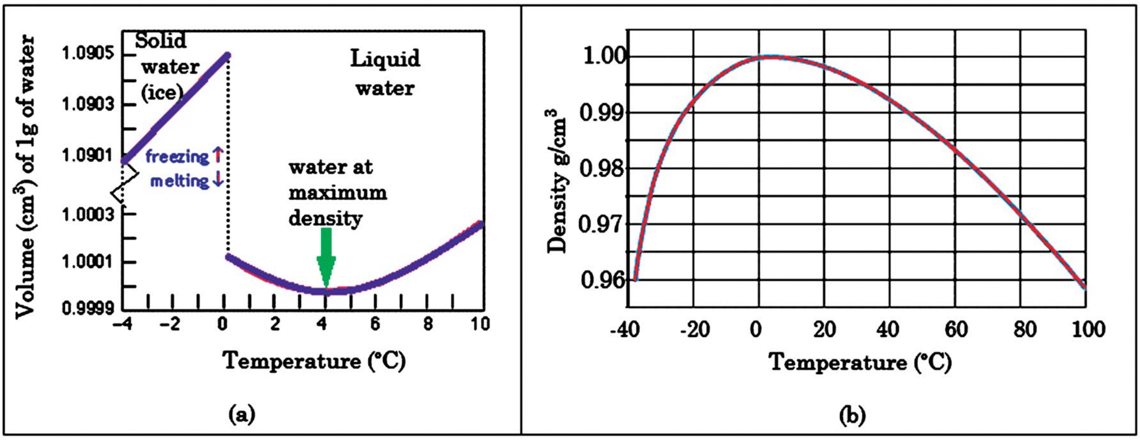

Figure 1.9: Changes of volume and density of water with temperature.

Water has such anomalous behaviour due to a special type of intermolecular forces that tend to produce an open structure as the water solidifies. These forces are called hydrogen bonding. As shown in figure 1.10.

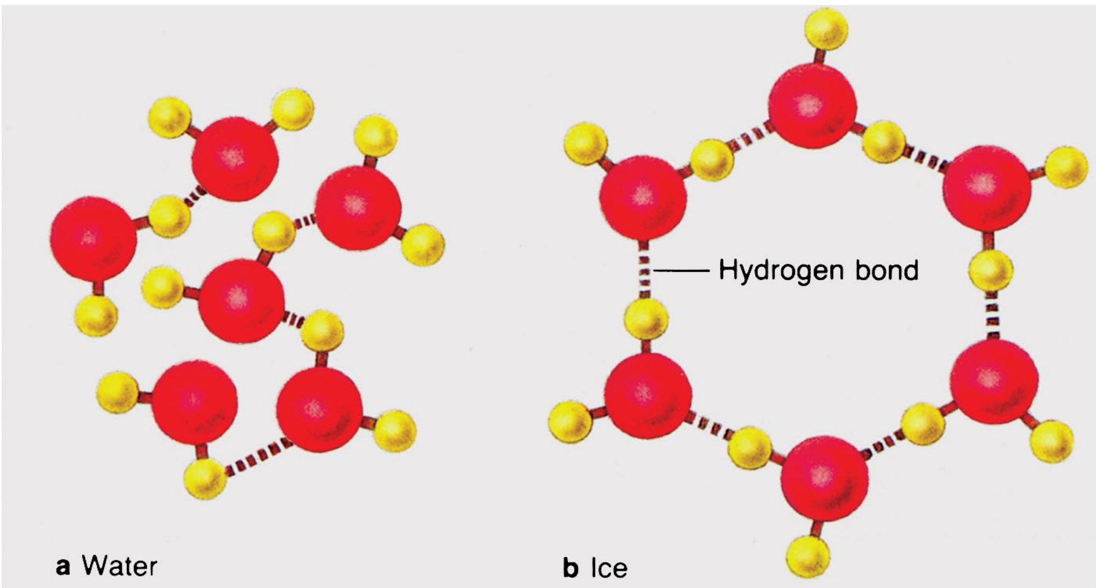

Figure 1.10: Open structure of water

Key point
All matter contracts when cooled. But water expands when cooled below 4°C. This is called anomalous behaviour of water which has a number of effects including floating of ice.

Exercise1.3

1. Pure water freeze at 0°C and boil at 100°C at sea level. Explain what happens when water is heated at the following temperatures.
   a. 20°C
   b. 3°C
2. Explain why ice floats on water instead of sinking.

Effects and applications of thermal expansion

One of the consequences of a change in temperature of a body is that it expands and contracts. This is so because as temperature increases, atoms vibrate back and forth or move over greater distances and with greater average speeds. The larger range of motion causes the atoms to have a larger average distance between them hence material expands.

Thermal expansion and contraction of materials have both advantages and disadvantages. Activity 1.4 will help you to explore some of the advantages and disadvantages of thermal expansion.

Activity 1.4

Explaining the effects and applications of thermal expansion

Materials
- Bimetallic strip
- Pyrex and ordinary glass containers
- Stuck tumblers or bottle tops

Method
1. In groups discuss and explain problems that arise due to thermal expansion.
2. Discuss and explain applications of thermal expansion.
3. Explain the following.
   a. How thermal expansion can be used to remove tightly screwed bottle tops.
   b. Uses of bimetallic strips.
   c. Why pyrex glass does not crack easily while ordinary glass does when heated.
   d. Why railways and concrete slabs have gaps between them?

(a) (b) (c)

Figure 1.11: Problems of expansion.

Figure 1.12: Thermal expansion in railways lines.

Feedback
Problems of expansion
Thermal expansion causes so many problems. Because water expands as it solidifies it tends to burst pipes in very cold regions as shown in figure 1.10 (a). A long continuous wall can break or crack during thermal expansion as shown in figure 1.10(b). Walls and slabs are built with gaps (called expansion joints) at intervals to allow for expansion as shown in figure 1.11(c).

Railway lines can also break or bend under thermal expansion as seen in figure 1.12(a). To allow for expansion, the rail line is lined up with gaps at intervals as shown in figure 1.12(b).
Pipes that carry steam expand and may break. To allow for expansion the steam pipe has loops which may be full or horse shoe in shape as seen in figure 1.13

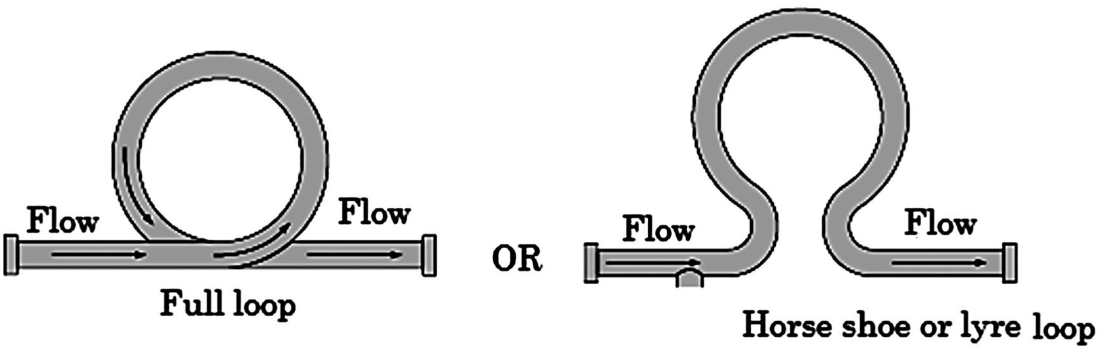

Figure 1.13: Expansion loops for steam pipes.

Applications of expansion
Some of the applications of expansion include the following.

1. Pyrex glass has very small linear expansion rate and for that reason it is unlikely to crack when heated than ordinary glass. For this reason many heating vessels in laboratory like beakers and boiling tubes are made of Pyrex glass.
2. Tubes made of materials called quartz have very low expansion. They are therefore used in conditions of extreme temperature changes since they are unlikely to crack.
3. Mercury-Silver amalgams are used by dentists to fill cavities. Its expansion rate is nearly equal to that of the tooth so that it expands or contract together with the tooth. If another material with lower or larger expansion rate than the tooth is used; painful stresses could be created by unequal thermal expansion or contraction when the tooth is exposed to high or low temperatures.
4. All methods of temperature measurementsuse observable physical properties which change with temperature in a precise and reproducible manner one of which is thermal expansion. Some of the ways that use expansion to measure temperature are as follows;
   - *Liquid expansion thermometers.* Liquid (mercury or alcohol) is filled in a narrow capillary tube. Any change in temperature causes a rise or fall in liquid level as it expands or contract respectively. The height in column of liquid is calibrated directly into temperate unit scale like °C.
   - *Bimetallic strip thermometers.*When a bimetallic strip is heated it bends towards a material with lower thermal expansion rate. The amount of bending is proportional to the temperature. It is this property that allows bimetallic strips to be used as oven and high temperature thermometers as shown in figure1.13 (a). The bimetallic strip can also be used as thermometers at very low temperatures since the amount of contraction will also cause bending. Bimetallic strips are also used as thermostats where their bending can open or close an electrical circuit as shown in figure 1.14(b). This is common in fire alarms, electric iron and cookers.

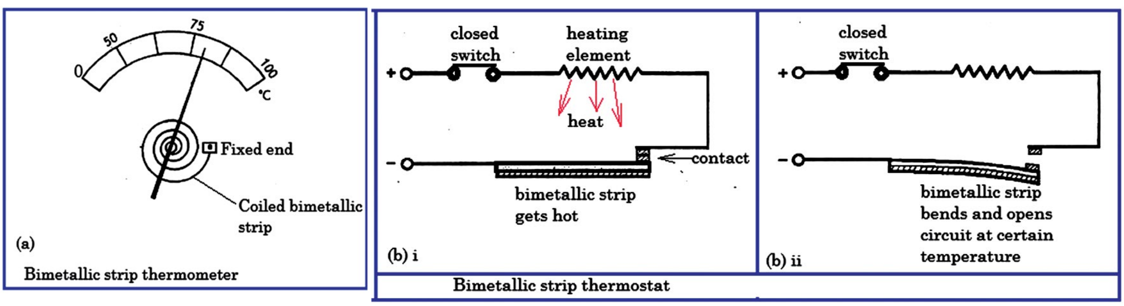

Figure 1.14: uses of bimetallic strip

5. Gears are normally fitted into axles by sliding in a very cold (contracted) axle into the gears and then leave it there to warm up. As the axle warms up, it expands and makes a very tight fix. This process is called shrink fitting as shown in figure 1.15. many parts of bicycle are joined by shrink fitting.
6. Riveting is a technique that uses thermal expansion to join flat sheets of metals. A hot rivet is inserted into a rivet hole as shown in figure 1.16 and hammered into shape while still hot. As the rivet cools it contracts and makes a tight fix.
7. When a bottle cover makes a tight fix, it can be unscrewed by pouring hot water on the cover so that it expands and become loose.

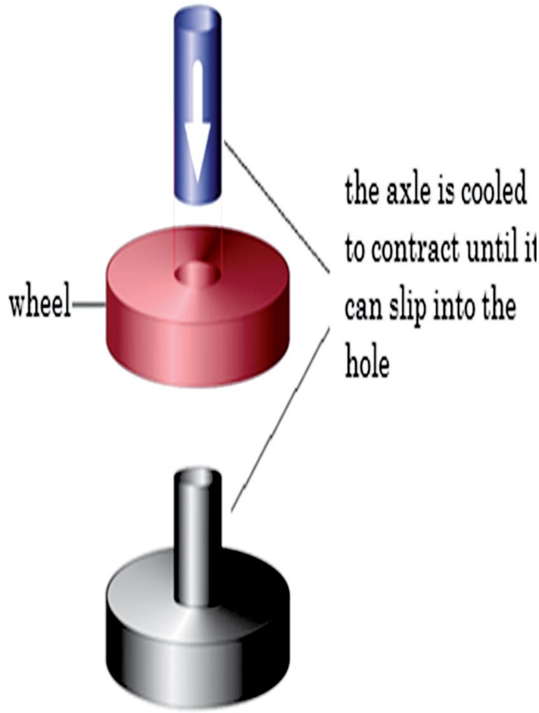

Figure 1.15: Shrink fitting

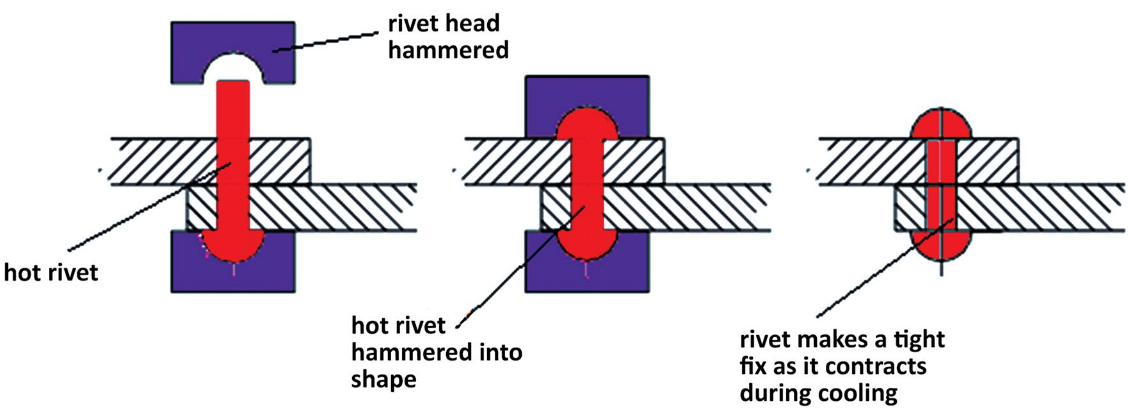

Figure 1.16: Riveting

Key point
Practical applications of thermal expansion may include the following
- Shrink fitting
- Riveting
- Separating stuck tumblers
- Removing bottle covers that are tightly screwed
- Putting gaps in fences, slabs and railway lines

Unit Summary

- Temperature of a substance is related to the degree of movement of the particles in the substance. The greater the molecular motion the higher the temperature.
- All substances expand when temperature rises and contract when cooled.
- Expansion is due to substance particles that move further apart when their motion increases with temperature rise.
- In general the expansion of solids is much less than that of liquids and expansion of liquids is much more less than that of gases. This is so because solids have stronger molecular forces than liquids and liquids have stronger molecular forces than gases. In gases the intermolecular forces are almost zero.
- Expansion of material is associated with decrease in its density because its volume increases while mass remain the same.
- Water behaves differently from other materials in that cooling it below 4°C, the water expands instead of contracting. This makes ice to have a lower density that liquid water so that ice floats on water.
- Thermal expansion of materials has problems as well as uses. The problems include breaking of walls, slabs, railways lines and steam pipes. Uses include, tooth filling, shrink fitting, riveting and unscrewing of tight fitted bottle tops

End of unit exercise

1. What is temperature?
2. What is the relationship between temperature and molecular motion of a substance?
3. Explain why materials expand when heated and contract when cooled.
4. Figure 1.17 shows a device used to switch on and off electricity automatically in an electric appliance like electric iron.

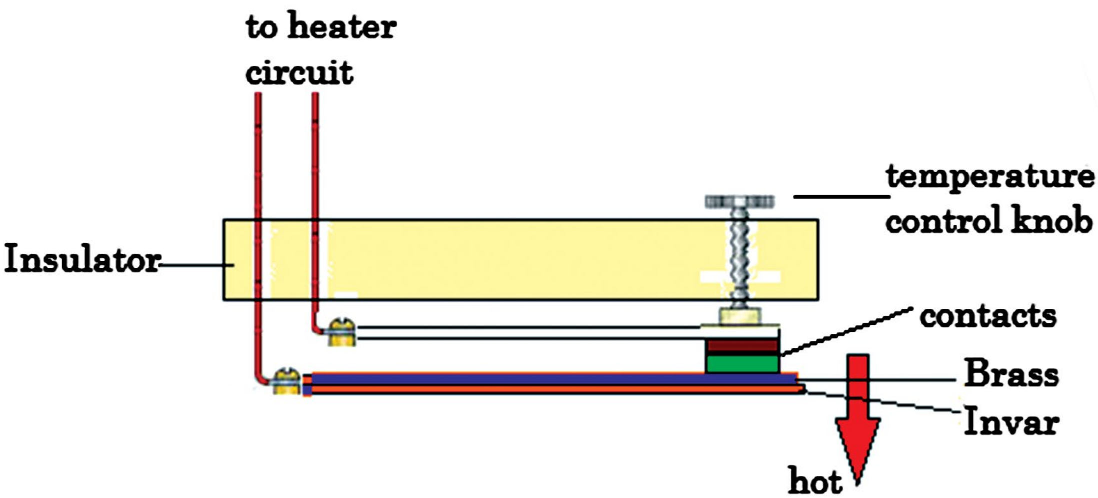

Figure 1.17: Exercise

a. Name the device.
b. Explain why bending occurs when device gets heated or cooled.
c. If bending occurs in the direction of arrow when heated, compare expansion of brass and invar.
d. Which other two electric appliances use this electric appliances other than electric iron.

5. Figure 1.17 is a graph showing temperature of water against density and volume.

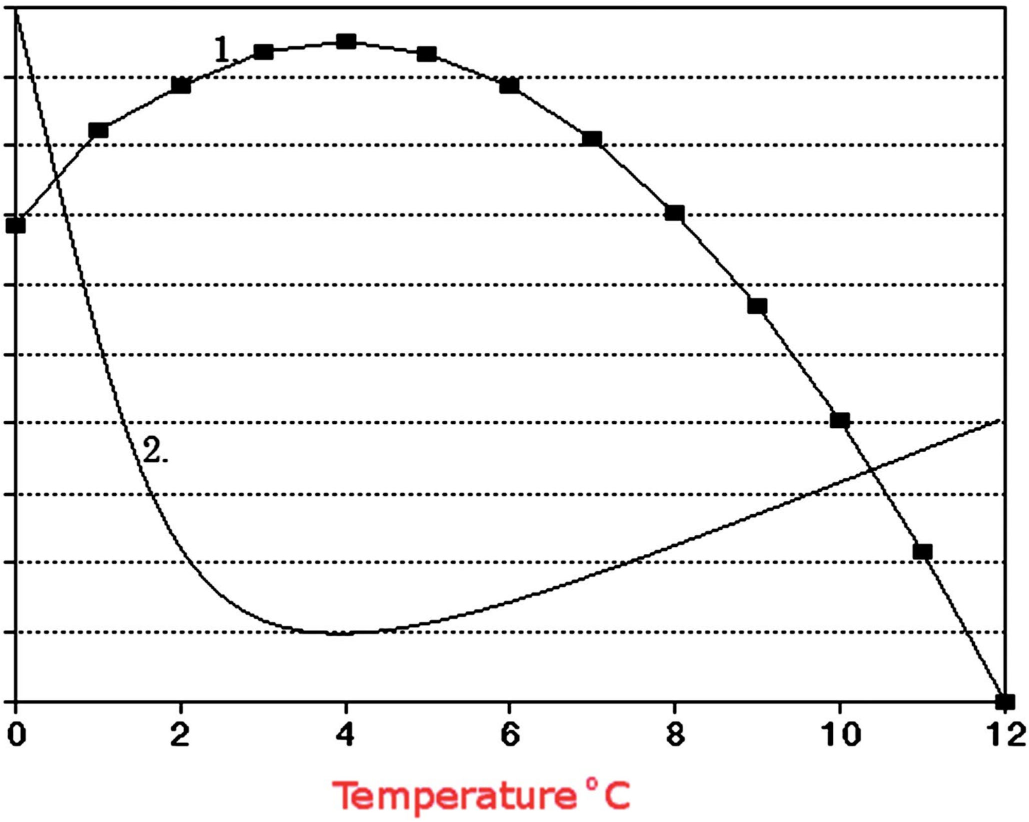

Figure 1.17: Exercise

a. Which of the two graph lines 1 and 2 represent a graph of water temperature against;
   i. Volume
   ii. Density
b. At what temperature will the water have the largest density? Explain.

6. Explain any two problems of expansion and how the problem is prevented.

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UNIT 2

Why does an object move like it does? How does the object accelerate or decelerate?Motion is described using quantities such as time, distance or displacement, velocity, and acceleration. Today scientists have managed to send spacecrafts to far planets. People are travelling around the world in a short time more possible than ever before. Newton's Laws are about ways in which motion can be explained.All motions are influenced by forces and Sir Isaac Newton (1642-1727), formulated laws that govern motion of any object. In this unit you will learn about these Newton's laws. You will also learn about inertia and the linear law of conservation of linear momentum.

Newton's laws of motion

Know your scientist.

Sir Isaac Newton.
(1642-1727)

- He explained how gravity works.
- Used to make wind mills and mechanical toys.
- Invented calculus.
- Discovered secret of light and colour.
- Knighted by Queen Anne in 1705.

Newton's laws of motion

There are three laws that govern motion as developed by Isaac Newton and so the laws bear his name. In this section you will notice that all the laws are relating motion to amounts and direction of forces acting on a body.

Activity 2.1

Describing Newton's first law of motion

Materials

- A tumbler
- Water
- Toy car
- Match box
- Tennis ball
- Large X mark on paper
- Paper card
- Coin

Method

1. Fill a tumbler with water to the brim
2. Holding the tumbler in your stretched

hand, quickly move the arm sideways from back to forward and stop the movement suddenly. Make observation on what happens to the water when
   a. Movement starts suddenly
   b. Movement stops suddenly
   c. Movement changes direction
3. Put a match box on top of a toy car as shown in figure 2.1 and place the toy on a flat surface with an obstacle in front of it.

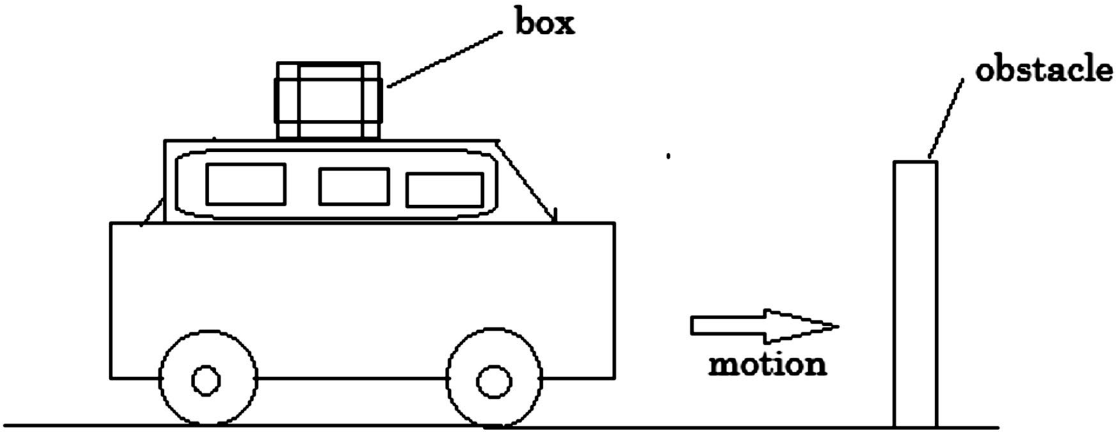


Figure 2.1: Investigating Newton's first law

4. Make the car move forward towards the obstacle and let it hit the obstacle. Observe and explain what happens to the box when the car hits the obstacle.
5. Go outside your classroom and put a piece of paper (or container) on the ground.
6. Let one person hold the tennis ball whilst running towards a target and drop the ball (do not throw it) on the paper or container while passing past the target as shown in figure 2.2. Repeat a number of times while others are observing alongside the running path. Make observation and explain;
   a. What happens when the ball is released right on top of target?
   b. What happens when the ball is released sometime distance before target?
7. Repeat step 6 using different speeds.

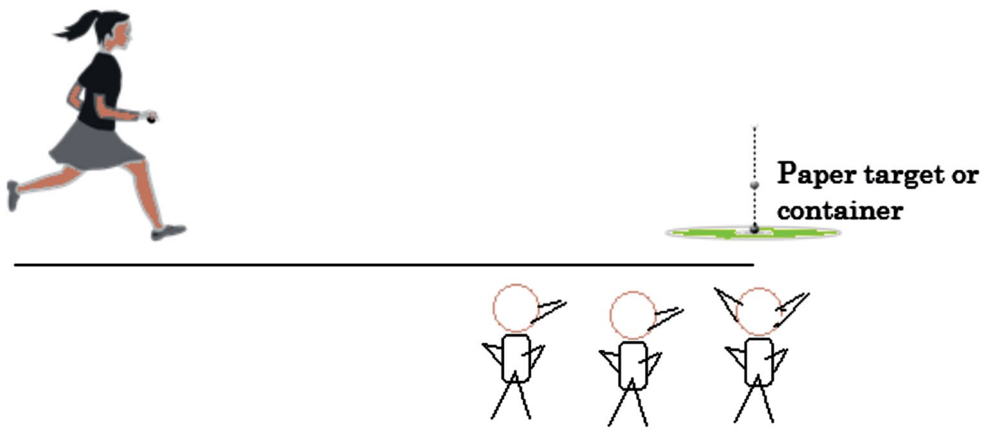


Figure 2.2: Dropping a ball on target whilst running.

8. Make a diagram to show how the ball moves to land on the target.
9. Place a card on top of a tumbler. With a coin on top of the card, pull the card sharply from under the coin. Make and explain the observation.

Feedback

When a tumbler with water is moved, the water spills out during starting and ending of motion. This is so because at starting the water is stationary and tries to remain so hence it spills over when made to start moving. At the end of motion, the water is moving and tries to keep on moving hence spills over when the motion suddenly stops. Changing direction has the same effect. A match box on top of the moving toy car is thrown forward when the toy car hits an obstacle because the match box is trying to keep on moving since there is no force that can stop it doing so. Only the car stops because the obstacle exerts an opposing force on it. To drop a tennis ball on target, it has to be dropped well before the target because the ball will continue moving forward whilst dropping down due to gravity as shown in figure 2.3.

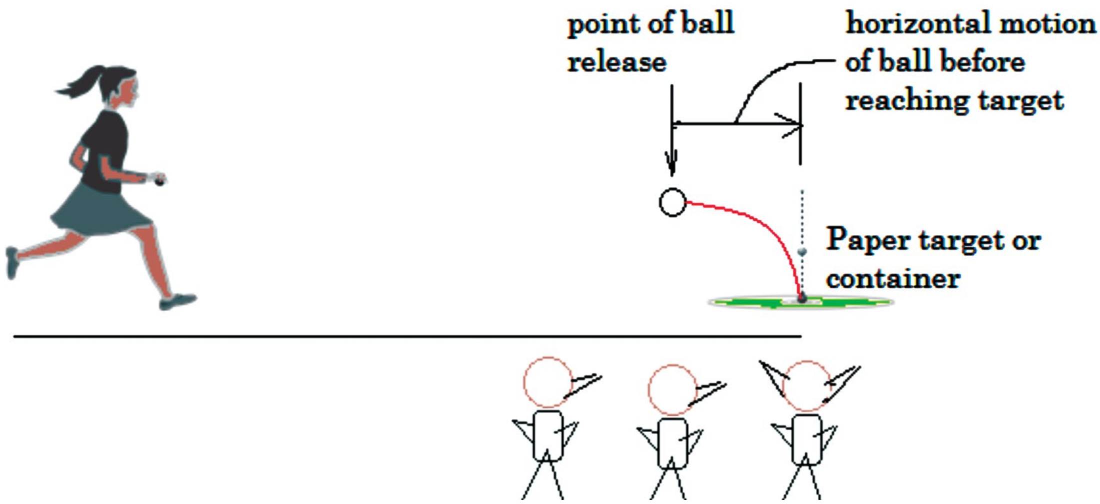


Figure 2.3 Horizontal movement of a vertically dropped ball

While force of gravity pulls the ball down, there is no force that changes its horizontal motion hence it keeps on moving forward.
The Newton's first law says that *an object which is at rest will remain at rest and a moving object continues to move at uniform speed in a straight lineunless it is acted upon by an unbalanced force.*

Figure 2.4 illustrates Newton's first law using a ball.

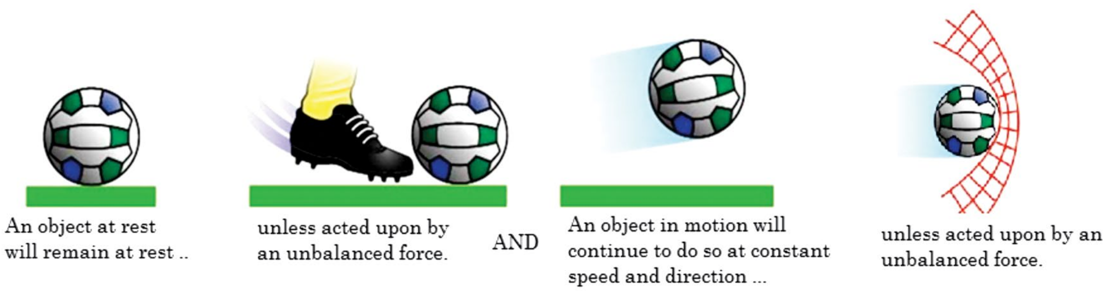


Figure 2.4 Forces that start or change motion

This is also called law of inertia. Inertia is the reluctance of a body to change its state of motion. Inertia makes a stationary object not able to start moving on its own. Objects start moving only when an external resultant force is exerted on them. Inertia also makes it difficult for motion to change its speed or direction. Inertia is large when mass of object is large. Because of this, mass of a body can be used as a measure of its inertia.

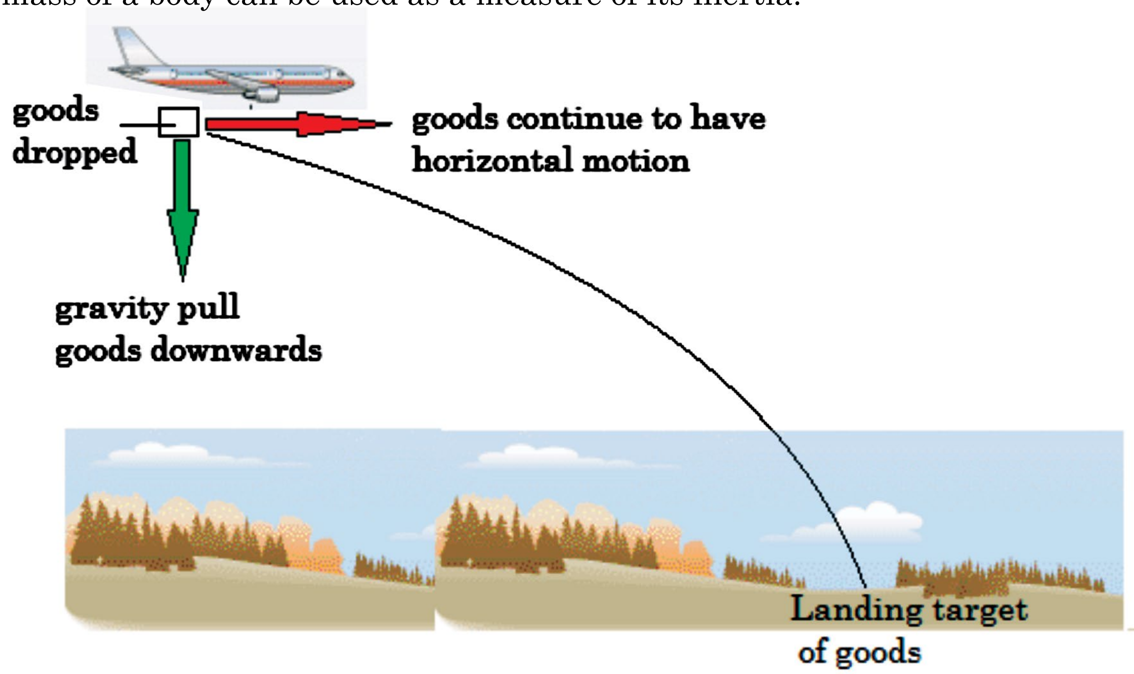


Figure 2.5 Goods dropped from a plane continue moving horizontally

Applications of Newton's first law

There are so many applications of Newton's first law in our day to day life. The following are just some of them.

- *Dropping goods from aircrafts.* When goods are dropped from aircrafts, they are dropped ahead of landing position as shown in figure 2.5. This is so because the goods continue to move horizontally with the aircraft and without gravity they would continue with such horizontal movement.
- Force of gravity pulls the goods down but the horizontal motion continues unless air resistance is large enough to slow it down.

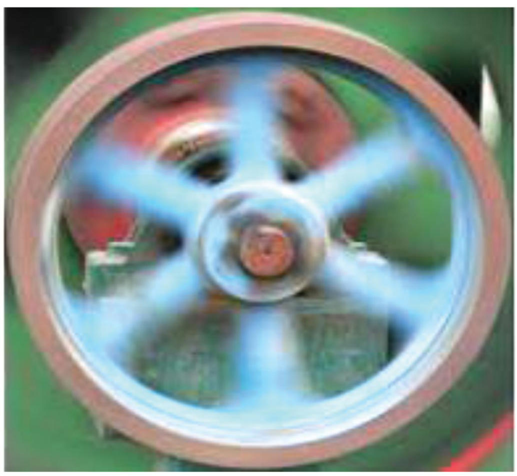


Figure 2.6 A moving fly wheel tends to keep on moving

- *Use of fly wheel.* Most engines have a flywheel attached to their crankshaft. Remember that a larger mass has large inertia. Once the engine is in motion the fly wheel helps to maintain a smooth running due to its large inertia. Of course the flywheel makes starting of the engine more difficult requiring a larger effort. Figure 2.6 shows a picture of a fly wheel attached to an engine to make it keep on running smoothly.

- *Action of seat belt.* A passenger in a car moves together and at the same speed as the car itself. When brakes are applied, an unbalanced braking force is applied on the car but the passengers continue to move at original speed and they may

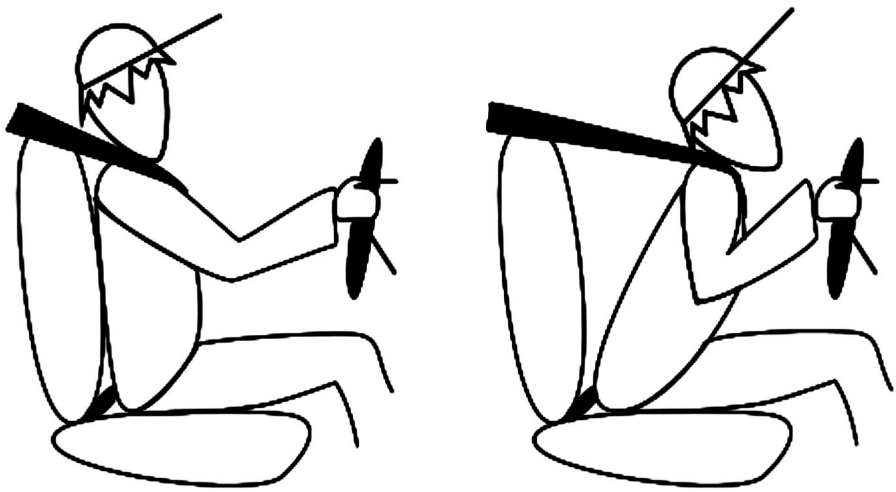


Figure 2.7 Action of seat belt in a car

collide with the windscreen, steering wheel or anything on their forward motion path. If a seat belt is used, the seat belt applies unbalanced force stopping the passenger from hitting objects. This protects passenger from dangerous injuries when accidents happen as shown in figure 2.7

Figure 2.8 Shows a picture of motorist who continues to move forward when the motorcycle is stopped suddenly after bumping into tyres during a race.

While the motor cycle is stopped the cyclist continue moving hence

Figure 2.8 Cyclistcontinue to move when motor cycle is stopped.

Source: www.pendrum.wordpress.com

is thrown forward.

- *Tightening hammers, hoes and axes.* Tools like hoes, axes and hammers are tightened by moving the handle down onto a hard object as shown in figure 2.9. The handles is suddenly stopped by opposing force of the hard object while the axe or hoe continue its motion down into the wood and in the process make a tight fix.

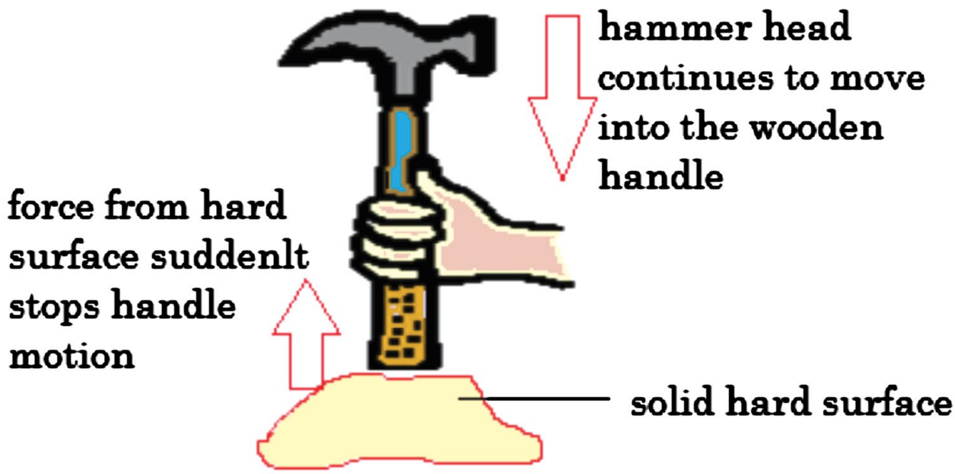


Figure 2.9 Hammer continues to move down when handle suddenly stops.

- *Dislodging jelly or paste from bottle.* Jelly or paste material can be dislodged from its container by flicking the container downwards. The paste or jelly continues to move out while the container is stopped.

Key point
Newton's first law of motion
An object which is at rest will remain at rest and a moving object continues to move at uniform speed in a straight1ight line unless it is acted upon by unbalanced force

Exercise2.1.

i. What is inertia?
ii. Two equal forces act on a body. What will be the effect on the body under the following situations?
   a. The two forces act on a stationary object opposite to each other.
   b. The two forces act on a moving object opposite to each other and the motion has same direction as one of the forces.
   c. The two forces act on a moving object opposite to each other and the motion has direction perpendicular to one of the forces.
   d. The two forces act on a stationary object acting in the same direction.

e. The two forces act on a moving object in the same direction and the motion has same direction as the forces.

iii. The figure 2.10 shows a truck involved in an accident.
   a. Explain this accident using Newton' first law.
   b. Suggest two solutions to avoid such accidents.

iv. Describe one experiment you can do to illustrate inertia of two objects of different masses.

Figure 2.10 Action of Newton's law

Activity 2.2

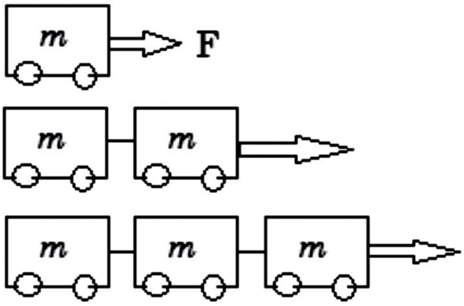
Describing Newton's second law of motion

Materials

- A stone
- Apiece of paper
- Sand (or flour) in a bucket
- Two identical toy cars (same mass)

Method

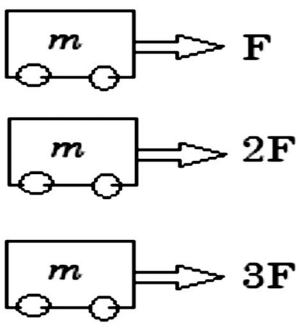
1. Drop a stone and wadded piece of paper at the same time from same height into a bucket containing sand or flour.
   a. What can you say about the values of acceleration on the two objects due to force of gravity, is it the same or different? Give reason for your answer.
   b. The stone has greater mass than the paper. Which object exerts greater force on impact when they hit the sand or flour in the bucket (check the size of crater or dent made in the sand)
   c. Deduce the relationship of force and mass by stating whether the following statements are true or false.
      i. More force is needed to make object with larger mass to move at the same acceleration as an object with smaller mass.
      ii. A moving object with larger mass exerts more force than an object with smaller mass if they move at the same acceleration.
2. Push the two identical toy cars on the floor at the same time giving one a harder push (greater force) than the other. Make observation and discuss the following;
   a. The two toy cars have same mass but different forces acting on them. Which car has larger acceleration, the one with smaller force acting on it or the one with larger force?
   b. Deduce the relationship of force and acceleration by stating whether the following statements are true or false.
      i. To move two objects with same mass at different accelerations, a larger force is needed to produce a larger acceleration.
      ii. Increasing a force on a body will increase its acceleration.
3. Fill the tables in figure 2.12 to illustrate relationships between force, mass and acceleration as follows;



acceleration	mass	force
a	m	F
a	$2m$	
a	$3m$	

Figure 2.11 Changes of force to accelerate different masses

a. To produce an acceleration, a on a body of mass, m, a force F is used. How much force would be exerted to produce the same acceleration a, on different masses, $2m$ and $3m$. Fill the table in figure 2.11



acceleration	mass	force
a	m	F
	m	$2F$
	m	$3F$

Figure 2.12 Changes of acceleration with different forces

b. To produce an acceleration, a on a body of mass, m, a force F is used. How much acceleration would be produced on the same mass m using different multiples of force $2F$ and $3F$? Fill the table in figure 2.12

Feedback

From the activity above, you must have observed that a larger force is needed to produce a larger acceleration. A larger force is also needed to produce acceleration on a larger mass than on a smaller mass. This is what is contained in Newton's second law which states that the amount of force needed to move an object is directly proportional to the mass of the object and the acceleration produced. Mathematically this law can be expressed as 'when an object is acted on by an external force F, the magnitude of this force F equals the product of the mass, m of the object and the resultant acceleration, a'. This gives us the formula for calculating force as *Force = mass x acceleration* or simply $F = ma$

Remember that the units of force are newtons. To achieve this unit using Newton's second law, the value of mass must always be in kilograms and the acceleration must always be in metres per second squared.

A force of 1N is the amount of force that is required to move an object of mass 1kg so that it accelerates at $1ms^{-2}$. This means $1N = 1kgms^{-2}$.

In a situation where many forces are acting on a body, the resultant force acting in the direction of acceleration is used in this formula. Opposing forces such as friction are added or subtracted to or from total to find the resultant force.

For all objects under the influence of force of gravity, the acceleration is always the same, known as acceleration due to gravity, g which is approximately $10ms^{-2}$ on most places on earth. For such situations the force F is called weight W hence formula for Newton's second law formula, $F = ma$ becomes $W = mg$

Examples

1. How much force is required to kick a ball of mass 400g so that it achieves an acceleration of $2ms^{-2}$

   Solution:

   $F = ma$

   $m = 400g = 0.4kg$ and $a = 2ms^{-2}$

   $F = ma = 0.4\ kg \times 2ms^{-2} = 0.8\ kgms^{-2} = 0.8N$

2. A box is pushed across the floor using an effort of 300N when friction between the box and the floor is 120N. What is the acceleration on the box whose mass is 15kg.

Solution:

$F = ma$

$$a \rightarrow \frac{F}{m}$$

$F = 300-120 = 180N$ and $m = 15kg$

$$\therefore a = \frac{180N}{15kg} = 12ms^{-2}$$

3. A force of gravity of 6N acts on an object. What is the mass of the object?

   Solution:

   This is under influence of force of gravity, therefore

   $F = ma$ becomes $W = mg$

$$\rightarrow m = \frac{W}{g}$$

$W = 6N$ and $g = 10 \text{ ms}^{-2}$

$$\therefore m = \frac{6N}{10\text{ms}^{-2}} = 0.6kg$$

Key point

Newton's second law

Force needed to move an object is directly proportional to the mass of the object and acceleration produced.

Exercise 2.2

1. Work out the values of force required to make an object with mass 3000g move with the following accelerations?
   a. 1ms^{-2}
   b. 0.5ms^{-2}
   c. 3ms^{-2}
   d. 4cms^{-2}
2. What is the acceleration of an object of mass 12kg when a force of 360N is used to make it move?
3. If a push of 3N on a suspended ball made it to move with an acceleration of 1.5ms^{-2}, what is the mass of the ball?
4. ∴ Explain why a truck uses more fuel than a saloon car when they travel through the same distance within the same time.

Activity 2.3

Describing Newton's third law of motion

Materials

- A thin nylon string
- Ball pen casing
- A balloon
- A straw
- Rubber band
- Cello tape
- Two spring balances

Method

1. Slide the nylon string through the ball pen casing and then tie the nylon string between two chairs or desks so that it stays tight between the chairs.
2. Insert a straw half way into the mouth of the balloon and tie the mouth tightly with rubber band making sure that the straw is not tied closed.
3. Stick the balloon to the ball pen casing using cello tape and slide it to one end of the nylon string as shown in figure 2.13.

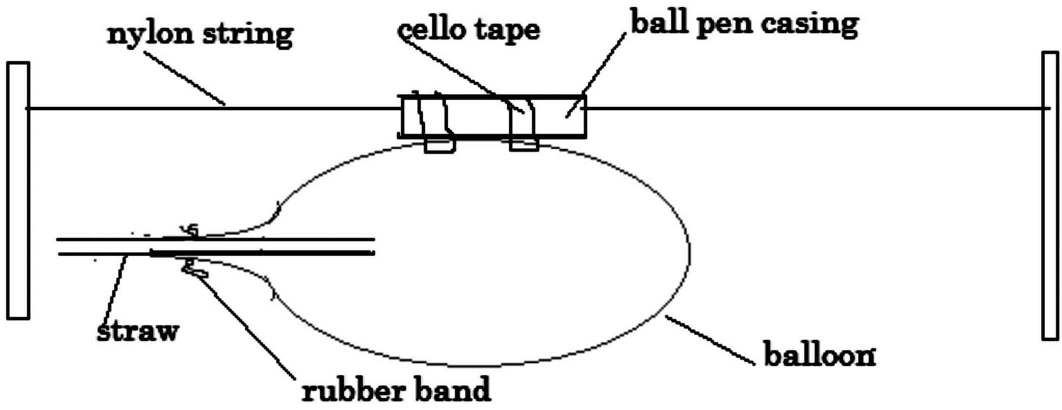


Figure 2.13 Demonstrating Newton's third law

4. Inflate the balloon through the straw and when fully inflated leave it so that air comes out of the straw. Make observations and discuss the following:
   a. What is the direction of air compared to the direction of travel of the balloon?
   b. How do you compare the direction of forces that move the air and the balloon?
   c. How do you compare the magnitude of the two forces that move the air and the balloon?
5. Attach a spring balance to an object that cannot move. Attach a second spring balance to the first one and pull on the second spring balance as shown in figure2.14.

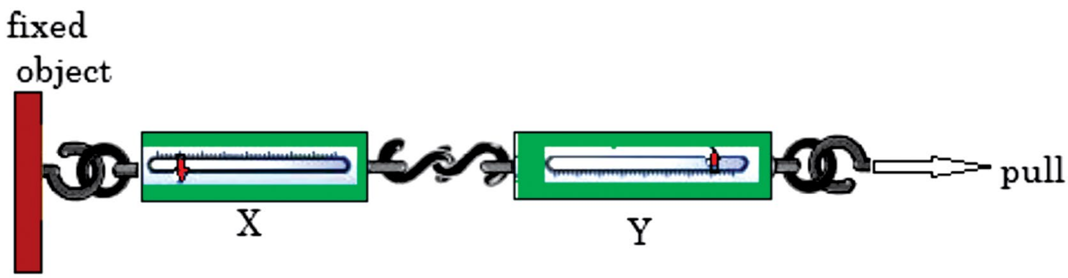


Figure 2.14 Values of opposing forces

   a. By how much force is the fixed object pulling on the spring balances?
   b. By how much force are pulling on the fixed object?
   c. At any point how do you compare the pull of the fixed object as read on spring balance X and your pull as read on spring balance Y?

Feedback

In the activity above you noted that forces act in pairs. This is what is expressed in Newton's third law which states that, 'to every force of action, there is an equal but opposite force of reaction'. In the balloon experiment, the amount of force that pushes the air out of the balloon is equal to the amount of force that pushes the balloon forward. This is true all the time. When you lean against a tree, the force you exert on the tree is actually equal to the amount of force that the tree exerts on you in order to support you. When you put books on a table, the table exerts an upward force on the books which is equal to weight of the books. This is the reason why you noticed that the force readings on the two spring balances were always equal in step 5 of the activity above. The fixed support was pulling on you just as you were pulling it with equal forces.

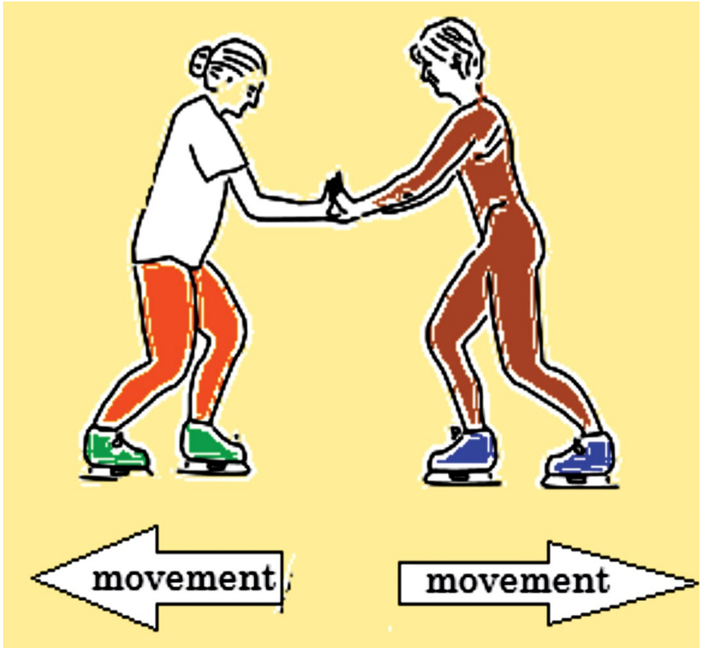


Figure 2.15 Opposite forces that do not cancel each other

It is important to take note that although the two opposite forces are equal , they do not cancel each other to zero. This is so because the two forces act on two different bodies and each one may cause acceleration on the body it is acting on. For this reason two people that may push each other with equal forces on a skater may move away from each other as shown in figure 2.15.

Key point
Newton's third law
To every force of action, there is an equal but opposite force of reaction

There are so many applications in our everyday life of Newton's third law. Some of such applications are discussed below.

The action of jet engine

A jet is one type of airplanes well known by its high speed. This is achieved using Newton's third law just as in the balloon experiment. The steps of the jet engine as shown in figure 2.16 works as follows:

1. The fan helps to suck air from front into the engine. Much of such air bypasses the engine by going through duct around the engine. Some of the air goes into the engine.
2. The air that enters the engine is squeezed together by compressor blades raising its pressure when it enters a combustion chamber.

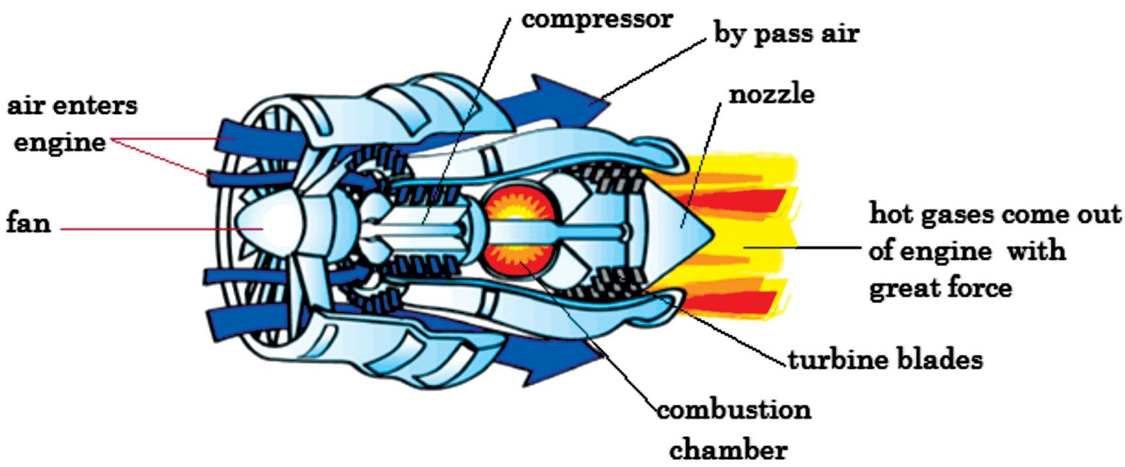


Figure 2.16 Action of jet engine
Source: http://www.grc.nasa.gov/WWW/k-12/UEET/
StudentSite/engines.html

3. In the combustion chamber, the high pressure air is mixed with fuel and then burnt to produce hot expanding gases. In the combustion chamber the temperature may be as high as 2700°C.
4. When the hot gases from combustion engine passes through the turbine, they turn the turbine blades round. The turning turbine helps to rotate both the intake fan and the compressor blades.
5. At the end of the engine there is a nozzle which makes the exhaust duct of the whole engine. The hot air flows from the turbine and the cool bypass air are pushed out from the back of the engine and this produce an equal forward force that propels the air plane forward.

The action of rocket engine

A rocket engine works by forcing gases produced when fuel burns, out of its nozzle with very big forceas shown in figure 2.17. An equal but opposite force pushes the rocket forward. This is Newton's third law since the rocket

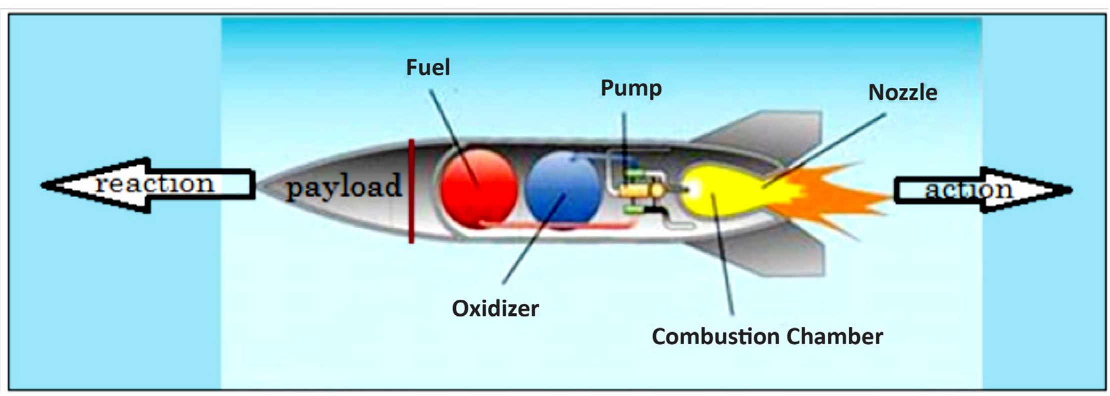


Figure 2.17 Action of a rocket
Sourced: http://www.teachengineering.org/

act by pushing on the gases and in turn the gases react by pushing the whole rocket forward.

Figure 2.18 shows a real rocket during its launch into space carrying a load which is normally called payload.

Figure 2.18 Rocket launch
Source http://everydaylife.globalpost.com/

Walking, swimming, and movement of tyres

For us to walk forward, our foot pushes the ground backward. It is the ground that pushes us forward with a force equal to the push of our foot. This is true when tyres of a car push the ground backward as they roll so that an equal opposite reaction force from the ground pushes the car forward. If there is not enough friction from the ground as in the case of loose or muddy ground it is difficult to move forward. Such reaction force is well observed when one tries to jump out of a boat, where the boat is seen pushed backward as it equally pushes you forward. Figure 2.19 shows some examples of Newton's third law in action.

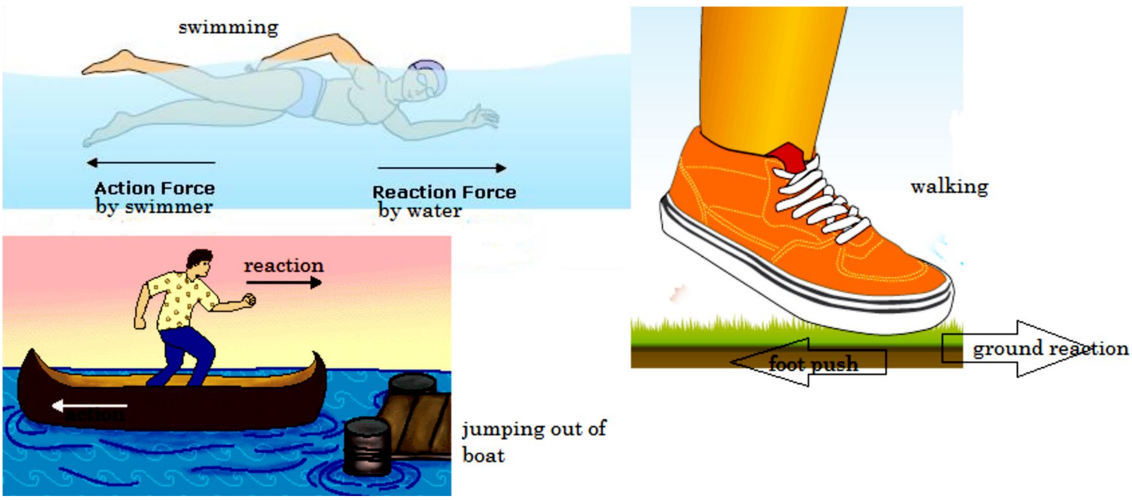


Figure 2.19 Newton's third law in action

Linear momentum

The Newton's second law can also be explained using the idea of momentum.

You remember the following two famous equations

$$v = u + at \text{ or } a = \frac{v\text{-}u}{t}$$

and Newton's second law $F = ma$

Substituting for a gives

$$F = m\left(\frac{v\text{-}u}{t}\right)$$

$$F = \frac{mv\text{-}mu}{t}$$

Crossing t to the left gives $Ft = mv - mu$

Momentum is *mass* **x** *velocity*. The unit of momentum is $kgms^{-1}$. Momentum represents the ability of a moving object to drive through. The formula shows that momentum increases with mass of the object and its velocity.

Example

What is the momentum of the following moving objects?

a. A 4.2g bullet fired from a rifle moving at 1200m/s
b. A 100g stone thrown at a speed of 20m/s
c. A car with an average mass of 1500kg moving at a speed of 25m/s.

Solution

a. momentum = mass x velocity
mass = 4.2g = 0.042kg

$$Velocity = \frac{1200m}{s}$$

$$momentum = 0.042 \times \frac{1200m}{s} = 50.4\ kg$$

$\therefore$

b. momentum = mass x velocity
mass = 100g = 0.1kg

$$Velocity = \frac{20m}{s}$$

$$\therefore velocity = 0.01kg \times \frac{20m}{s} = 2kgms^{-1}$$

c. momentum = mass x velocity

mass = 1500kg

$Velocity = \frac{25m}{s}$

$\therefore$ momentum = 1500 x $\frac{25m}{s}$ = kgms^{-1} = 37 500kgms^{-1}

Notice how a bullet from a gun possesses large momentum due to its high speed than a large stone moving at a smaller speed. The large mass of a car gives it large momentum when it moves. The momentum increases even more when the car increases its speed.

Since momentum is *x velocity, mv - mu* gives change in momentum as a moving object changes its velocity from u to v. The part $\frac{mv-mu}{t}$ gives rate of change in momentum. Since $F = ma$ becomes

F = $\frac{mv-mu}{t}$ Newton's second law can also be defined as the rate of change in momentum.

In the formula $Ft = mv - mu$, Ft is called impulse. From this equation, change in momentum gives us impulse. The units of impulse are *Ns* which should be equal to the units of momentum, $kgms^{-1}$.

Example

A football with a mass of 430g is kicked and reaches the hands of a goal keeper at a speed of 25m/s. work out;

a. Momentum of the ball just before reaching the hands of the goal keeper
b. Momentum of the ball after being caught in the hands of the goal keeper.
c. The average force used by the hands of the goal keeper
   i. in catching the ball slowly for 0.5seconds
   ii. in catching the ball suddenly for 0.1second

Solution

a. *momentum = mass x velocity = 0.43kg x* = $10.75\ kgms^{-s}$

b. *momentum = mass x velocity = 0.43kg x* $\frac{0m}{s} = 0$

c. $Ft = mv - mu$

i $F \times 0.5s = 0.43kg \times 0 - 0.43kg \times \frac{25m}{s}$

$$\therefore F = \frac{-0.43kg \times \frac{25m}{s}}{0.5s} = \frac{10.75}{0.5} = -21.5kgms^{-2} = 21.5N$$

ii. $F \times 0.1s = 0.43kg \times 0 - 0.43kg \times \frac{25m}{s}$

$$F = \frac{-0.43kg \times \frac{25m}{s}}{0.1s} = \frac{10.75}{0.1} = -21.5kgms^{-2} = 107.5N$$

From the example above, notice how increasing time through which momentum changes reduces the amount of impact force. This is the principle of the seat belts and air bags in a car to prevent accidents from becoming fatal or serious injuries. The seat belt and air bag increases the time a passenger moves to the front and hence collision has less force of impact. A cat lands slowly when it jumps just as a goal keeper catches a ball slowly, to increase time of impact and consequently reduce impact force on its legs and hands respectively.Figure 2.20 shows seat belts and a cat in action.

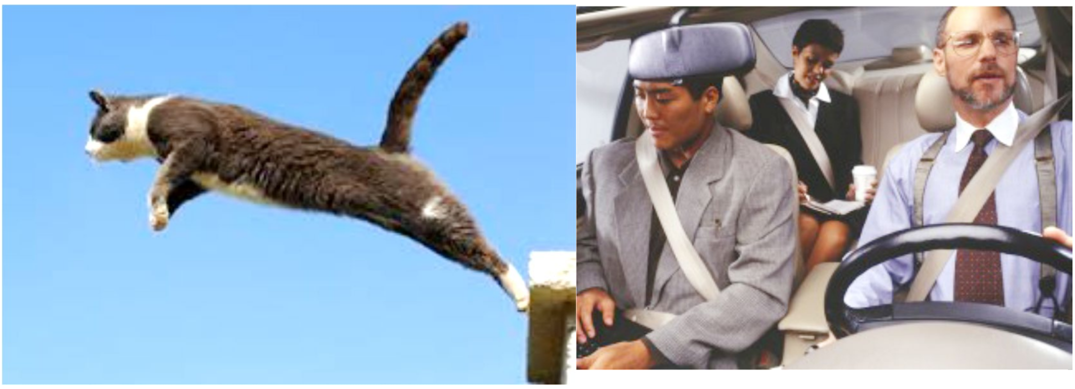


Figure 2.20 a cat careful landing and use of seat belt to reduce forces of impact

Many cars have along front which bends and fold back during collision and this increases time of change of momentum which reduces force of impact. This long front is called crumple zone. A combination of seat belt and air bag is more advantageous than seat belt alone as illustrated in figure 2.21

Figure 2.21 A combination of crumple zone of car, seat belt and air bag is better used to achieve maximum reduction in force of impact

Conservation of Linear momentum

The idea of conservation of momentum helps us to understand what happens to motion and forces during collisions or separation of objects in motion.

If two objects collide, each of the bodies exerts a force on the other. Each one receive an equal but opposite impulse, *Ft* or indeed equal change in momentum, *mv -mu. The principle of conservation of linear momentum states that the total momentum of objects under collision remains constant provided there is no external force acting on them.*

Example 1

A trolley with mass 200g moves at 10m/s and collides with a stationary trolley of mass 150g. What will be the new velocity if

i. The two trolleys move together.

ii. The approaching trolley stops while the stationary trolley moves.

Solution

Let mass and velocity of trolley 1 be m_1 and v_1 respectively. Similarly let mass and velocity of trolley 2 be m_2 and v_2 respectively

(i) The initial total momentum = The final total momentum

$$(m_1 \, x \, v_1 + m_2 \, x \, v_2)_i = (m_1 \, x \, v_1 + m_2 \, x \, v_2)_f$$

$$\left(200g \, x \, \frac{10m}{s} + 150g \, x \, 0\right)_i = ((200 + 150) \text{ x v})_f$$

$$2000gms\text{-}1 = 350v$$

$$\therefore \; v = \frac{2000 \, gms^{-1}}{350 \, g} = 5.7m/s$$

(ii) The initial total momentum = The final total momentum

$$(m_1 \times v_1 + m_2 \times v_2)_i = (m_1 \times v_1 + m_2 \times v_2)_f$$

$$(200g \times 10m/s + 150g \times 0)_i = (200g \times 0 + 150g \times v_2)_f$$

$$(2000gms^{-1} + 0)_i = (0 + 150 \times v_2)_f$$

$$v_2 = \frac{2000 \, gms^{-1}}{150 \, g} = 13.3m/s$$

Note: In the above example it was not necessary to change the masses to kilograms since these will cancel out in the solving process.

Example 2
When a gun shoots a bullet, the gun always jerks backwards due to recoil of the spring inside it. What would be the recoil velocity of a rifle with mass 3.5kg when it shoots a bullet of mass 50g at a speed of 1400m/s?

Solution
Initially the total momentum of the gun and the bullet is zero.

The initial total momentum = the final total momentum

$$(m_1 \times v_1 + m_2 \times v_2)\_i = (m_1 \times v_1 + m_2 \times v_2)_f$$

$$(0)_i = (3.5kg \times v_1 + 0.05kg \times 1400\text{m/s})_f$$

$$-70\text{kgms}^{-1} = (3.5\text{kg} \times \text{v}^1 +)$$

$$\therefore v_1 = \frac{-70kgms^{-1}}{3.5\ kg} = -20ms^{-1}$$

Notice that the minus sign shows that the velocity was backward than forward.

Key point
The law of conservation of linear momentum
The total momentum of objects under collision remains constant provided there is no external force acting on them.

Exercise 2.3

1. The figure shows two cars in head on collision. Using this figure 2.23 answer the questions that follow:
   a. What is momentum
   b. State the law of conservation of linear momentum.
   c. How do forces of impact between the two cars compare. Explain.
   d. State three measures employed in a car to minimise force of impact on passengers in a car.

Figure 2.22 Collision of cars

2. Calculate the momentum of the following:
   i. An electron of mass 9.1 x 10^{-31}kg moving at 2.2 x10^6m/s.

ii. A bullet of mass 0.16kg fired at a speed of 900m/s
iii. A 90kg base ball player running at 9.2m/s
iv. A passenger plane of mass 350 000kg, coming down on a runway at 1.5m/s

3. A bicycle and its cyclist have a momentum of 24kg/m/s. What would be the momentum if
   i. The mass doubled at the same speed
   ii. The mass remained the same but the speed doubled
4. A bullet of mass 300g is fired into a stationary wooden trolley of mass 5kg. The bullet and the trolley move together at a velocity of 6m/s.
   i. What was the initial velocity of the bullet before entering into the wooden trolley?
   ii. Suggest one assumption you can make in solving this problem.
5. Two cars are involved in a head on collision accident on a straight stretch of a road as shown in figure 2.23

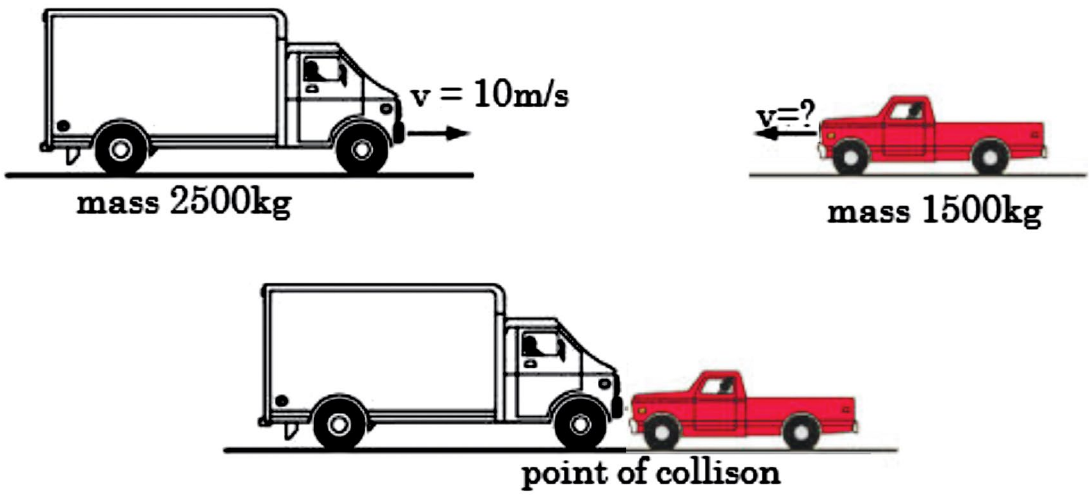


Figure 2.23 Change of momentum during collision

a. What was the momentum of the van just before the collision took place?
b. If the cars lock to each other and come to rest on the spot of collision, what was the initial velocity of the truck?

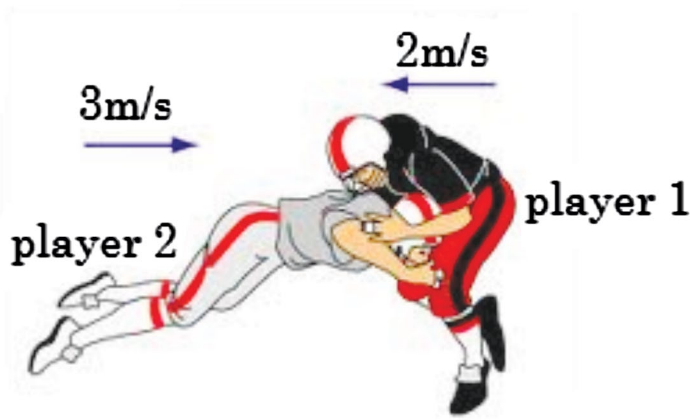


Figure 2.24 Collision of rugby players

c. If the van takes 0.75seconds to come to rest during the collision
    i. Work out the deceleration of the van.
    ii. The force while stopping during the collision.
    iii. The impulse of the van.

6. Figure 2.24 shows two rugby players under collision.
Work out the new velocity if the two players hold onto each other after collision and each one has a mass of 80kg.

Unit Summary

- Newton's laws of motion are laws that govern motion.
- The Newton's first law says that *an object which is at rest will remain at rest and a moving object continues to move at uniform speed in a straight line unless it is acted upon by an unbalanced force.*
- Newton's second law states that *acceleration of a moving object is directly proportional to the resultant force acting on it and inversely proportional to the mass of the object.*
- Mathematically, Newton's second law is written as
Force = mass x acceletion or simply $F = ma$
- Newton's second law can also be described in terms of momentum, that is *Force is equal to the rate of change in momentum,*

$$F — \frac{(mv - mu)}{t}$$

- Newton's third law states that "*whenever a force acts on one body, an equal and opposite force acts on the other body" or "to every force of action there is an equal and opposite force of reaction*"
- Momentum is the product of mass and velocity of a body.
- The principle of conservation of linear momentum states that *the total momentum of objects under collision remains constant provided there is no external force acting on them.*

End of unit exercise

1. A car with mass 1500kg is pulled so that it accelerates at $0.5ms^{-2}$.
    a. State Newton's second law of motion.
    b. Using Newton's second law work out the amount of force applied to the car.
2. A car with mass 2000kg travelling at 36km/h is made to stop over a distance of 30m when brakes are applied. Work out the following:
    ii. Its deceleration.
    iii. Amount of force applied by the brakes.
3. If a 40g stone is thrown and penetrates a cliff at 32m/s, stopping in a time of 0.04 seconds, work out the;
    ii. Distance of penetration into the cliff
    iii. Deceleration.
4. State the law of conservation of momentum.

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UNIT 3

Friction is another very important force that is all around us which occurs when ever two surfaces are in contact. What causes friction? Which factors affect the magnitude of friction? How can we apply the knowledge about friction? These are some of the questions that need answers when talking about friction? In this unit you will learn to answer such questions among others.

Frictional Force

Activity 3.1

Describing application of friction force.

Materials .

- Calculator
- Spring balance
- Masses with known values
- Block(wood, plastic or glass)
- Smooth and rough surfaces
- String

Method

1. Measure the weight of block by suspending it in air using a spring balance as shown in figure 3.1
2. Attach a wood block to a spring balance using a string and place it on a smooth surface.

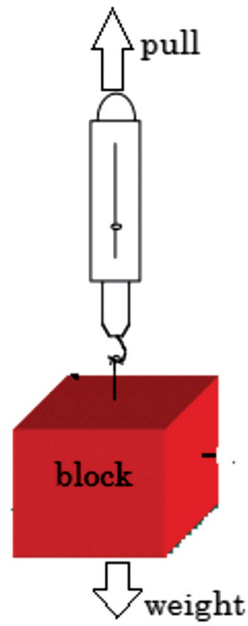

Figure 3.1 Measuring weight of block

3. Pull the block using the spring balance until it just starts moving as shown in figure 3.2. Note and record the value of force as read on

the spring balance.

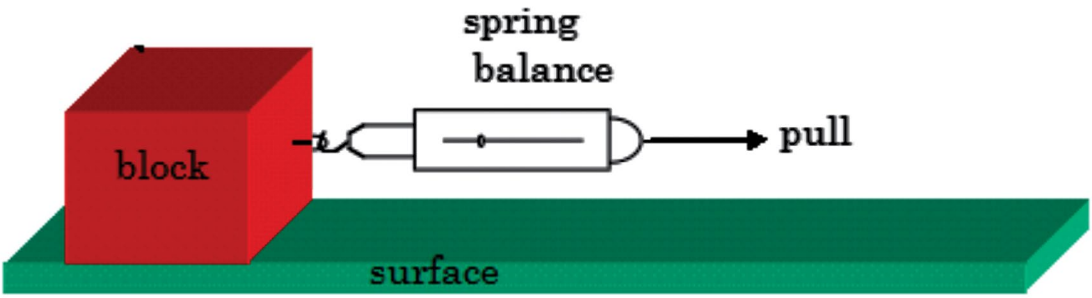

Figure 3.2 Measuring force to pull a block

a. What is the weight of the block on the surface?
b. Every force of action has an equal but opposite force of reaction. How much force is acting upwards onto the block by the surface?
c. Discuss the value and direction of frictional force between the block and surface.

4. Pull the block again so that it moves uniformly (or steadily). Read the spring balance while the block is in motion.

a. What is the comparison of friction when the object is moving and when it is static?
b. Discuss and explain the difference.

5. Repeat step 3 with different known values of additional mass placed on top of the block as shown in figure3.3.

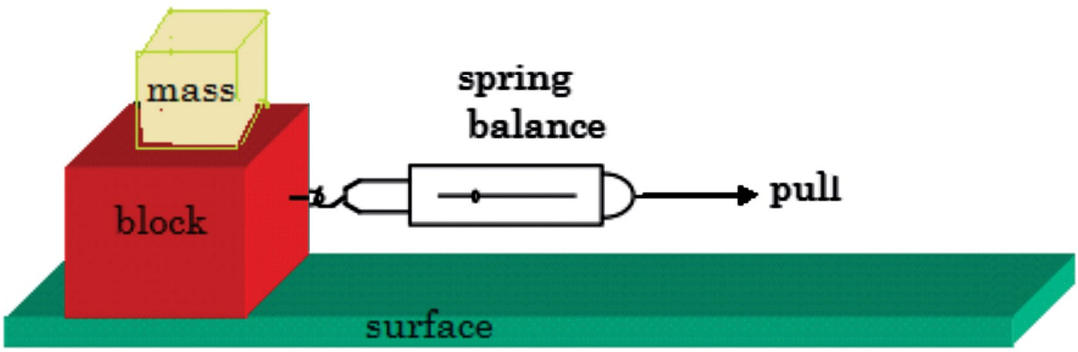

Figure 3.3 Measuring force to pull block of m ore mass

Table of results

Total weight of block and additional masses	Reaction force of surface	Value of pull as read on spring balance	Friction

6. Repeat step 3 on a rougher surface.
a. Discuss the comparison of friction on a rough and smooth surface.
b. Explain the differences of friction on rough and smooth surface.
7. Discuss situations where friction is necessary and where friction is a problem.
8. Discuss ways of reducing friction.

Feedback

Friction is force produced when two surfaces are in contact with each other. Friction acts to oppose motion or attempted motion; it does not cause the motion itself. Friction acts parallel to surfaces.

The magnitude of friction depends upon nature or details of surfaces in contact. For example; friction is less on wet surface than on dry surface, it is less on smooth surface than on rough surface. The materials of surface like rubber or wood or concrete also decide the nature of surface. For rough surfaces it is mainly due to surface projections which interlock hence resist motion as illustrated in figure 3.4.

Even for negligible surface projections, friction is still present resulting from surface adhesion and electrical properties.

Key point

Friction is an opposing force to motion between two rubbing surfaces caused by interlocking of surface projections.

In step 4 of the activity above, you noticed that friction is actually less when the object is in motion than when it is about to start moving. It takes greater force to start motion of object than to keep it in motion at constant velocity. This is so because at rest, surface projections interlock more hence larger force required to start its motion. When surfaces are moving, some projections bounce along, providing less resistance.

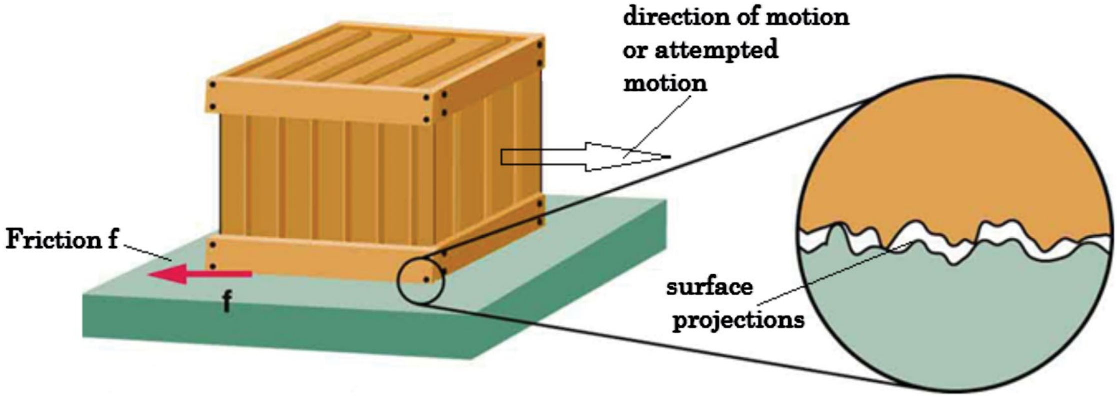

Figure 3.4 Projections between surfaces interlock

The second factor that affects magnitude of friction is the normal force between the two surfaces. When a block is on a horizontal surface, the normal force is actually the weight of the block as shown in figure 3.5. Greater weight of the block produced larger normalforce. From the activity above you have noticed that friction increases with the normal force, so that it can be concluded that friction is a partner of normal force. Figure 3.5 shows details of forces between surfaces including the friction force.

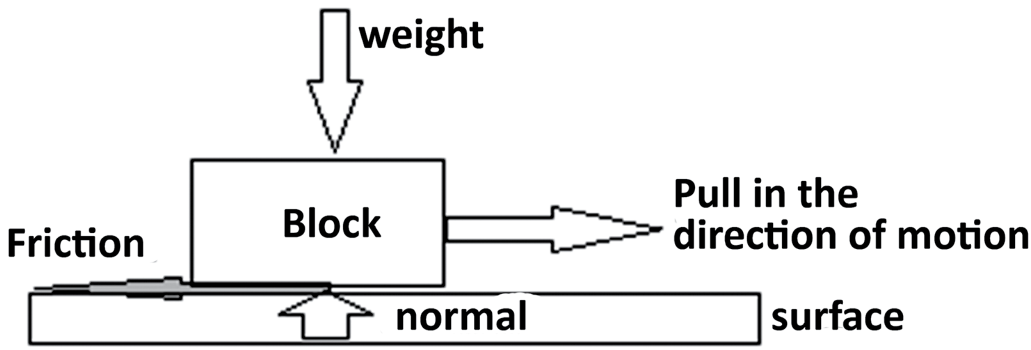

Figure 3.5 Forces when pulling object on surface

The figure 3.5 shows that a larger load on a surface increase the area of contact by making more deep interlocking between surface projections as illustrated in figure 3.6.

The friction force, F and the normal force, N are related by the equation $F = \mu N$ where μ is called coefficient of friction. Since friction for static object is different from friction for moving object there are two equations that can be applied.

1. If surfaces are not moving relative to each other the static friction opposite the start of any motion and the equation becomes $F_{static} = \mu N$ and in this case μ is called coefficient of limiting friction.

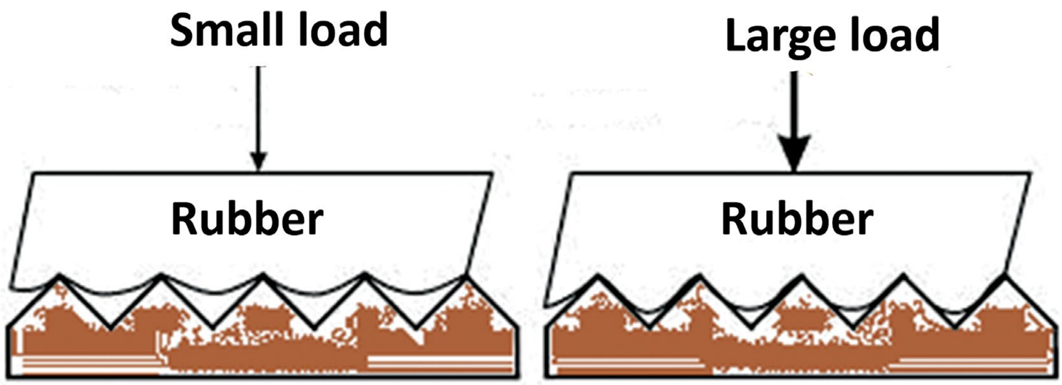

Figure 3.6 Large load makes surface projections interlock more

2. If two surfaces are moving relative to each other then the equation becomes $F_{kinetic}$=μ'N where μ' is called coefficient of dynamic friction or dynamic.

The ratios of the static and kinetic friction to the forces pressing surfaces together are called coefficients of static or limitation friction μ and coefficients of kinetic friction μ', respectively, denoted by Greek letter mu (μ) where .

$$\mu = \frac{F_{friction}}{N}$$

For any two given surfaces μ' is less than μ. Figure 3.7 shows the basic definitions of coefficient of friction while the table gives examples of coefficients of friction for different materials and surfaces.

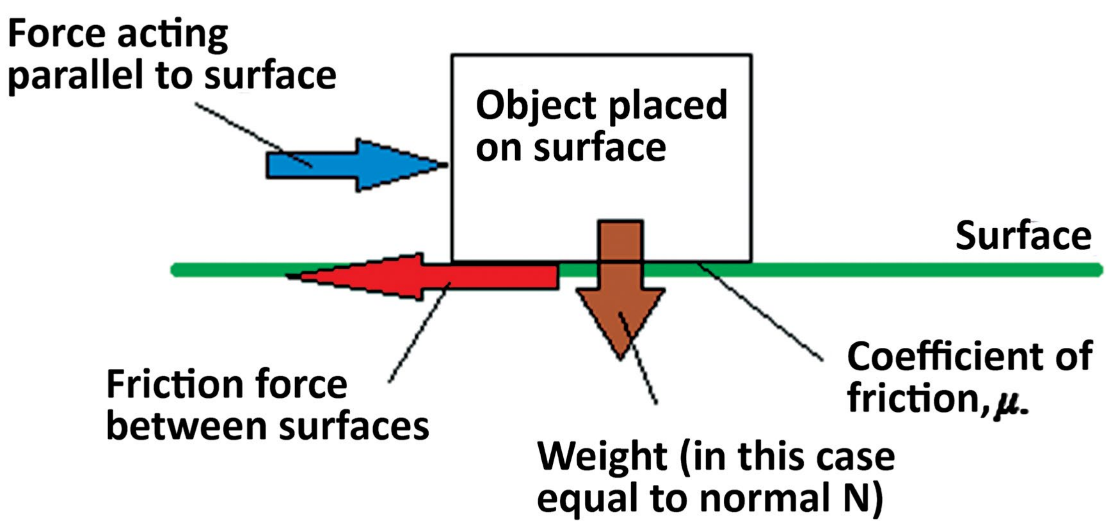

Figure 3.7 Details about coefficient of friction

Surface	Approximate coefficient of friction	
	Kinetic	**Static**
Rubber on concrete (dry)	0.68	0.9
Rubber on concrete (wet)	0.58	
Rubber on asphalt (dry)	0.67	0.85
Rubber on asphalt(wet)	0.53	
Rubber on ice	0.15	
Wood on wood	0.30	0.42
Steel on steel	0.57	0.74
Copper on steel	0.36	0.53
Teflon on Teflon	0.04	

Table above shows how coefficient of friction changes on a surface under different conditionsfor various surfaces. Notice that a smaller coefficient of friction gives less friction.

Key point

The magnitude of friction, F is a function of normal force N, and nature of surface measured as coefficient of friction, μ.

$$F= \mu N$$

Table below shows static coefficient of friction between road surface and tire.

Road condition	Normal tire (treaded)	Racing tire (smooth
Dry	0.7	0.9
Wet	0.4	0.1
Snowy	0.2	
Icy	0.1	

It is kinetic friction that tends to make things that rub against each other hot. The work done against the friction is changed into heat energy. There is no heat generated with static friction. Friction is needed in brakes, sharpening tools, holding things in our hand, writing and painting.

Friction has problems as well, like making things too hot, tear and wear of materials and waste of energy in form of heat. Some of the ways used to reduce friction include, lubrication, making surface smoother, use of ball bearings and air cushioning.

Example.

A piece of wood of mass 2kg is put on a wooden table. Using the table of coefficients given above, work out the following:

a. The force required to make the piece of wood start moving.
b. The force required to keep the piece of wood moving.
c. What would be the static and kinetic friction force if same mass of steel was put on steel surface?.
d. Sketch a graph of friction against the applied force to illustrate their changes from start to when the object is in motion
e. Which ways would you employ to reduce friction between the two surfaces?

Solution

a. When not in motion the force required to make object start moving is equal to maximum static friction force

$F_{static} = \mu N$

$$F_{static} = 0.42(2 \times 10) = 0.42 \times 20 = 8.4N$$

b. In motion the force required to keep object moving is equal to kinetic friction force

$F_{kinetic} = \mu N$

$$F_{kinetic} = 0.3 \times (2 \times 10) = 0.3 \times 20 = 6N$$

c. For steel

i. $F_{static} = \mu N$

ii.

$$F_{static} = 0.74(2 \times 10) = 0.74 \times 20 = 14.8N$$

iii. $F_{kinetic} = \mu N$

iv.

$$F_{kinetic} = 0.57 \times (2 \times 10) = 0.57 \times 20 = 11.4N$$

d. The graph will be as shown in figure 3.8. Notice that kinetic friction is less than static friction. Static friction has its maximum when object just starts to move and then it drops suddenly as the object is in motion.

e. Some of the ways to reduce friction include making the surfaces smoother or putting air between the two surfaces (air cushioning).

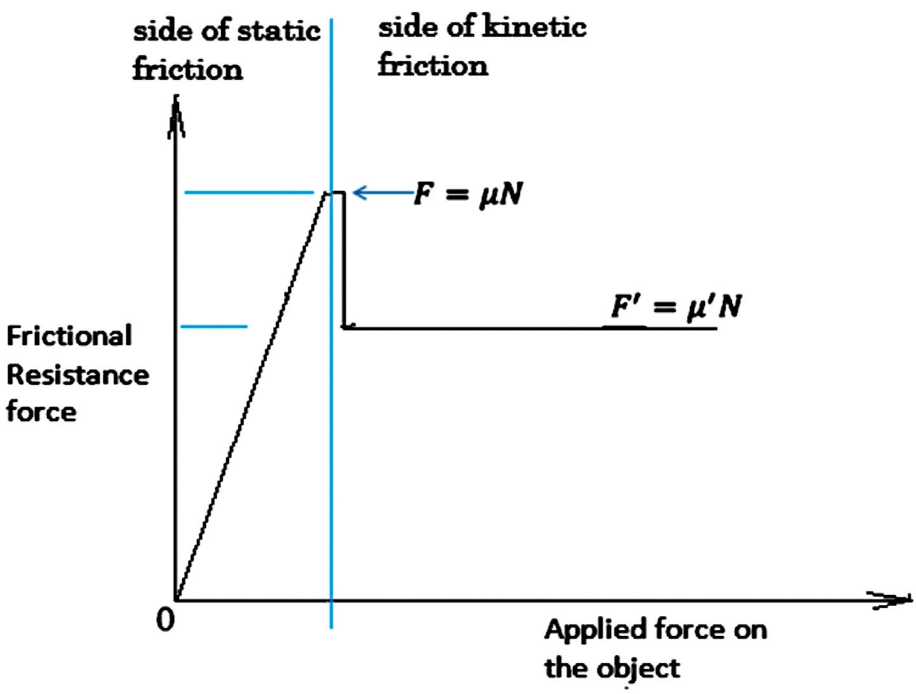

Figure 3.8 Exercise

Summary

- Friction is a force that opposes motion and acts between two surfaces that are in contact.
- Friction is caused by interlocking of surface projections
  The amount of friction force is dependent on the normal force N and coefficient of friction between the two surfaces given as $F=\mu N$
- Kinetic friction is always less than maximum static friction. For this reason kinetic coefficient of friction is always less than static coefficient of friction.
- Friction is increased where it is required and reduced where it creates problems.

End of unit exercise

1. What is friction
2. With aid of diagrams explain how friction is caused between two surfaces.
3. The table show coefficients of friction between a car tyre and the road surface under different conditions. Study it to answer the questions that follow

Road condition	**Normal tire (treaded)**	**Racing tire (smooth**
Dry	0.7	0.9
Wet	0.4	0.1
Snowy	0.2	
Icy	0.1	

   a. Work out the total friction forceon all four tyres of a 1500kg car when
      i. The road is dry
      ii. The road is wet
   b. Why is friction less when the road is wet?
   c. Explain why car tyres are treaded while those of a racing sports car are not.
4. There are so many ways of reducing friction. Explain how the following reduces friction
   a. Making surface smoother
   b. Lubrication.

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UNIT 4

The speed of moving object depends on the forces that oppose its motion and those that push or pull it forward. Friction is the major opposing force to motion. You know that all things fall under the influence of gravitational force. According to Newton's second law, (F=mg), the falling object should continuously accelerate all the way to the ground with acceleration due to gravity g =10m/s^2. In that situation the sky divers would hit the ground at fatal speeds and goods released from air crafts would break into unimaginable pieces during emergencies. In this unit you will learn about terminal velocity which makes it possible for safe landing.

Terminal velocity

Meaning of terminal velocity

When objects fall through fluids (liquids and gases), their acceleration go through a number of changes. It increases and then decreases. What happens to forces that act on the objects to increase and then reduce the acceleration? What will happen when the acceleration reaches zero? These are questions that involve terminal velocity. The activity 4.1 will help you to explain terminal velocity.

Activity 4.1

Explaining terminal velocity

A. **Falling through liquid**

Materials

- Fluids of different viscosity (glycerin/paraffin oil and water)
- Mass (ball bearing)
- Morceps or tongs
- Long glass tube or burette
- Stop watch
- Retort stand and bosses
- Metre ruler
- Pental marker
- Graph paper

Method.

1. Arrange a ruler and a long tube with glycerin or paraffin oil in it as shown in figure 4.1. Fill the tube up to the brim.

1. Get pental marker and stop watch ready. Using forceps or tongs release a ball bearing at the top of the tube at the same time start the stop watch.
2. As the ball falls let one person give a count every 2 or 3 seconds and a second person should mark position of ball bearing on the tube for every count. Counting should start when the ball reaches the top zero mark of ruler. Do this until the ball bearing reaches the bottom. (hint: you need to try few balls before you can do the actual reading to practice timing, and marking)
3. Read position of the ball from the ruler on the marks made. Record in table form like one below, the position of the ball and time.

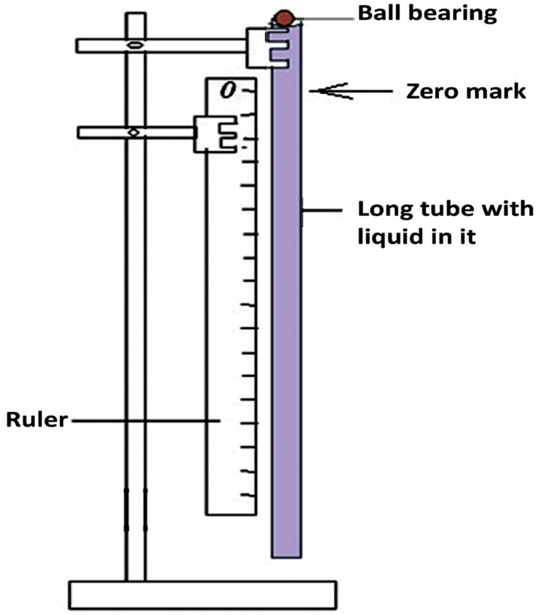


Figure 4.1 Investigating terminal velocity

Time (s)	0	2	4	6	8	10	12	14	16
Position (cm)	0								

4. Look at the spacing of the marks and describe the motion that is happening as the ball bearing falls.
5. Plot a graph of distance covered against time. Use the graph to describe the motion from the start to the end. Discuss with others in a group and give explanation to the motion.
6. Repeat the experiment using less viscous liquid like water. Describe the motion through the liquid. Give difference of motion between falling in water and falling in glycerine.

B. **Falling through air and vacuum.**

Materials

- free fall apparatus
- vacuum pump

Method

1. Hold a free fall apparatus vertical so that the feather and the ball are both at the bottom.
2. Quickly turn the apparatus upside down and take note which of the two reaches the bottom first. (You may need to try a number of times to get a more precise observation.)

3. Connect the free fall apparatus to a vacuum pump (manual or electronic.). Pump all the air out of the glass envelope and close the tap tight. Remove the pump.
4. Repeat step 1 and 2
5. Discuss and explain the difference of fall in air and in a vacuum.

Feedback

In part A of activity 4.1, the marks made on the tube and the distance time graph could be as shown in figure 4.2 (this is just a sample which should be similar to your work but not equal).

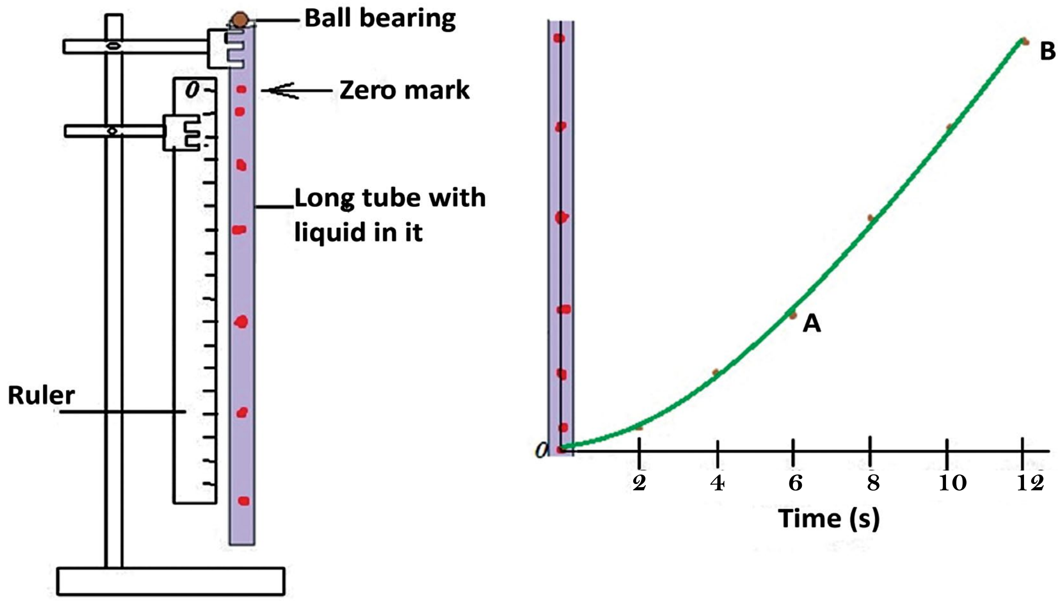


Figure 4.2 Motion of falling through liquid

The marks made on the glass and the shape of distance-time graph shows that the distance covered within same period shows two kinds of motion. From zero mark to fourth the distance covered per every 2 seconds increased successively. There was acceleration between 0 and point A (fourth mark). After point A, there are equal distances showing that the velocity is uniform. The ball bearing then continues to fall at this speed up

Key point

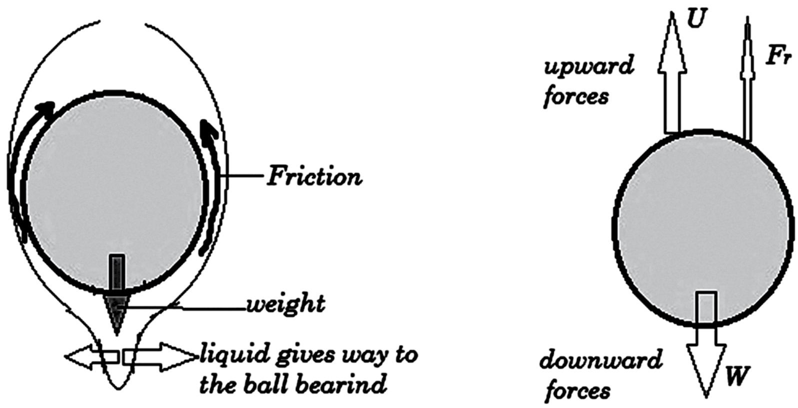
Terminal velocity is the uniform velocity at which a body falling through air or liquid moves when upward forces of resistance (upthrust and friction) acting on it becomes equal to downward force of gravity.

to the bottom. The uniform speed that a falling object eventually reaches as the ball is falling is called terminal velocity.

Explanation of terminal velocity

The speed of the moving object depends on the forces that oppose its motion and those that push or pull it forward. Friction is the major opposing force to motion. There are three forces that act on the ball bearing as it falls and these are:

1. Weight (W) of the ball bearing or force of gravity which pulls the ball bearing downwards.
2. Upthrust (U) is the upward resistance which the liquid produces to give way to the ball bearing. The liquid is creating upthrust as it is displaced sideways.
3. Friction force (F_r) or simply upward liquid resistance. The liquid molecules collide into a falling ball bearing creating an upward force opposite to gravity



as the result of contact between the ball surface and liquid surface. Figure 4.3 shows the three forces that are acting on the ball bearing.

Figure 4.3 Forces that act on falling body

At the start of motion the upward forces $(U + F_r) = U + 0$ since there is no friction. The downward force W is therefore greater than upward force. $W>U$. The resultant downward force makes the ball bearing to accelerate.

As the ball continues to fall, the U and W remain the same but F_r increases as speed increases. By the time the ball bearing reaches point A, the friction has increased enough that the total upward force becomes equal to downward force $U + F_r = W$. The resultant force is now zero hence the ball bearing moves at the same speed attained at that point called terminal velocity. This agrees with Newton's first law. There is no increase in speed when resultant force is zero.

Terminal velocity is the uniform speed that a falling body eventually reaches when upward resistance of medium through which it is falling becomes equal to downward force, preventing any further acceleration. The velocity time graph for a falling body that reaches its terminal velocity is as shown in figure 4.4.

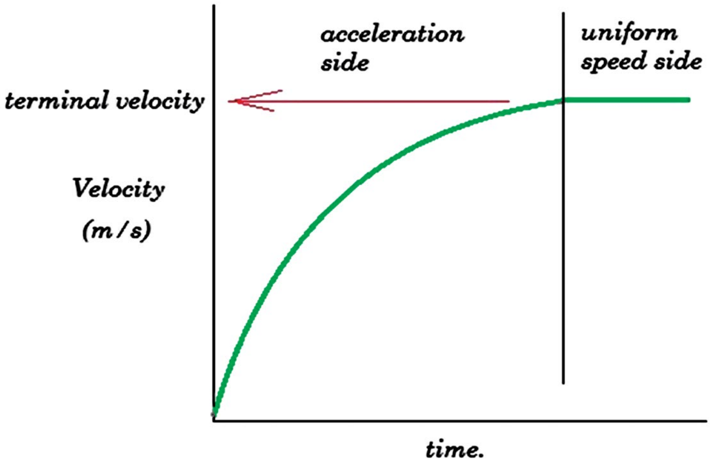


Figure 4.4 Velocity time graph to attain terminal velocity.

The motion of ball bearing when it falls through a less viscous liquid like water is the same except that; the ball accelerates for a longer period of time before reaching terminal velocity. The value of terminal velocity is therefore high. This is so because the friction in water is lower due to small viscosity. Enough friction to balance the weight of the ball is reached at a very high speed. Figure 4.5 shows comparison of velocity time graphs for falling of same ball in water and in glycerine.

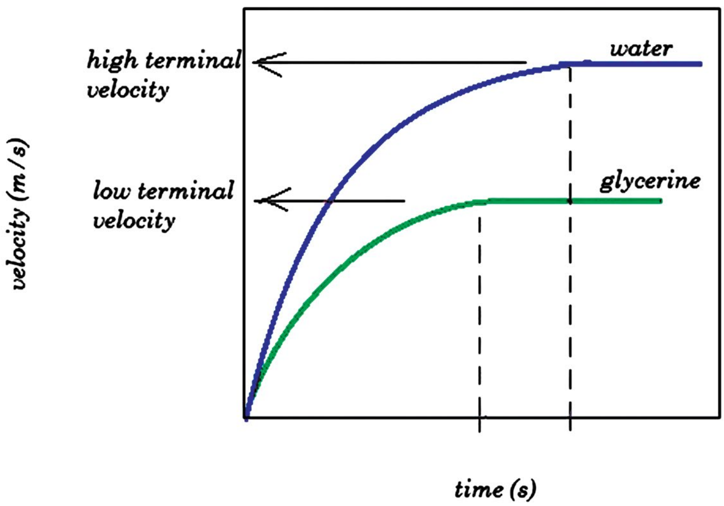


Figure 4.5 Falling through liquids of different viscosities

In part B of above activity, the ball falls first then the feather when the two are made to fall through air inside the free fall apparatus. Obviously the weight of the ball is always larger than friction that it can build between itself and the air. The upthrust in air is too small so it can be neglected. The large surface area of the feather makes it produce enough friction quickly. This is the reason that when a parachute is opened, a sky diver reduces speed rapidly.

This friction balances its weight and so reaches a very small terminal velocity which makes it reach the bottom much later than the ball. The weight of object, shape of object, size, and viscosity of fluid are factors that affect terminal velocity reached during a fall.

In a vacuum both the ball and the feather reach the bottom at the same time. This is so because in a vacuum, there is no friction and no upthrust. The only force available is weight. Under the influence of weight, (force of gravity), they both accelerate at the same rate ($10m/s^2$) and so reach the bottom at the same time. In a vacuum no terminal velocity is reached because speed keeps on increasing forever.

Figure 4.6 shows relative positions of ball and feather when they fall in air and when they fall in vacuum.

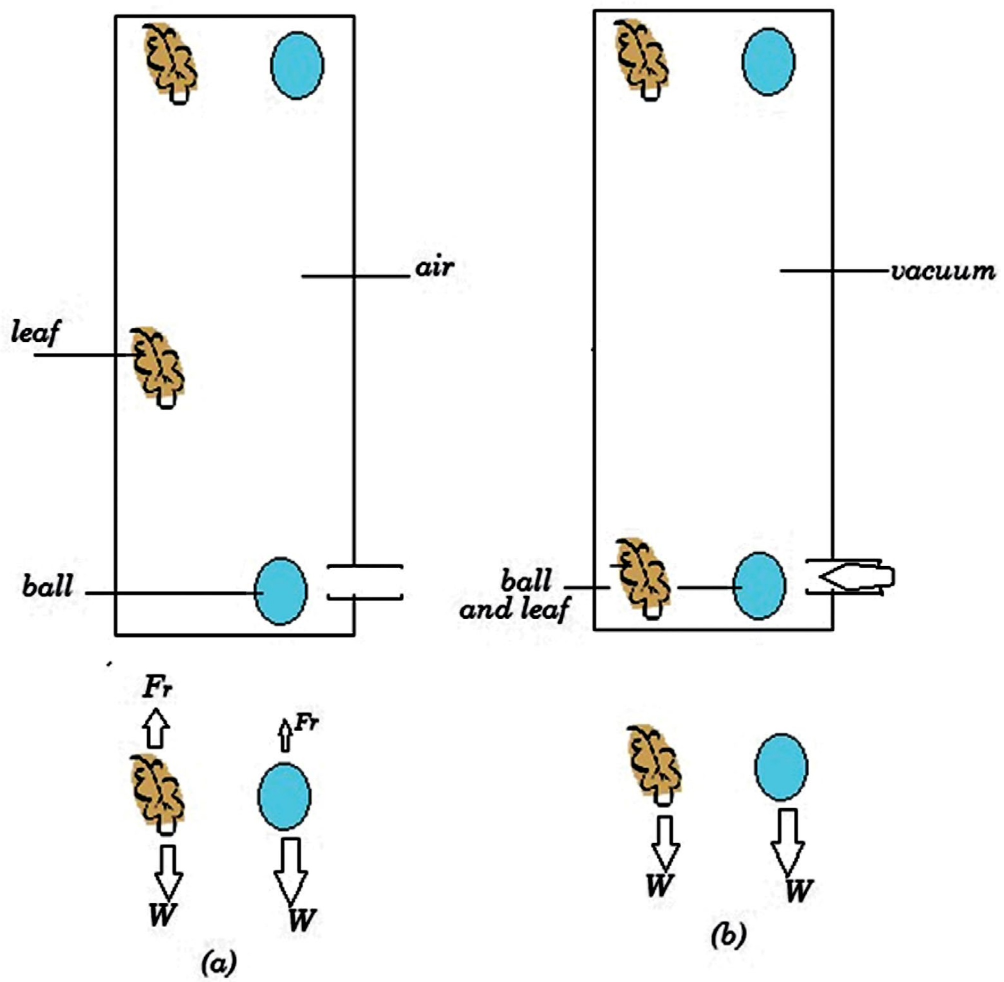


Figure 4.6 Fall through air and vacuum

Unit Summary

- Falling objects face three forces of upthrust, friction and weight.
- When the downward force of weight is greater than upward forces of upthrust and friction, the object accelerates downwards.
- Friction increases as speed of object increases. When friction has increased enough on a falling object, the sum of upward forces become equal to downward forces giving a resultant force of zero hence the object moves at the same speed called terminal velocity.
- Terminal velocity is the uniform speed reached because the resistance forces on a falling object cancel the weight.
- Terminal velocity reached depends on viscosity of fluid, weight of object, size and shape of object.
- In a vacuum objects accelerate for ever without reaching any terminal velocity due to lack of resistance forces.

End of review exercise.

1. Objects falling in fluids obey Newton's law.
   a. State part of Newton's law about object in motion.
   b. What is the condition for a falling object in a fluid to reach terminal velocity?
2. A man falls from an aircraft
   a. Name two forces that act on a man that falls through air.
   b. Explain why a person with a parachute falls slowly than a person without one.
3. The figure 4.7 shows two ball bearings but of different masses, made to fall at the same time through engine oil.

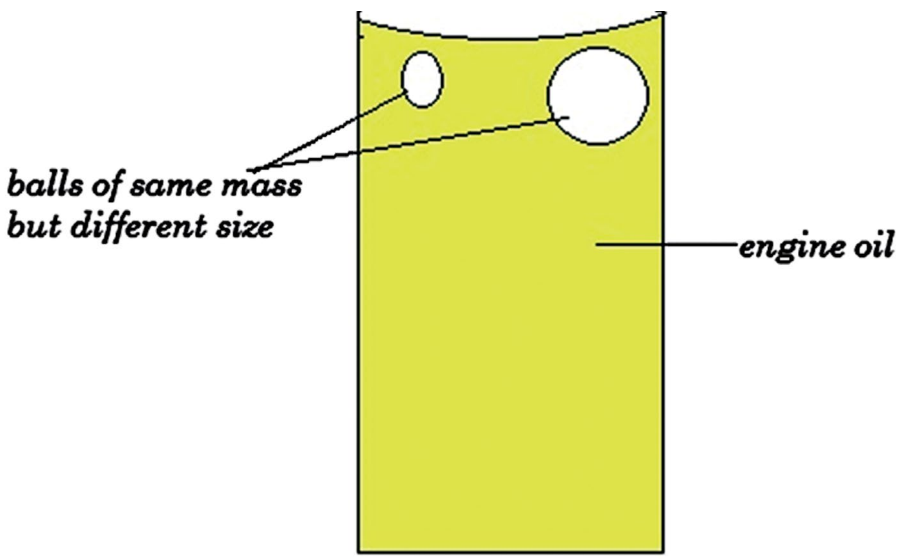


Figure 4.7

a. What is terminal velocity?
b. Which ball will reach the terminal velocity first?

c. Which ball will have a higher terminal velocity than the other? Explain your answer.
d. What will happen if the two balls were made to fall through vacuum? Explain your answer.

4. Explain the change in force of air resistance on a falling body which cause it to eventually reach terminal velocity.
5. Sketch a velocity time graph for a parachutist who is falling freely and reaches a terminal velocity of 70m/s after 2 minutes of fall. The parachutist falls at this velocity for 10 minutes and then opens the parachute which slows her down for 5 minutes to reach a new terminal velocity of 7m/s. She moves at this lower terminal velocity for 3 minutes before landing.

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UNIT 5

Forces have so many effects. One of such effects involves deformation that they cause. Is there a profound relationship between the force and the amount of deformation that they cause? That question is what Robert Hooke pondered on in the seventh century. In this unit you will learn to explain effects of force and verify Hooke's law experimentally. You will also learn the limitations to Hooke's law and how to use the law to solve problems.

Hooke's law

Effects of force

When a force is applied on materials and objects a number of things can happen. The activity 5.1 helps you to discover some of such effects.

Activity 5.1

Explaining effects of forces

Materials

- Rubber band
- Flexafoam
- Expendable spring
- 30cm plastic ruler
- Trolley model
- A ball

Method

1. Stretch a rubber band between your hands. What happens to its length? What effect of force is shown by stretching the rubber band?
2. Squeeze a flexafoam in your hand. What effect of force is demonstrated by squeezing the flexafoam?
3. Compress and extend a spring. What effects of force is shown by compressing and stretching a spring?
4. Bend a plastic ruler between your hands. What effect of force is shown by bending a ruler?
5. Give a trolley model a light push on a bench. What effect of force is shown when you push the trolley? Do you need a force to make it stop moving?
6. Kick and pass a ball between two people? What are you using to make the ball move and make the ball change direction?
7. Make a summary of the effects of forces that you have discovered from steps 1 to 6.

Feedback

Forces can do lots of things. Forces can cause deformations by changing size and shape of objects. Forces can make objects move or stop moving. Forces can also change the direction of movement of an object. In this unit you will focus more on how forces cause deformations as prescribed by Hooke's law.

Key point

When a force is applied to an object, it can have one or more of the following effects

- It can cause deformation (changing size or shape of object)
- It can cause motion or stop motion
- It can change direction of motion

Hooke's law

Robert Hooke was a surveyor to the City of London and in 1660 he investigated stretching of springs and wires when forces were applied to them. He discovered that when a spring is fixed at one end and a force is applied to the other, the extension of the spring is proportional to the applied force, provided the force is not large enough to stretch the spring permanently. This is called Hooke's law which states that the extension of a spring is directly proportional to stretching force, within elastic limit. In activity 5.2, you will verify whether Hooke's law is true.

Activity 5.2

Verifying Hooke's law experimentally

Materials

- Expendable spring
- Retort stand
- Bosses
- Clamp
- Graph paper
- Pencil
- Slotted masses
- 1m ruler

Method

1. Suspend a spring to a clamp stand so that is hangs as shown in figure 5.1. Fix a ruler along the spring. Measure the length of the spring and label it l. Record in the table of results as shown below.
2. Hang a 50g carriage weight on the spring and measure the new length of the spring.
3. Add more masses making total mass of 100g, 150g, 200g, and 250g and each time measure spring length and calculate extension produced. Record in the table of results.

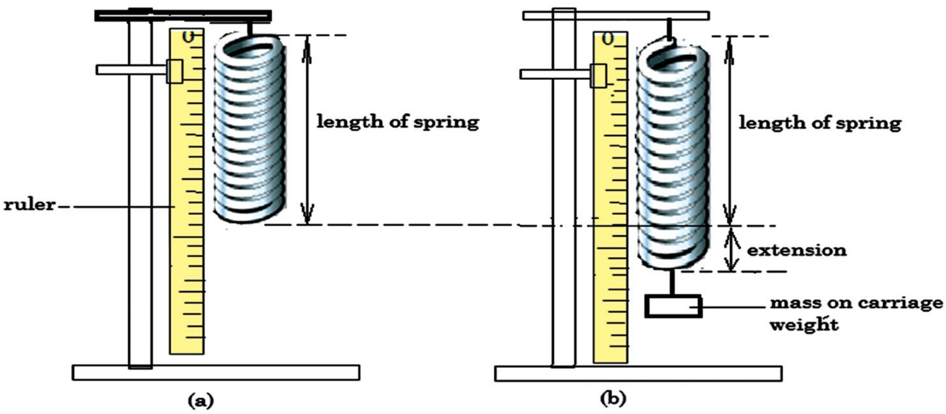

Figure 5.1 Measuring extension due to load at end of spring

4. Obtain a second set of spring length by unloading the masses in 50g steps from the carriage weight.
5. Calculate the average of the spring reading and use this to calculate extension, e of the spring. You should also calculate weight of the mass or load in newtons (100g = 1N).

Mass (g)		50g	100g	150g	200g	250g
Load (N)		0.5	1	1.5		
Length of spring, l (mm)	loading					
	unloading					
Mean reading of length (mm)						
Extension , e (mm)						
$\frac{extension}{Load}$						

6. Fill the last row of the table by calculating the ratio of extension to load.
   a. What do you notice about the values of $\frac{Load}{Extension}$?
   b. What does this tell you about the relationship between load and extension of the spring?
7. Using the graph paper plot a graph of extension (e) against the load (N) .
   a. What shape is the graph line?
   b. What relationship does this graph show between the load and the extension?
   c. Work out the slope of your graph line.
   d. Formulate a mathematical equation using the load, the slope and the extension.
   e. Does your equation in 4(d) agree with Hooke's law?
8. Discuss and explain what would happen if too much load is used in stretching the spring.

Feedback
When a load is used to stretch a spring, the spring stretches more and more as the load is increased. Extension is calculated as the difference between the length of spring without load and the new length of the spring with load. Notice that when the load is removed, the spring returns to its original length. The spring is said to be elastic.

In all cases, the extension is directly proportional to the load on the spring. This means when the load is doubled the extension of the spring also doubles.

This is not the case when too much load is attached to the spring. In this case the spring will deform permanently and it is to be stretched beyond its elastic limit. How the spring is said to be plastic. The Hooke's law only works within elastic limit of the spring. Like spiral springs, wires, beams and watch springs also obey Hooke's law as force acts on them. Rubber band does not obey Hooke's law.

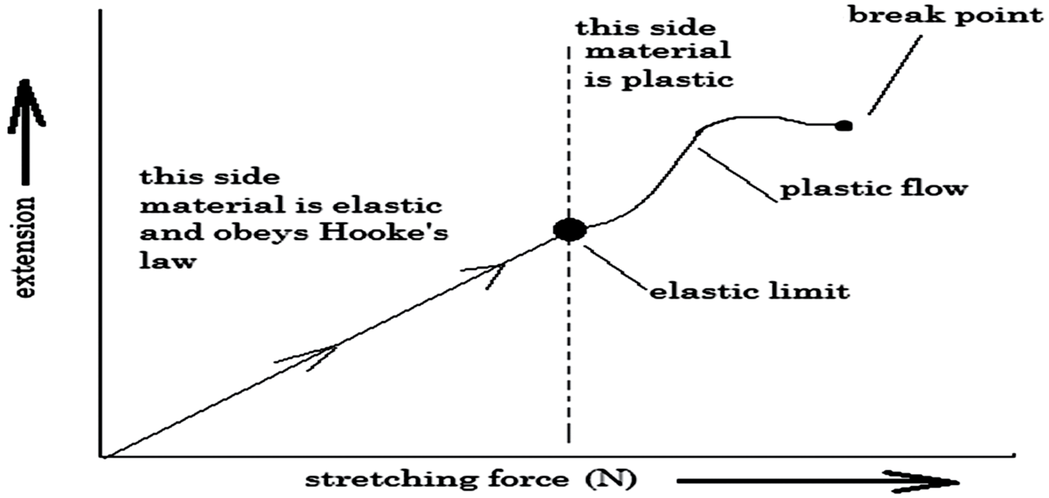

Figure 5.2 Graph of extension against stretching force on a spring

Figure 5.2 shows a graph of extension against load within elastic limit and beyond the elastic limit.

Mathematically Hooke's law can be expressed as

Force = *k* x *extension* (F =kx) where k is called force constant of a spring. A spring with large force constant needs large load to produce enough extension. Definitely the force constant of a spring in a saloon car is smaller than that in a big truck.

Key point
Within the elastic limit of a solid object, the size of deformation is directly proportional to the deforming force.
The deforming force can be applied by squeezing, stretching, bending, compressing or twisting

Elasticity can be explained at molecular level. All the atoms and molecules in matter are held together by electrostatic forces. When stretched the particles move further apart hence the whole object stretches. When the deformation force is removed, the electrostatic forces pull the particles into original positions as long as the force in not too large, hence the object is elastic. When the applied force is too much the particles move too much further apart. When such large force is removed, the particles can no longer be pulled into original positions. In this case the material remains deformed and is said to be plastic.

Assignment

Stretching rubber band and wire

Arrange an apparatus as shown in figure 5.3 to investigate whether rubber band and a 32G copper wire (or any other wire) obeys Hooke's law when stretched.

Materials needed

- Rubber band
- Wire (at least 2m)
- G-clamp
- Pulley
- Masses and its carriage weight
- Ruler
- A straw for pointers
- Graph paper

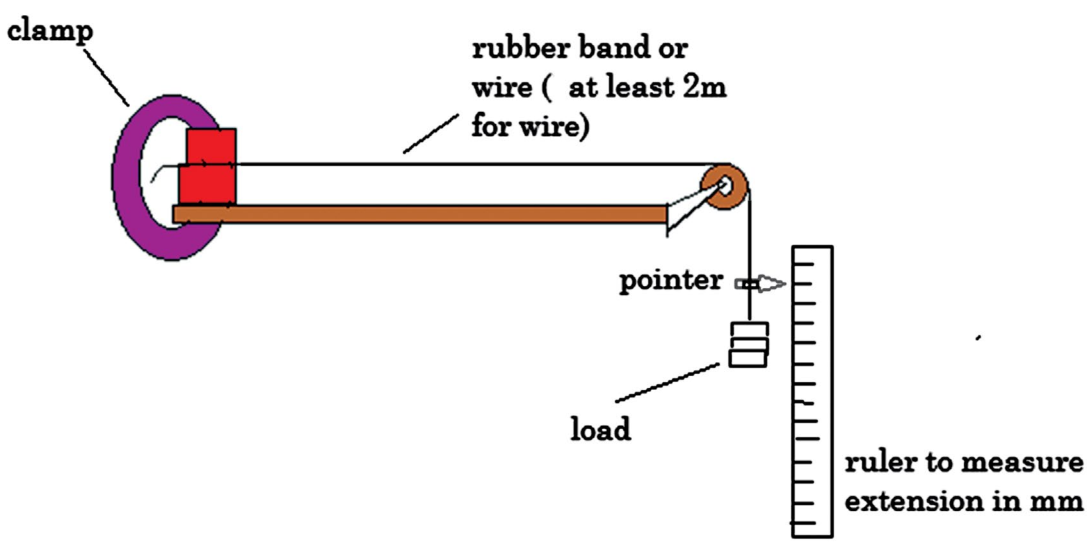

Figure 5.3 Investing Hooke's law in wire and rubber band

Example

A load of 18N produces an extension of 4mm within elastic limit. How much load would be required to produce an extension of 10mm within elastic limit?

Solution

$F = kx$

$$\therefore k = \frac{F}{x} = \frac{18N}{4mm} = \frac{4.5\text{N}}{\text{mm}}$$

$$\rightarrow F = \frac{4.5N}{mm} \times 10mm = 45N$$

Making and calibrating a spring balance

You can make your own spring balance. In activity 5.3 you will practice making a spring balance. After you have made it, think of best ways to improve it.

Activity 5.2

Constructing and calibrating a spring balance

Materials

- Spiral spring
- Cardboard paper for calibrating a scale
- Paper clip for hooks
- Razor blade or scalpel
- Pair of scissors
- 50g standard masses
- stone

Method

1. Fold a cardboard paper so that it forms a box with a closed top as shown in figure. Using scalpel make a slit to form an opening that runs along the front side
2. Using money clips hook a spiral spring at its two ends and suspend it on the covered top as shown the figure 5.4.
3. Using a money clip make a pointer with one end connected to the base of the spiral spring while its

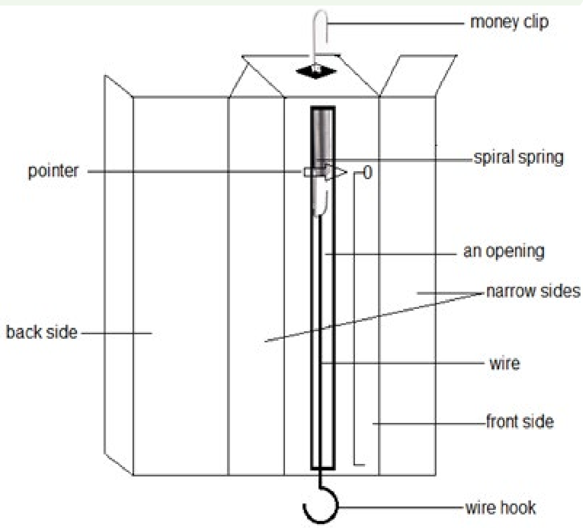

Figure 5.4. Making a spring balance

other end protrudes outside the box and has horizontal point as shown in figure 5.4 . Label its position as 0.

4. Attach a 100g mass and carriage weight to the wire hook and label the position of the pointer as 1N (since 100g has 1N weight)
5. Continue adding more masses in 100g steps until the pointer reaches the bottom, each time labeling and marking the positions as 2N, 3N, and so on
6. Divide each segment into five equal parts so that each division is 0.2N.
7. Use your spring balance to measure weight of a small stone.

Effect of arranging springs in series and parallel

What will be the total extension when two spiral springs are connected in series? What if they are connected in parallel? In other words, what would be the effective spring constant of two arrangements. The answers to these questions can be found if you go through activity 5.4.

Activity 5.3

Extending springs in parallel and in series

Materials

- Two spiral springs made of same material and with same length
- 100g Carriage weight
- Ruler
- Clamp and stand

Method

1. Suspend a spiral spring to a clamp and measure its length
2. Attach a 100g carriage weight to the spring. Measure its new length and calculate the extension
3. Suspend a second spiral spring to the clamp as in 1 and repeat step 2
4. Add the two extensions and record its value in table of results below

Length of spring 1 without load	Length of spring 1 with 100g load	Extension of spring 1	Length of spring 2 without load	Length of spring 2 with 100g load	Extension of spring 2	Total extension

5.Join the two springs so that they are in series and then suspend them to a clamp. Attach the 100g carriage weight and measure the total length of the two springs. Calculate the total extension. a. How does this total extension for springs in series compare with one you calculated in step 4

Total length of springs in series without load	Total length of springs in series with 100g load	Total extension of springs in series

6. Separate the two spiral springs and suspend bot of then to the clamp so that they are parallel to each other. Attach the carriage weight to both springs and then measure the total length. Calculate the extension.
7. Discuss and explain the effect of joining springs in series on its extension
8. Discuss and explain the effect of joining springs in parallel on its extension

Feedback

Figure 5.5 shows a summary of setup of the experiment and their relative expected extensions *e*.

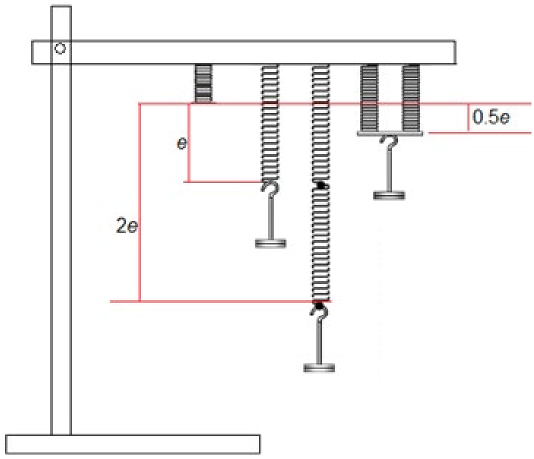

Figure 5.5. Arranging springs in series and parallel

When the springs are connected in series, each spring is subjected to 100g load and so each one is stretched by the same amount of 100g in each. This results into double stretch or double extension. The Hooke's law becomes F = k (2e). The force constant k represents stiffness of the spring and so in this case, $= \frac{F}{2e} = \frac{1}{2}\frac{F}{e}$ This implies that the stiffness for the system as a whole is halved.

On the other hand when the springs are connected in parallel, the 100g load is shared by the two springs and so the extension is halved. The Hooke's law now becomes $F = k(\frac{1}{2}e)$ This implies that the stiffness for the system as a whole is doubled, since $k = \frac{2F}{e} = 2 \times \frac{F}{e}$

Key point

Spiral springs arranged in parallel can take more load with very small extension. Arranging spiral springs in series reduces their effective stiffness.

Activity 5.4

Determining the force constant for a spring.

Materials

- A spiral spring
- Clamp and stand
- Ruler
- Carriage weight
- Standard slotted masses

Method

1. Attach a spiral spring to a clamp as shown in the figure 5.6 below with a pointer, and attach a ruler so that it stands vertical.
2. Attach a 50g carriage weight to the spring and note the position of the pointer on the ruler scale. Record in the table of results as one shown below.
3. Add masses in 50g steps to the carriage weight and each time take the reading of the pointer position on the ruler. Go as far as 350g provided the spring does not deform permanently

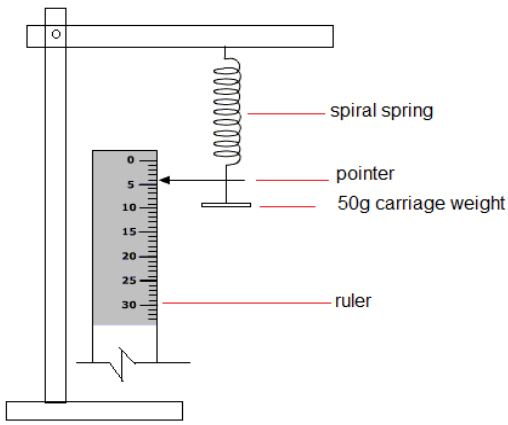

Figure 5.6. Finding force constant of a spring

Mass (g)	Load (N)	Position of pointer (loading)	Position of pointer (unloading)	Average position of pointer	Extension of spring
50					
100					
150					
200					
250					
300					
350					

4. Have a second set of results as you remove the masses form the carriage weight in 50g steps
5. Work out the average positions of the pointer for each mass
6. Using the average readings work out the extension for each 50g mass step

7. Plot a graph of load in newtons against extension

8. Work out the force constant of the spring as a slope of the best fit graph line.

    i. Write the Hooke's law equation using the force constant obtained.

    ii. What force would be required to make the spring extent by 3.5cm?

    iii. What would be the extension of the spring if a force of 2.3N is applied?

Feedback

The mathematics form of Hooke's law is F=kx where k is force constant and x is extension. In this case $k = \frac{F}{e}$. Taking the slope of Force against extension graph, therefore, gives the force constant since the vertical side is force and the horizontal side id extension.

Unit Summary

Forces have so many effects which include; setting object into motion or stopping motion, changing direction of a moving object and changing size and shape of an object.

- Hooke's law states that extension on a material is proportional to load applied to it within elastic limit.
- Mathematical form of Hooke's law if F =kx, where K is force constant of a spring and x is extension, while F is force applied.
- Elasticity is the ability of a material to return to its original size and shape after being deformed by being stretched, or compressed, bent or twisted.
- A material is plastic when it stays permanently deformed even when a deforming force is removed from it.
- Elastic limit is a maximum point of elasticity of a material, where any force applied beyond it makes the material plastic.

End of unit Exercise

1. Describe the following
    i. Elastic limit
    ii. Elasticity
    iii. Plastic
2. State Hooke's law.
3. The figure 5.7 shows a graph obtained from an experiment that involves Hooke's law

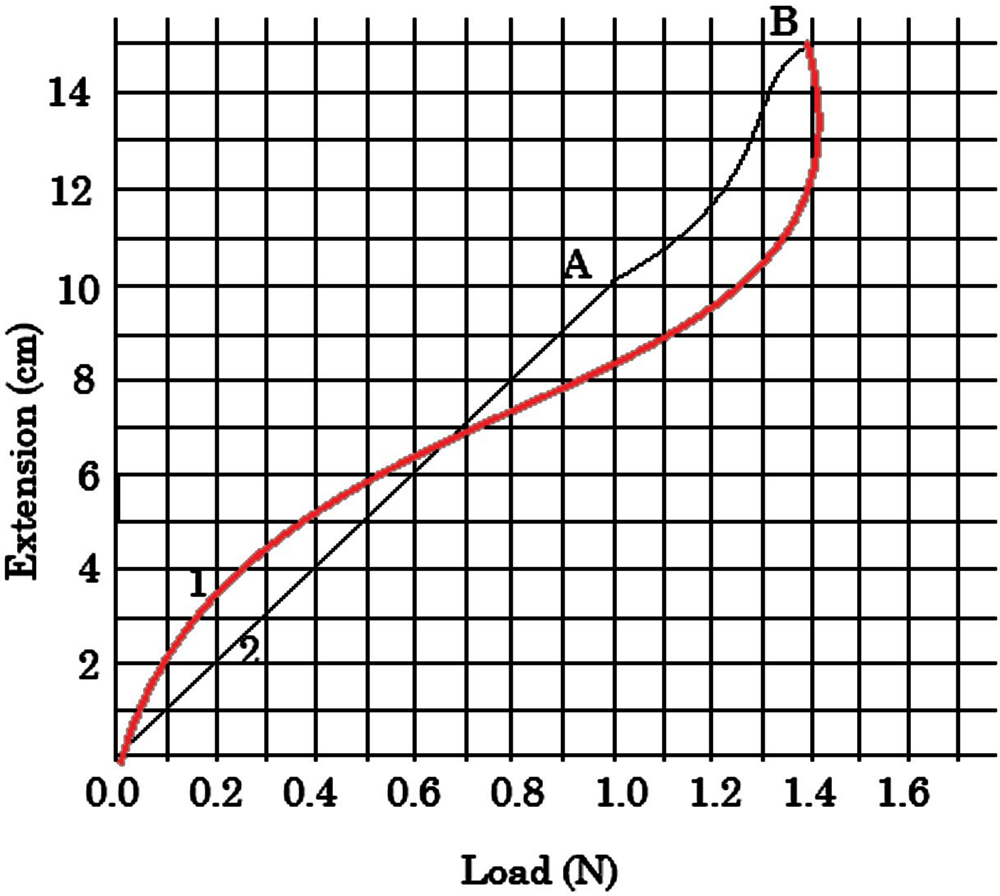

Figure 5.7.

a. Which graph line between 1 and 2 follows Hooke's law?
b. What name is given to point labelled A on the graph?
c. Which graph line is likely to be that of a rubber band?
d. What is the force constant for spring represented by graph 2
e. For graph 2
   i. What is the extension when load applied is 0.5N
   ii. What is the load that produces an extension of 9cm?

4. An experiment on a spring was done that produced the following data

Load (N)	0	X	25cm
Length of spring (cm)	15cm	18cm	200N

Using data in the table above work out
(i) Extension produced by the 200N force.
(ii) Force constant of the spring.
(iii) Load x in the table.
(iv) Length of the spring when a load of 120N is attached to the spring.

5. Table shows data from an experiment that involved stretching a spring using

Different values of load.								
Load attached to spring	0	2	4	6	8	10	12	14
Length of spring (mm)	33	40	47	54	61	70	95	120
Extension of spring (mm)								

a. What is the actual length of the spring
b. Complete the table by working out extension for each load.
c. Using a graph
    i. Find elastic limit of the spring.
    ii. Force constant of the spring.
    iii. A load that can produce an extension of 50mm.
    iv. An extension when a load of 5N is attached to the spring.

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UNIT 6

Motion can be translational like that of a jet or car on straight flat road. Motion can also be circular like when a car moves on aroundabout or when a ball spins and planets move round the sun. The car tyre has circular motion. How can we describe displacement and velocity of such circular motion? How do forces influence such circular motion? These are some of the questions that you will learn to answer in this unit. You should always remember that a change in direction is an example of acceleration and all accelerations happen with a resultant force not equal to zero.

Uniform circular motion

Angular displacement and angular velocity

Linear motion is described in terms of displacement, velocity, time and acceleration. Similarly rotation or any other circular motion is described in terms of angular displacement, time, angular velocity and angular acceleration. In activity 6.1 you will learn to differentiate angular displacement and angular velocity from linear displacement and linear velocity.

Activity 6.1

Differentiating angular displacement and angular velocity

Materials

- Football ground
- Chalk board protractor
- Measuring tape
- Stop watch
- White wash.

Method

1. Draw a line round the centre circle of a football pitch using white wash. (Alternatively, you can also draw any large circle on a bare ground). Mark the centre of the circle.
2. Draw two lines OA and OB joining the centre O as radii of the circle as shown in figure 6.1.
3. Measure the diameter of the circle

using measuring tape and record. Let one person walk along the diameter of the circle and second person measure the time it takes to cross the circle using the stop watch.

1. Find the following
   i. Displacement.
   ii. The time it takes to move along the diameter line.
   iii. The rate of covering that displacement by walking.
   iv. Velocity of walking.

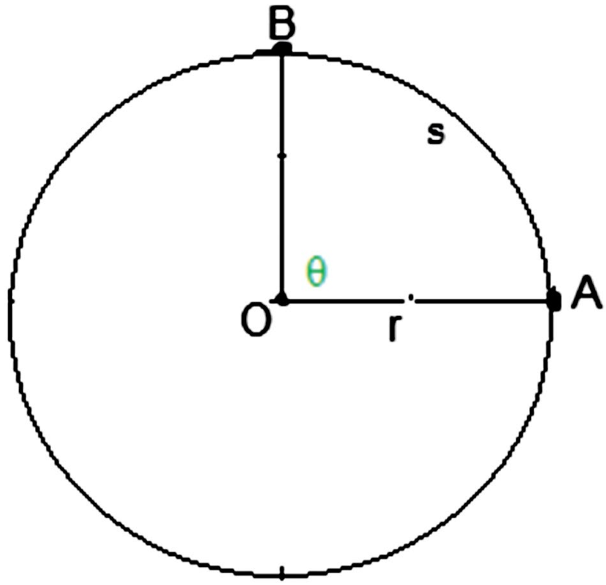

Figure 6.1 Quantities in circular motion

4. Measure angle θ subtended at the centre by an arc s between A and B using the protractor and record. Let one person walk along the arc and second person measure the time it takes to walk between the two points.
   a. Find the following
      i. Angular displacement (The angle between the two points A and B).
      ii. The time it takes to move through that angle.
      iii. The rate of covering that angle by walking.
      iv. Angular velocity.

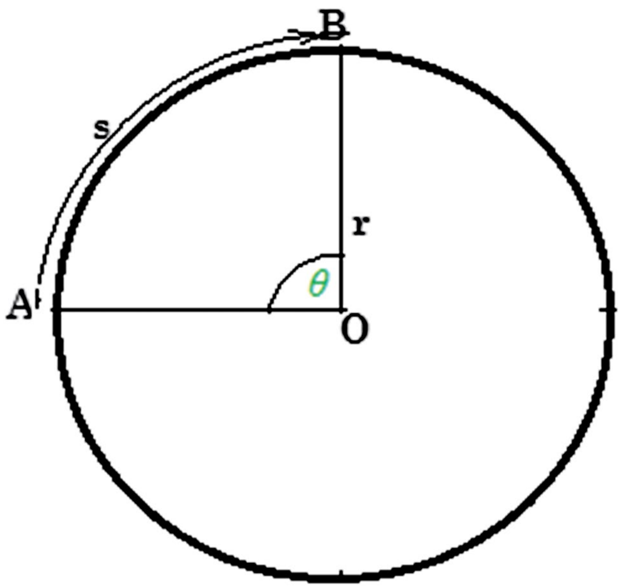

Figure 6.2 Angular displacement and velocity

Feedback

In the study of linear motion, displacement is the change in position of an object in a particular direction. Displacement gives the shortest distance that an object takes from its initial final positions. A good example is walking along diameter of a circle. In circular motion, angular displacement has similar but not equal meaning as explained in the passage below.

Angular displacement.

Consider the figure 6.2 where an object moves round from position A to position B on a circumference of a circle with centre O and radius r.

Assume that the object takes time t to move from position A to B through an arc s.
The object moves through the angle θ which is the difference in final and initial angle from A to B. The angular displacement moved is defined as the angle through which a body moves in circular path in this case θ. The units of angular displacement are therefore called degrees (°)

Note:
The relationship between angular displacement θ, arc moved s and radius r is

$$\theta = \frac{s}{r}$$

In this case the angular displacement θ is measured in other units called radians (rad), where 360° angle = $2\pi rad$ or 180° angle = π *rad*
To covert radians to degrees use the formula

$$Degrees = rad \times \frac{180^c}{\pi}$$

or

$$\boldsymbol{Degrees = rad \times 57.3}$$

Angular velocity
In linear motion, velocity is defined as the rate of change in displacement

$$velocity = \frac{displament}{time}.$$

Similarly, in circular motion, angular velocity is the rate of change in angular displacement of an object moving in a circle, denoted by Greek small letter omega, ω.

$$Angular\ velocity = \frac{angular\ displacement}{time}$$

$$\omega = \frac{\theta}{t}$$

The units of angular velocity are therefore °/s or rad/s.

Example

A stone tied to a string is whirled round with a radius of 1.5m. If the body moves along an arc length of 2.0m, work out

a. the angular displacement of the stone.

b. angular velocity of the stone if it takes 4 seconds to travel through that arc

Solution

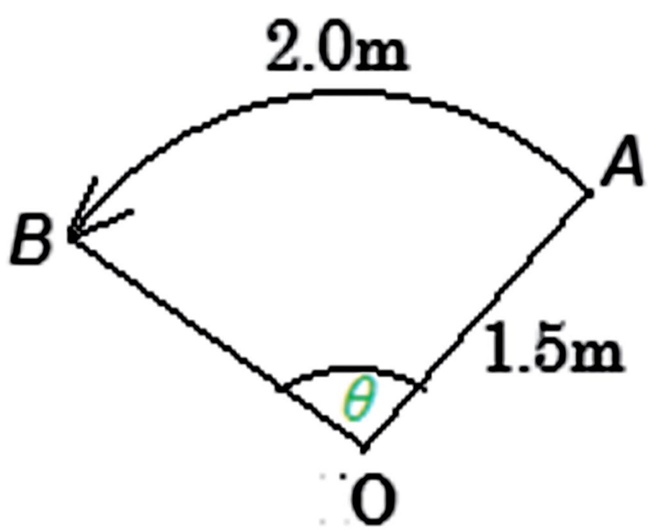

Figure 6.3

The problem can be represented by the figure 6.3

a. the angular displacement is found using

$$\theta = \frac{s}{r} = \frac{2.0m}{1.5m} = 1.33rad = 1.33 \times 57.3° = 76.2°$$

b. angular velocity is found by

$$\omega = \frac{\theta}{t} = \frac{1.33rad}{4s} = 0.33rad.s^{-1} or\ 0.33 \times 57.3°s^{-1} = 19.05°s^{-1}$$

Tangential and angular velocities

For an object having a uniform circular motion about an axis, every point on the object has the same angular velocity but its tangential velocity (which is actually linear velocity) changes constantly. Velocity is speed in a particular direction, so that a change in speed can be achieved by either changing its direction or changing magnitude of its speed. Whenever velocity changes it means it is accelerating and the acceleration is in the direction of resultant force that causes that acceleration.

Figure 6.4 shows tangential velocity, v and angular velocity ω

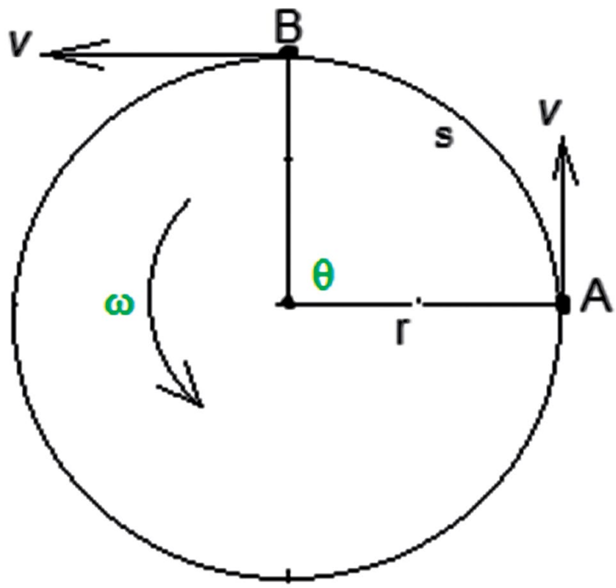

Figure 6.4 Tangential velocity and angular velocity

Consider an object that covers an arc distance s, from point A to point B, in time t.

Remember angular displacement is

$$\theta = \frac{s}{r}$$

Re-arranging gives $s = \theta r$

Around the arc s the velocity $v = \frac{s}{t} = \frac{\theta r}{t}$

But angular velocity $\omega = \frac{\theta}{t}$

It follows that tangential velocity $v = \omega r$

Rearranging for angular velocity gives $\omega = \frac{v}{r}$
The relationship between tangential velocity and angular velocity is therefore given by the equation;

$$angular\ velocity\ = \frac{tangential\ velocity}{radius}$$

$\omega = \frac{v}{r}$ in radians.

Notice from the equation that increasing the tangential velocity v increases the angular velocity ω of the object.
Similarly if arranged for r ($r = \frac{v}{\omega}$), shows that increasing r increases the velocity of the object.

Example
The wheels of a car were found to rotate with an angular velocity of 65.5rad/s. What is the tangential velocity on the outside ages of the wheels with radius of 45cm.

Solution.

$$\omega = \frac{v}{r}$$

$$\therefore v = \omega r = 65.5rads^{-1} \times 0.45m = 29.48ms^{-1}$$

$in\ km/hr =$

106.1km/hr.

Comparison of linear and circular quantities.

Linear motion	Circular motion		
Displacement	Shortest distance covered from final to initial position, s Units: m	Angular displacement	Angle covered to move on an arc from final to initial position, θ. Formula $\theta = \frac{s}{r}$ Units° or rad
Velocity	Rate of change in displacement	Angular velocity	Rate of change in angular

	Formula $v = \frac{s}{t}$ Units m/s		velocity, ω Formular $\omega = \frac{\theta}{t}$ Units °/s or rad/s
Acceleration	Rate of change of velocity, a	Angular (centripetal)	The rate of change of angular
	Formula Units ms^{-2}	acceleration	velocity ω, Formula $\alpha = \frac{\Delta\omega}{t}$ Or $\alpha = \frac{v^2}{r}$ Units $rads/s^2$

Relationship between linear velocity and angular velocity, v = ωr

Key point

For circular motion as shown

Angular displacement $\theta = \frac{s}{r}$

Angular velocity $\omega = \frac{\theta}{t}$

Tangential velocity $v = \frac{s}{t}$ or $v = \omega r$

Angular acceleration $\alpha = \frac{\Delta\omega}{t}$ or $\alpha = \frac{v^2}{r}$

Exercise6.1

1. An object in circular motion has an angular velocity of 59rad/s.
   a. What is its angular displacement after a time of 5 seconds?
   b. How many complete rotations does this represent?
2. A car racing round a circular truck covers distance of 50m. If the radius of the track is 4m, what is the angular displacement?
3. The angular velocity of a motor cycle moving round a circular track is 35rad/s. Work out its angular displacement at a time 5 seconds from the initial position.
4. A bus is passing through a large round corner whose radius is 300m with steady speed of $40ms^{-1}$. Work out the following
   a. Angular velocity of the bus.
   b. Angular displacement in a time of 3 seconds.

Centripetal force

Why do passengers in a car feel outward force acting on them when the car moves on a round about? This is explained by forces that act on objects whenever they move round. The activity 6.2 will help you to appreciate such forces.

Activity 6.2

Describing centripetal force

Materials
- String
- Spring balance
- Mass

Method
1. Tie a mass to a string leaving about 1m length of the string
2. Whirl the mass round and round your head with your arm stretched and feel the force that is acting on your hand.
   a. In which direction is the force that acts on your hand.
   b. Why does the mass not move out of the circle?
3. Whirl the mass round more strongly.
   a. How do you compare the force acting on your hand between low and high circular speed.
   b. If you were to let the string go, would the mass continue to move with circular motion? Explain what would happen.
4. Discuss why the mass in circular motion is in constant acceleration. In which direction is
   a. The acceleration that keep the circular motion
   b. The resultant force that causes the motion.

Feedback

In the activity above, the string is pulling out on the hand at one end and pulls inward on the mass at the other end. The two forces are equal and opposite as described by Newton's third law. Take note that the two forces are acting on two different objects one is acting on the mass being whirled while the second one is acting on the hand.

The resultant (unbalanced) force that acts on the ball changes its motion, by directing it towards the centre of its circular path. Is the mass really accelerating towards the centre? Consider the mass at position A under circular motion as shown in figure 6.5.

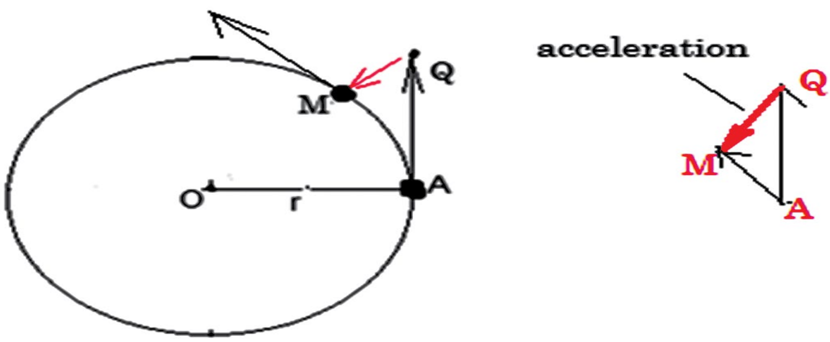

Figure 6.5 Centripetal acceleration

If the mass is let go at A, it would move in a straight line towards Q. Instead the mass has followed path AM. In other words it can be said that the mass has moved from Q to M towards the centre of its circular path.
The unbalanced inward force that acts on a body in circular motion is called centripetal force. The role of the centripetal force is only to change the direction of motion of the ball towards the centre. This centripetal force causes an acceleration towards the centre which can be obtained using Newton's second law, $F = ma$
It can be shown that the magnitude of acceleration for a mass moving with a speed v around a circular path of radius r is $a = \frac{v^2}{r}$. Substituting this into Newton's second law gives $F = m\frac{v^2}{r}$. The formula shows that the centripetal force varies with mass, speed and radius of the orbit.

Key point

Centripetal force

This is a force acting on an object in circular motion, directed towards the circular path centre

Example.

1. A stone of mass 50g is whirled round using a string at a steady speed of 8m/s. the radius of its orbit is 2m. work out the following:
a. The centripetal force acting on the mass
b. The acceleration of the mass towards the centre of its orbit.

Solution

a. Centripetal force

$$F = m\frac{v^2}{r} = 0.05kg \times \frac{8^2}{2} = 1.6N$$

b. $F = ma \therefore a = \frac{F}{m} = \frac{1.6}{0.05} = 32ms^{-2}$

Alternatively use formula for centripetal acceleration

$$a = \frac{v^2}{r} = \frac{8^2}{2} = 32ms^{-2}$$

2. A maize miller has a fly wheel of radius 30cm and mass 50kg as shown in Figure 6.6. At its full speed, the fly wheel rotates at 100revs per minute (rpm). Work out the following

a. Angular velocity of the fly wheel.
b. Linear velocity of the flywheel.

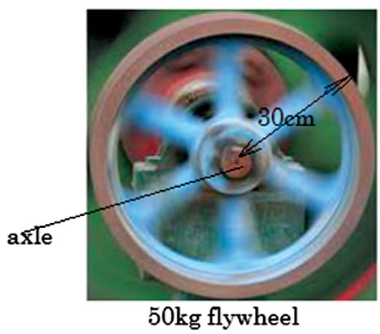

Figure 6.6

c. The centripetal force at the outside surface of the wheel.
d. The centrifugal force acting on the axle at the centre of the wheel.
e. The centripetal acceleration of the wheel towards the centre.

Solution

a. Angular velocity can be found from rpm

$$1 \text{ rotation} = 360^\circ = 2\pi rad$$

$$\therefore 100rpm = \frac{100 \times 2\pi rad}{1min} = \frac{100 \times 2\pi rad}{60sec} = 10.47rads^{-1}$$

b. $v = \omega r = 10.47 \times 0.03m = 0.31ms^{-1}$

c. $F = m\frac{v^2}{r} = 50kg \times \frac{0.31^2}{0.03m} = 160.2N$

d. Centrifugal force = -centripetal force = -160.2N (Newton's third law)

e. $a = \frac{v^2}{r} = \frac{0.31^2}{0.03} = 3.2ms^{-2}$ Or $\therefore a = \frac{F}{m} = \frac{160.2N}{50kg} = 3.2ms^{-2}$

All objects that have an orbit are experiencing a centripetal force. Gravitational force is one of the centripetal forces from the sun that pulls planets and keeps them in their orbit. Gravitational force of the earth keeps satellites and the moon in orbit.

The second force pulls the hand outwards. This is called centrifugal force. The centrifugal force tends to throw objects in circular motion outwards from the centre of orbit. Objects with larger masses tend to move outwards more than the objects with smaller masses. This is so because a larger mass has to increase its radius r in order to attain enough acceleration that can allow it to accelerate towards the centre. This is the principle of centrifuge machines which are used to separate low dense particles from high dense particles by rotation.

Activity 6.3

Applying principles of uniform circular motion

Materials

- Chart paper
- Pental markers
- Centrifuge

Methods

1. On the chart paper list at least five things that work with circular motion.
2. Explain how banking of a road helps circular motion of cars at a corner or roundabout.
3. Explain how a satellite is kept in orbit.

4. Use the centrifuge and explain how a centrifuge works to separate suspended particles of different densities

Application of principles of uniform circular motion

Feedback

The horizontal centrifugal force would fly the car out of a circular path if there is not enough friction between the tyres and the road surface. There is need for enough frictional force to balance the centrifugal force. If the track is at horizontal level the friction may not be sufficient to balance the centrifugal force and the car may slip away from the track. To avoid this, the horizontal level of the curved track is formed (banked) as to tilt inwards. Such formation is called banking of curved tracks. This is true for water ways, and railways.

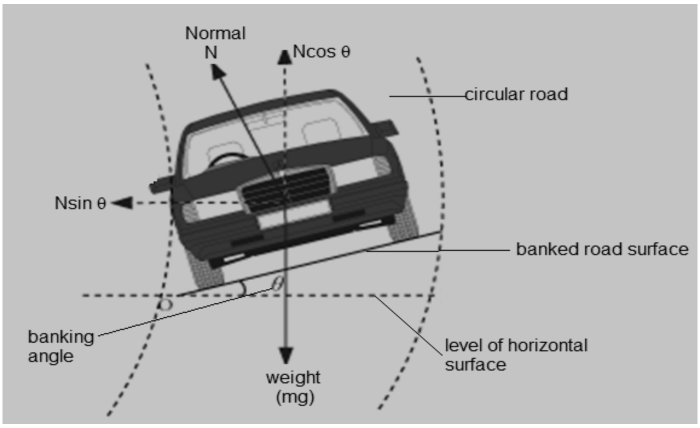

Figure 5.7 A car on a banked road

Orbit of satellite round the earth or moon, planets orbiting around the sun are all examples of circular motion. The gravitational pull of the earth gives centripetal force to make satellite and the moon go round a circular orbit around the earth.

Opposite and equal to centripetal force is a centrifugal force which tend to pull objects that are moving in circular motion outwards in a straight line. A centrifuge uses this centrifugal force to separate materials of different density or mass when a force greater than gravity is required. Materials that are denser move faster and further away from centre than less dense materials. It acts as gravity which causes denser particles sink to the bottom of test tube while less dense particles float. When the centrifuge is spinned at high speed the centrifugal force acting on the substance is many times greater than the earth's gravity.

Centrifuge can be used to separate cream from milk, plasma from heavier blood cells, and high speed centrifuges (ultracentrifuges) can even separate microscopic particles such as molecules and parts of cells.

Unit Summary

- Circular motion is described in terms of angular displacement, angular velocity and angular acceleration.
- The angular displacement moved is the angle through which a body moves in circular path in this case denoted as θ. Its SI Units are degrees or radians.
- Angular velocity is the rate of change in angular displacement of an object moving in a circle, denoted as, ω, where

$$\omega = \frac{\theta}{t} \text{ in °/s or rad/s.}$$

- Tangential velocity of a body in circular motion is the linear velocity at any point on its path measured in m/s.
- The relationship between tangential velocity, v and angular velocity is given by the equation;

$$v = \omega r.$$

- The unbalanced inward force that acts on a body in circular motion is called centripetal force given by the formula:

$$F = m\frac{v^2}{r}.$$

- The centrifugal force on an object in circular motion acts outwards from the centre of orbit.

End of unit Exercise

1. Mention any two every day examples of circular motion.
2. The motion of bodies in circular motion has centripetal force, angular displacement and angular velocity. Briefly describe the following:
    i. Centripetal force.
    ii. Angular displacement.
    iii. Angular velocity.
3. How much force acts on a 3kg stone whirled round a circular path of radius 40cm at 4rads^{-1}
4. An audio CD is rotating at 150rpm. What is the linear speed of a small dot on the CD that is 10cm from the centre?
5. The orbit of the moon has a radius of 3.84 x 10^8m and has a period of 27.32days. Find out the following
    i. Linear velocity
    ii. Its centripetal acceleration(hint change the days to seconds)
6. A rubber ball with mass of 50g is attached to a string one meter in length. What is the tension in the string if the ball moves in a circle on a horizontal frictionless table with a constant speed of 4.2m/s?
7. A cyclist turns a corner with a radius of 50m at a speed of 10m/s
    i. What is the cyclist's centripetal acceleration?
    ii. If the cyclist and the cycle have a combined mass of 120kg, what is the force causing them to turn?

References

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UNIT 7

Moments of forces

You use a long crow bar in order to lift a big box and a long spanner to loosen a nut easily. A child can balance an adult on a see saw. A racing car cannot easily over turn than an ordinary car.All these activities use forces to create or balance turning motion. Just like in linear motion, rotational speed can only happen with a resultant force. Unlike in linear motion, the same force can yield different effects depending on position and direction of the applied force. The term moment (or torque) combines the effects of force and the position applied. In this unit you will learn to describe moment of a force and how to apply the principle of moments in everyday life.

Moment of a force

When a force is applied on a body in such a way that it tends to turn the body round, such a force is said to have a turning effect, called moment. How large is the moment? The activity 7.1 will help you to find out quantities that determine the magnitude of moment of a force.

Activity 7.1

Describing moment of a force

Materials

- String or carriage weight
- 1m ruler
- Masses
- Hinged object like a door

Method

1. Hang about 500g of mass to a ruler using a string so that the position of the mass can easily be moved.
2. Lift the ruler with your hand closer to one of its end. Hold the ruler horizontally as shown in figure 7.1 and feel the turning force in your hand.

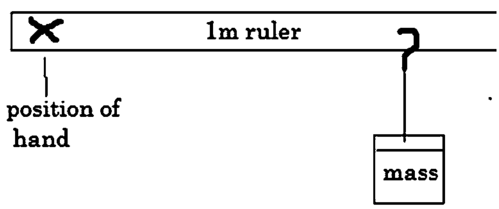

Figure 7.1 Feeling turning effect of force

3. Move the mass away from the hand
   i. Has the size of mass changed?
   ii. How do you compare the turning effect with initial position of mass
   iii. What happens to the turning effect when the mass is moved much closer to the hand?
4. Increase the mass hanged to the ruler. Feel the magnitude of turning effect in your hand. What happens to the turning effect when the mass is
   i. Increased
   ii. Reduced
5. Try to close a door by pushing it with a tip of your fore finger at different distances from the hinge as shown in figure 7.2. Sample positions are 1, 2, and 3.
   i. Which position has larger turning effect among 1 , 2 and 3
   ii. What is the relationship between turning effect and the distance from turning point?
6. Using the observations above, discuss and state two factors that affect the magnitude of turning effect.

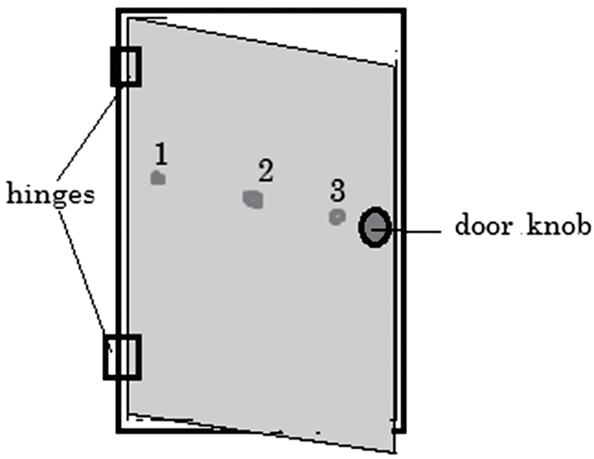

Figure 7.2 changes of turning effect with distance from turning point

Feedback

The turning effect of a force on a body is called moment of a force or torque. The moment of a force depends on the amount of force and distance from the turning point called fulcrum or pivot. The moment of a force can be worked out by multiplying the force applied with perpendicular distance from the fulcrum to the force as shown in figure 7.3. The perpendicular distance

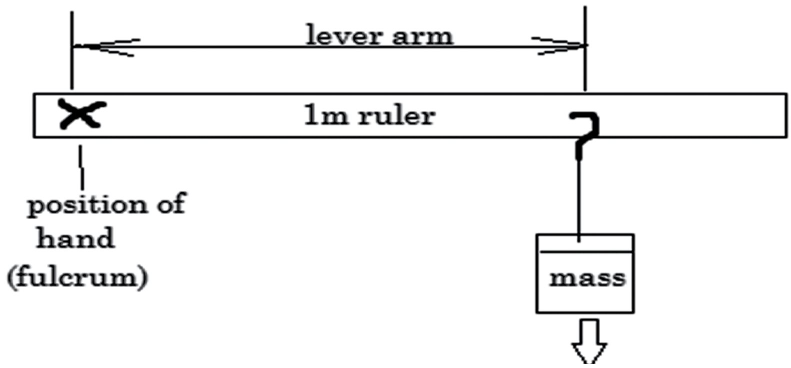

Figure 7.3 details of lever arm and force that produce moment

from the fulcrum is sometimes called lever arm.

The formula for moment is

Moment of force about a point = force X distance from the point
where the symbol ⊥means perpendicular.

$\tau = f \perp d$

The units of moment are newton metres (Nm)

The moments are usually descried to be clockwise or anticlockwise depending where they turn the object to.

Key point

Moment (or torque) = force X perpendicular distance

τ=F□d

Example
Work out the moments of forces in the diagrams (i), (ii) and (iii) of figure 7.4

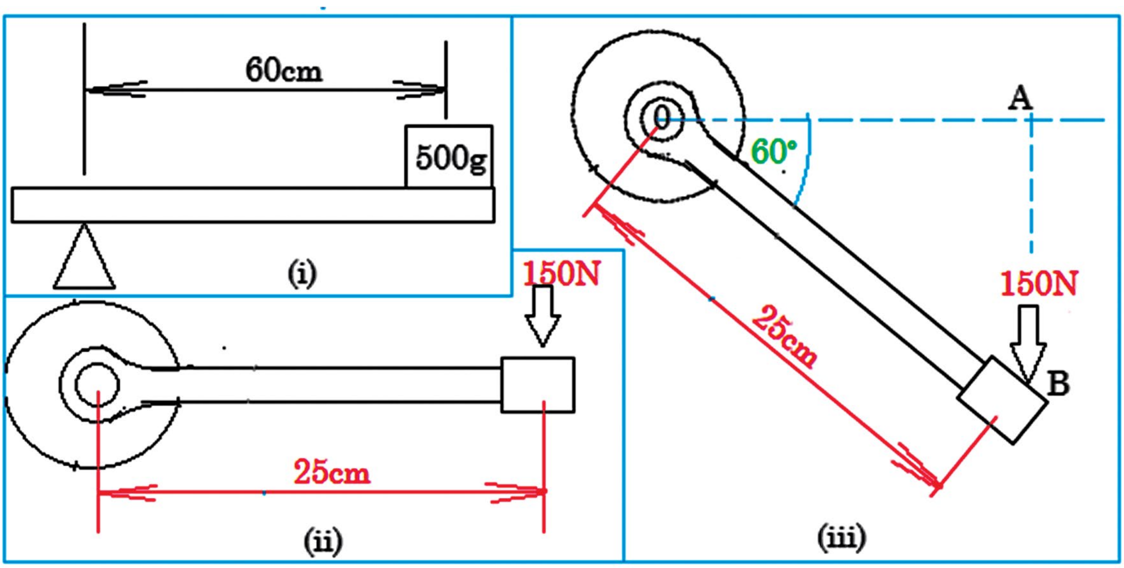

Figure 7.4

Solution

i. $\tau = f \perp d$

F = 5kg x 10 = 50N and d = 60cm = 0.6m

$\therefore \tau = 50N \times 0.6m = 30Nm$, clockwise

ii. $\tau = f \perp d$

f = 150N and d = 25cm = 0.25m

$\therefore \tau = 150N \times 0.25m = 37.5Nm,$ clockwise

iii. $\tau = f \perp d$

f = 150N,
d has to be perpendicular distance OA.
using trigonometry in triangle OAB gives

$OA = 25cm \times cos60° = 12.5cm = 0.125m$

$\therefore \tau = 150N \times 0.125m = 18.75Nm$, clockwise

Exercise 7.1

1. The figure 7.5 shows two forces acting on a beam with a pivot at position Q.
   i. What is the moment of the 400N force?
   ii. What is the moment of the 100N force?
   iii. What is the resultant moment?
   iv. In which direction will the beam turn?

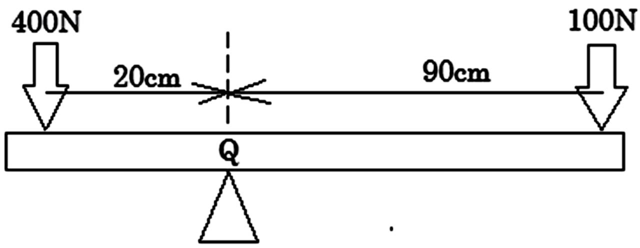

Figure 7.5

2. The figure 7.6 shows a carrier used to carry goods for hire in town. The man can exert a downward force of 700N. The load is 300kg. The perpendicular distances from pivot are 1.5m and 3m as shown.

   i. What is the moment of the load?
   ii. What is the moment of the force exerted by the man?
   iii. What is the resultant momentum?
   iv. Will the man manage to lift the load? Explain.
   v. How can the man improve the situation?

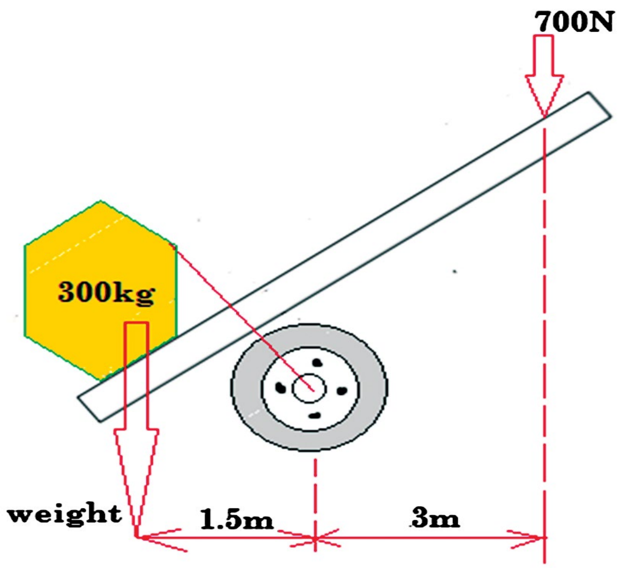

Figure 7.6

The principle of moments for a body in equilibrium

Do you wonder how a small boy can balance an adulton a see saw. This is about the idea of principle of moments or law of levers.

The principle of moments state that:
"For a body in equilibrium, its sum of clockwise moments about any point is equal to the sum of anticlockwise moments".

Activity 7.2 will help you to verify the principle of moments.

Activity 7.2

Verifying the principle of moments

Materials
- 1metre ruler
- Strings
- Needle
- Masses
- Plasticine

Method
1. Make a small hole through a 50cm mark of a 1 metre ruler.
2. Suspend the ruler using a needle through the drilled hole and make sure it balances. Stick the plasticine on the lighter side until it balances horizontally.
3. Attach and hung two different weightsW_1 and W_2 to either side of the pivot and adjust their distances d_1 and d_2 respectively until the ruler balances as shown in figure 7.7. Record the weights and distances in a table as shown below:

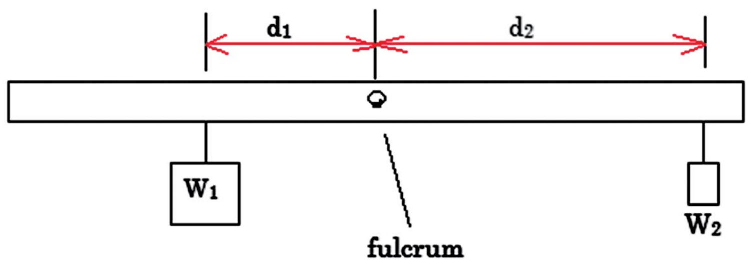

Figure 7.7 Verifying principle of moments

4. Repeat the experiment using different values of weight and distance.

W_1 (N)	d_1 (cm)	W_2 (N)	d_2 (cm)	Anticlock wise moment W_1 x d_1	Clock wise moment W_2 x d_2

5. For each set of experiment work out clockwise and anticlockwise moments
   a. What do you notice about the anticlockwise and clockwise moments when the ruler and the masses are in equilibrium?
   b. Discuss and explain how the principle of moments is obeyed in the experiment.
   c. Discuss and find out the total sum of moments for the ruler in equilibrium.

Feedback
In the above activity, when the weights balance, the anticlockwise moments are always equal to the clockwise moments. The moments can be equated as

$$clockwise moment = anticlockwise moment$$ or

$$clockwise moment - anticlockwise moment = 0$$

The ruler balances because the resultant moment is actually zero.

An object is in equilibrium under the following conditions
1. The sum of forces in one direction must be equal to the sum of forces in the opposite direction.
2. The sum of clockwise moments must be equal to the sum of anticlockwise moments.

Understanding these conditions can help to solve problems that involve turning.

Problems using the principle of moments.

Key point

For an object to be equilibrium

1. the vector sum of forces is equal to zero

2. the sum of moments is equal to zero

Example 1.

The figure 7.8 shows two loads attached to a beam. If the beam is in equilibrium, what is the value of distance d

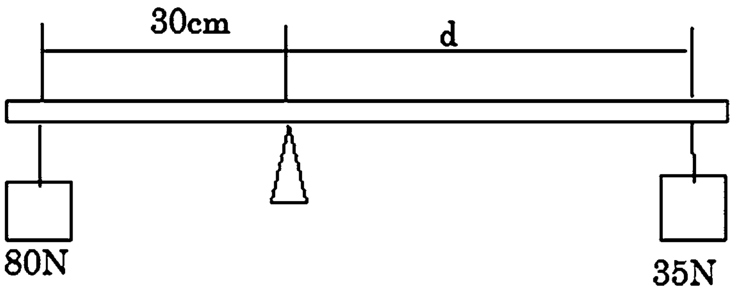

Figure 7.8

Solution

$$clockwise moments = anticlockwise moments$$

$$35N \times d = 80N \times 30cm$$

$$\therefore d = \frac{80N \times 30cm}{35N} = 68.6cm$$

Example 2

The figure 7.9 shows three weights attached to a system that is in equilibrium. Work out the value of distance d.

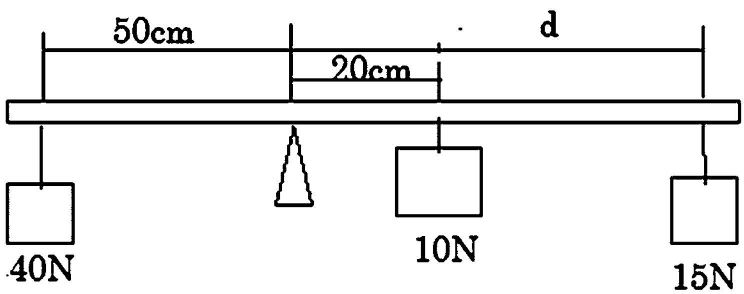

Figure 7.9

Solution

$$clockwise moments = anticlockwise moments$$

$$15N \times d + 10N \times 20cm = 40N \times 50cm$$

$$15d + 200 = 2000$$

$$15d = 2000 - 200$$

$$15d = 1800$$

$$d = \frac{1800}{15} = 120cm$$

Exercise 7.2

1. An object in equilibrium obeys the principle of moments.

i. State the principle of moments.

ii. Under what conditions is an object said to be in equilibrium.

2. The figure 7.10 shows two weights on two sides of a pivot. The values shown are markings on a ruler from zero mark in cm.

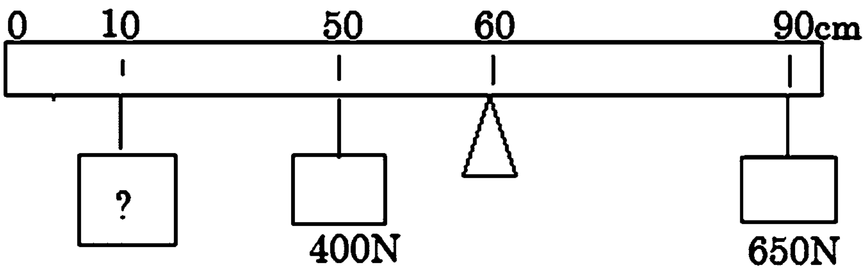

Figure 7.10

i. Work out the moment of the 650N force.

ii. Work out the moment of the 400n force.

iii. What should be the value of load placed at 10cm mark in order for the system to be in equilibrium?

Applying principle of moments in everyday life

Activity 7.3

Applying principle of moments in everyday life

Materials

- See saw
- Wheelbarrow
- Bottle opener crow hammer

Method

1. Use the above devices and in each case identify pivot, position of load and load arm, position of effort and effort arm
2. Discuss what happens to effort when effort arm is increased.

There are so many systems that use principle of moments in our day to day life. A see saw, cranes, wheelbarrow, spanners, bottle openers, pair of scissors, crow hammers and use the principle of moments. In our body the action of muscles using length of bones as levers and joints as pivots. A beam balance works on the same principle.

In many cases, there are two parallel and opposite forces that act to turn a system. In this case the two turning forces are called a *couple*. Some examples of couple include:

- Turning a steering wheel of a car, handles of bicycle and water tap, cap of a bottle when opening and closing, a door key, and a spanner. Pushing on pedals of a bicycle is also example of couple.

Figure 7.11 shows forces used to turn a steering wheel of a car.

The total moment in couple is $F_1r + F_2r$
When the two forces are equal the total moment is $Fr + Fr = 2Fr = Fd$ where d is diameter.

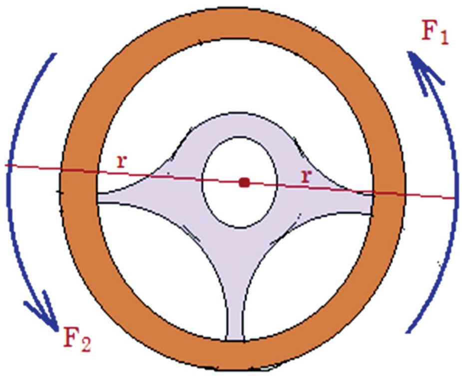

Figure 7.10 A couple of force acting on steering wheel

Centre of mass in lamina and uniform rods
All objects whether uniform all irregular in shape and composition have a balance point. Such balance points are called centre of mass of an object. The activity 7.3 will help you to find centre of mass of objects.

Activity 7.4

Finding centre of mass of objects

Materials

- Knife
- Pencil

- 1 metre ruler
- Cardboard paper
- String
- Nail
- Mass
- Pair of scissors
- Needle pierced into cork

Method

1. Place and hold a knife on a table so that its edge faces upwards. Put a metre ruler on the edge of the knife on its side perpendicular to the length of the knife edge. Adjust its position until it balances on the knife edge. Mark the position that balances on the ruler using pencil.
2. Repeat step 1 with the ruler standing on its edge on the edge of the knife.
   i. At what position does the ruler balance? Is it the same as before or different?
   ii. What can you say about the moment of gravitational forces that act on particles in the ruler on either side of the knife edge when the ruler balances?
3. Cut a piece of cardboard paper into any irregular shape and make holes at all its corners as shown in figure 7.12. Pin the cardboard to the nail through holeon one of its corners so that it swings freely.

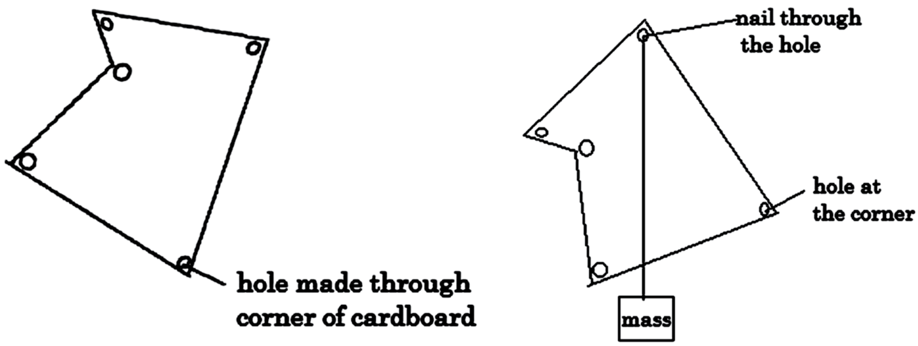

Figure 7.12 finding centre of mass

4. Suspend a mass attached to a string on the nail, with the string of the mass running on top of the cardboard as shown in figure7.13. Use the pencil to draw a vertical line against the string.
5. Repeat step 4 using the other corners of the cardboard.
   i. What do you notice about the lines drawn?
   ii. Discuss any significance of your observation.
6. Place the cardboard on the needle that has been inserted into a cork

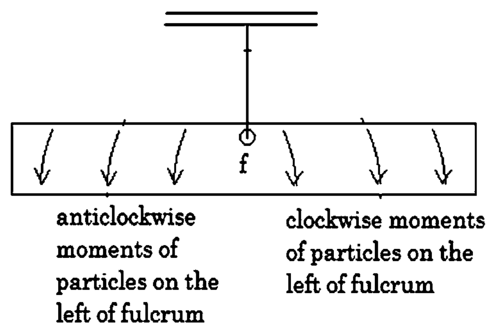

Figure 7.13 Moments of particles in an object balance about centre of mass G

through the intersection point of the lines drawn.

i. What do you notice?
ii. What can you say about moment of forces on all sides of this point?

Feedback

All objects on earth experience force of gravity acting on them. An object like a ruler has so many particles in it and each one is acted upon by this force of gravity. If a uniform homogenous ruler is suspended at its centre it balances because the sum of clockwise moments of each particle on one side of pivot balances the sum of anticlockwise moments of particles on the other side as illustrated in figure 7.14.

The position at which all the moments of particle gravitational force in the object balances is called centres of mass or centre of gravity, denoted as G. The small gravitational forces act like a single resultant gravitational force at centre of mass. The weight of the body is assumed to act through the centre of mass. For all homogenous solids with symmetrical shape, the centre of mass is at its geometrical centre. This is a balance point because the body suspended from that point has zero turning effect (has no moment to turn or rotate it).

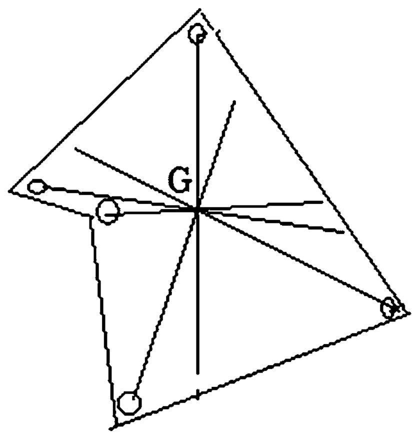

Figure 7.14 centre of mass

The centre of mass for irregular shaped objects can be found by suspending method as explained in activity 7.3. All the lines intersect at one point G, as shown in figure 7.14

When the object is suspended through centre of mass G, the cardboard does not tip over because the clockwise and anticlockwise moments that act on the sides of this point balance and cancel out to zero.

Key point

Centre of mass of an object is a point at which the sum of moments of each particle due to force of gravity acting on each particle in the object is equal to zero.

It is assumed that the whole weight of an object acts through its centre of mass.

Unit Summary

- Moment is the turning effect that a force produces when applied to a body.
- The magnitude of moment is calculated using the formula $\tau = f \perp d$ where the distance d is perpendicular to force F.

- The unit of moments are Nm.
- The principle of moments says that "For a body in equilibrium, its sum of clockwise moments about any point is equal to the sum of anticlockwise moments".
- All lever machines work using principle of moments.
- Two parallel forces that are opposite and work together to turn an object are called a couple.
- The weight of an object appears to act downwards through a single point on the object called centre of mass.
- All objects balance when pivoted through their centre of mass because the moments on all sides balance and cancel out to zero.

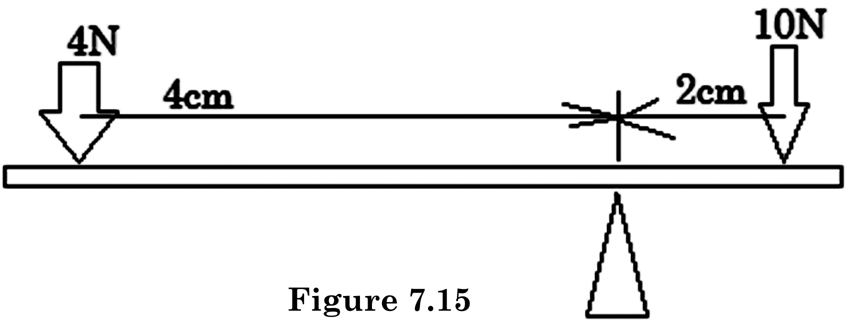

Figure 7.15

End of unit Exercise

1. Name two factors that determine the magnitude of moment of a force.
2. A spanner is used to remove a nut from its bolt. A force of 50N is applied at a distance of 30cm from the centre of the nut.
   a. Write the formula for calculating moments.
   b. What is the value of moment of the force used?
3. The figure 7.15 shows two forces acting on two sides of pivot.

Figure 7.15

   a. Work out the moment of each force about the pivot.
   b. To which side should another force be applied to balance the system?
   c. State the principle of moments.
   d. At what distance from fulcrum should a third 2N force be placed to let the system balance.
4. What is the moment of a couple of forces that are used to unscrew a bottle cap as shown in figure 7.15 if the cap has a radius of 5cm.

References

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UNIT

8

Magnetism

The word magnet comes from the name of ancient city called Magnesia in Asia Minor. This is the place where lodestone was first observed to attract magnetic materials. Today magnets have so many uses from toys to even containment of plasma. Which materials can be used to make magnets and how are magnets made? In this unit you will describe magnetisation and demagnetisation.

Magnetisation and demagnetisation

So many magnets are made in industry today to be used in various applications. Activity 8.1 will help you to learn how magnets are made and how they lose their magnetism.

Activity 8.1

Describing magnetisation and demagnetisation

Materials

- Connecting wires
- Steel bar
- Ac and dc power supplies
- Hammer
- Solenoid
- Two bar magnets
- Retort start and bosses

Method

1. Suspend a bar magnet with labelled poles to a retort stand as shown in figure 8.1
2. Bring one end of a magnet near one pole of suspended magnet and notice what happens. Bring the same end of magnet towards the other pole of suspended magnet and make observations.

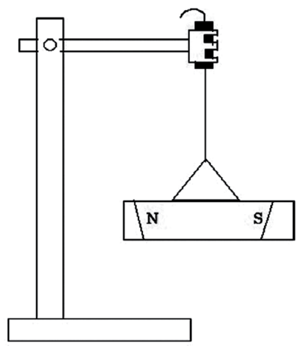

Figure 8.1

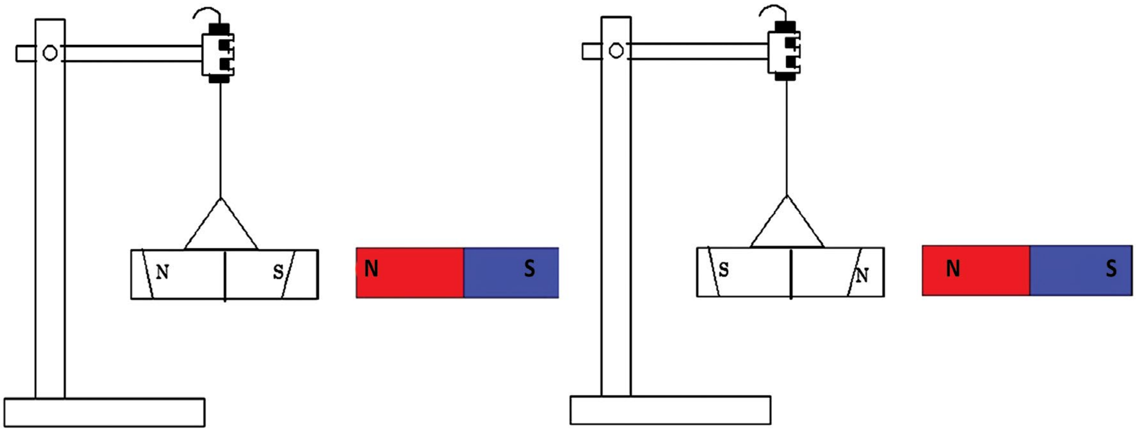

Figure 8.2 Testing for magnets and magnetic materials

3. Repeat step 1 and 2 using steel bar.
4. From you observations
   a. Is the steel bar a magnet?
   b. Discuss meaning of a magnet.
5. Place the second magnet on a table and stroke it from one end to the other several times using the steel bar as shown in figure 8.3 repeat step 1 and 2 using the steel bar that you rubbed against the magnet.
   a. Is the steel bar now a magnet? Discuss and explain your answer
6. Hit the steel bar with a hammer several times and repeat step 1 and 2 and make observations.
   a. Is the steel bar still a magnet?
   b. Discuss and explain what the hammering has done.

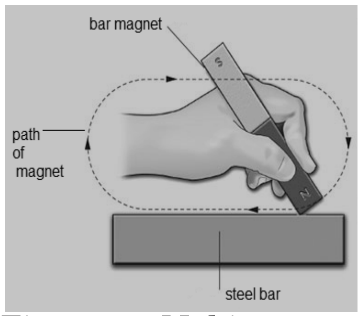

Figure 8.3 Making magnet by stroking

7. Put the steel bar inside solenoid connected to dc power supply as shown in figure 8.4.

   Close the switch for a second and then off. Repeat step 1 and 2 and observe what happens.
8. Connect the solenoid to the ac power supply with the steel bar inside the solenoid. Repeat step 1 and 2 and notice what happens.

Record your observations in table form as shown in figure below:

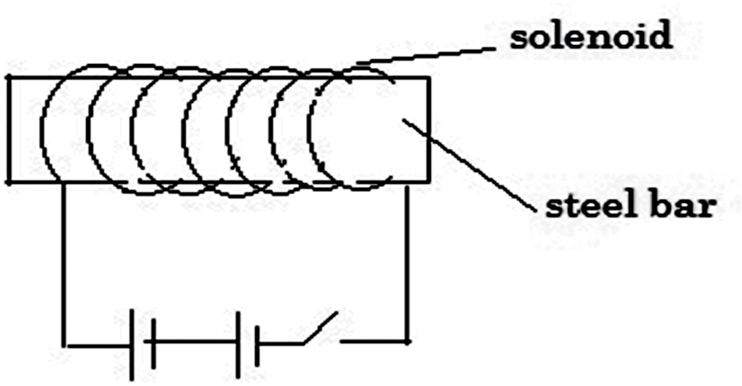

Figure 8.4

Activity What is brought near suspended bar	Action of steel near north pole of suspended magnet	Action of steel near south pole of suspended magnet	Is steel a magnet or not a magnet
Bar magnet			
Steel bar			
Steel bar stroked against magnet			
Hammered steel bar stroked against magnet			
Steel bar from dc supplied solenoid			
Steel bar from ac supplied solenoid			

Feedback
A magnet attracts or repels another magnet but always attracts a magnetic material. Materials that are strongly attracted by magnets are called *ferromagnetic*materials. Most magnetic materials contain iron, nickel and cobalt. All magnets have two magnetic poles namely north seeking pole (N) and south seeking pole (S). The law of magnetic poles state that like poles repel while unlike poles attract. As shown in figure 8. 5.

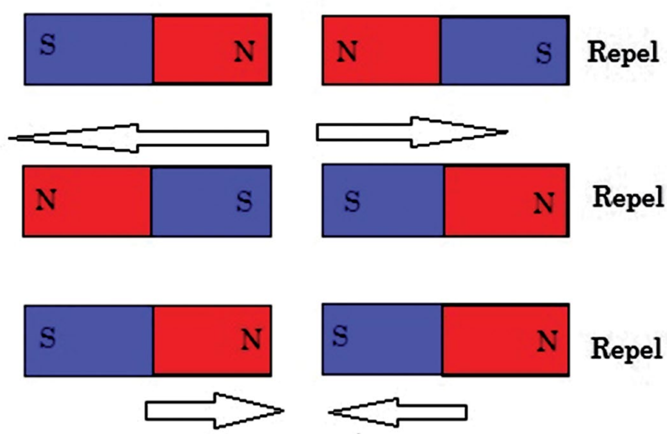

Figure 8.4 Law of magnetic poles

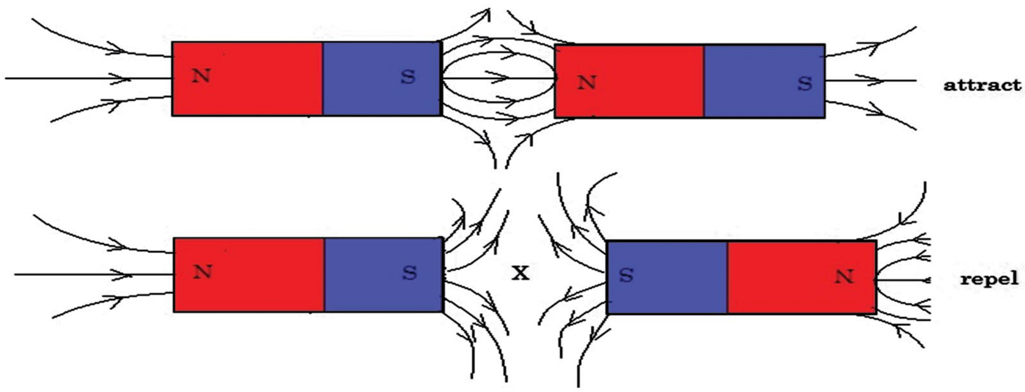

Figure 8.6 Magnetic fields during repulsion and attraction

All magnets have invisible lines of forces around them called magnetic field. It is the interaction of magnetic field that results into an attraction or repulsion. As shown in figure 8.5 magnets repel when their magnetic field points in the same direction. They repel when their magnetic fields are pointing in opposite directions.

Key point

Magnets

1. have both north and south seeking poles
2. attracts magnetic materials4
3. like poles repel, and unlike poles attract

Methods of making magnets

Magnets are made using magnetic materials. Some of the methods used to make magnets are:

1. **Stroking method**
   In single stroking, a magnet is used to stroke the material to be made into a magnet, repeatedly for so many times in one direction as shown in figure 8.7

   The magnet has to be raised enough when it reaches the end of the bar magnet.

   The poles on the new magnet will finally be as shown in the figure8.6 where the end parts have opposite poles.

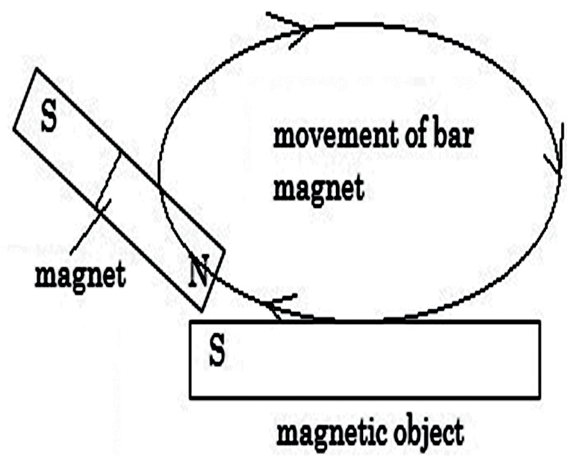

Figure 8.7 Making magnet by stroking

2. Double stroking method
In this method two magnets are used to stroke a magnetic object at the same time always starting from the centre. Each magnet is moved outwards and raised enough at the ends of the object as shown in figure 8.8

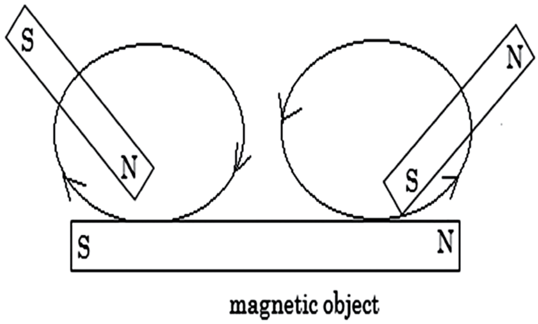

Figure 8.8 making magnets by double stroking

The poles on the new magnets are in such a way that the stroking end picks a pole that is opposite to the magnet at its end as shown above.

3. **Electric method.**
In this case the magnetic material is put inside a solenoid that has been connected to dc current as shown in figure 8.8. The electricity is then switched on for a second and then switched off. The magnetic material becomes magnet instantly. The poles of the magnet made can be deduced using right hand grip rule which says that if the fingers of the right hand grip a solenoid in such a way that the fingers point in the direction of the conventional current then the thumb points in the direction of north pole of the magnet formed in the solenoid.

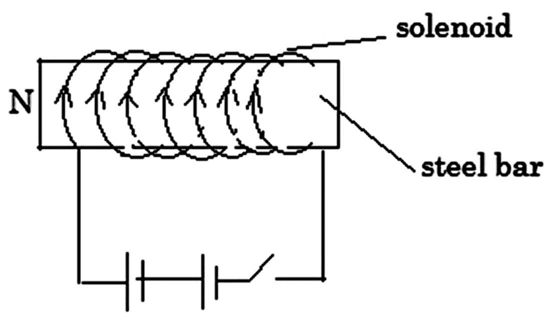

Figure 8.9

Key point

Permanent magnets are made from magnetic materials by

1. Stroking with magnet
2. Putting inside solenoid and let electric current pass briefly.

What makes magnets?

Permanent magnets can only be made from magnetic materials. This is so because atoms and sometimes groups of atoms in such materials are tiny magnets called domains. Each domain has both north and south seeking poles. Before any magnetization the domains are oriented randomly, so that the poles neutralise each other as shown in figure 8.10(a). All the methods used to make magnets involve turning the domains so that they point in one direction as shown in figure 8.10(b). The magnetic field of solenoid or permanent magnet use attraction and attraction effect to rearrange the domains. A substance whose domains point in one direction has magnetic poles therefore becomes a magnet.

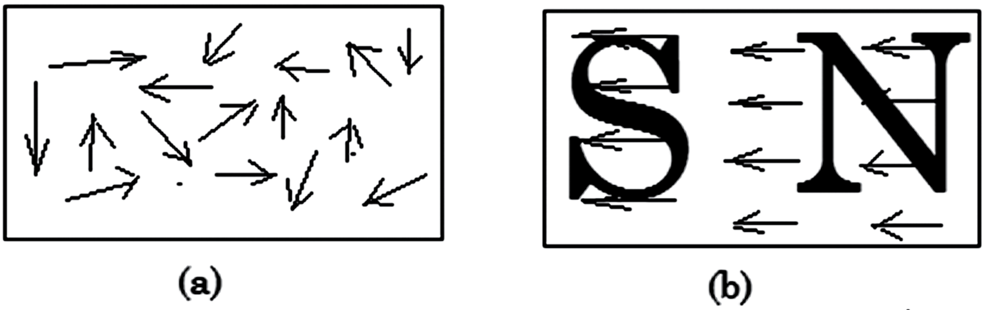

Figure 8.10 magnetic domains in (a) magnetic material and (b) magnet

When a magnetic material is attracted by a magnet it becomes a magnet temporarily. This is called induced magnetism. When the magnet is removed, it loses its magnetism because the domains return to their original random orientations. Figure 8.11 shows induced magnetism in a magnetic material as it is attracted to magnet

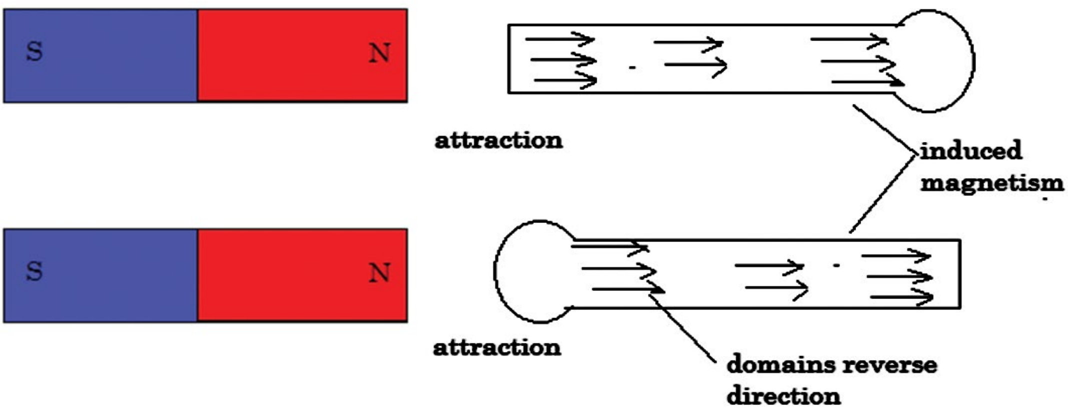

Figure 8.11. Induced magnetism

Soft and hard magnetic materials

Soft magnetic materials are easily magnetised and they also lose their magnetism easily. An example of soft magnetic material is iron.

These are used where quick changes in magnetic fields are required like transformers and electromagnets.

Hard magnetic materials are hard to magnetise but once magnetised they do not lose their magnetism easily. Such materials are best used to make permanent magnets. Example of hard magnetic material is steel.

Methods of making magnets lose magnetism

All methods used to make magnets lose their magnetism by disturbing the directed orientation of the domains in the magnet. Some of such methods are:

1. **Hammering**
   Hammering uses mechanical vibrations to turn the domains around and make them lose their directed orientation.

2. **Heating.**
   When heated the atoms vibrate rapidly. It is these vibrations that disturb domain orientation.

3. **Direct current method**
   Magnet is put inside a solenoid and then removed while electricity is kept switched on. The magnetic field of the solenoid interacts with the magnetic field of the domains which turn them round as the magnet moves from one end of the field to the other.

4. **Alternating current method**
   The magnet is put inside the solenoid connected to alternating current. When the current is switched on even for a moment the magnet loses its magnetism. Alternating current has magnetic field which keeps on changing directions. As the field changes directions, the domains are also made to change their orientation quickly to and fro and this disturbs their arrangement.

Storing magnets

Magnets can lose their magnetism as time goes when kept separate from each other. This is so because at the end of the magnet, the like poles of the domains are in such a way that they repel each other as shown in figure 8.12

(a). The domains at the free ends can change orientation at any time. Once they turn they interact with neighbouring domains in the process turning them and so on until the whole magnet loses its magnetism. Magnets are therefore stored in pairs, parallel to each other with opposite poles at their ends and soft magnetic material like iron placed at the end as shown in figure 8.12

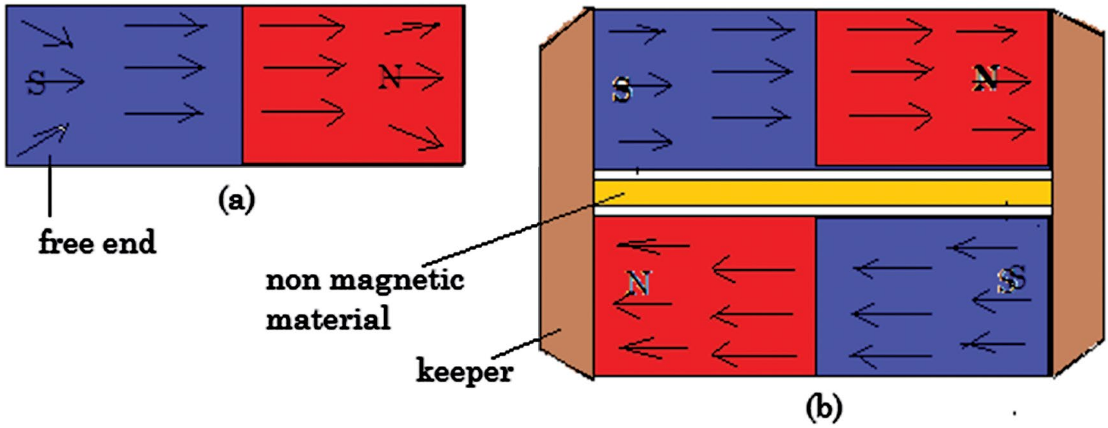

Figure 8.12. storing magnets in keepers

(b). These pieces of soft iron are called keepers. These keepers keep the domains parallel to each other than repelling themselves apart.

Uses of magnets

Magnets have so many uses. Today magnets are used in motors, generators, loudspeakers, microphones and compasses. They are also used in computer memories like floppy and hard discs. Audio and video cassette tapes are plastic sheets coated with magnetic powders. Even some metallic foreign bodies may be removed from person's body using magnets.

Unit Summary

- A magnet attracts or repel another magnet but always attractsmagnetic materials.
- Like poles of magnets repel, unlike poles attract.
- Magnets contain atoms or groups of atoms acting as tiny magnets called domains pointing in one direction.
- A magnet is made from magnetic material by stroking and electric methods.
- Magnets can lose their magnetism when atoms in it are forced to move rapidly by hammering or using electricity.
- Magnets are stored in pairs using keepers to prevent them from losing their magnetism due to free ends.
- Uses of magnets include computer memories and their use in generators and motors.

End of unit exercise

1. What are magnets?
2. Name any three uses of magnets
3. There is permanent and induced magnetism.
   a. What is the difference between permanent and induced magnetism

b. Copy and draw domains in a piece of iron nail shown in figure 8.12 when placed near magnet as shown.

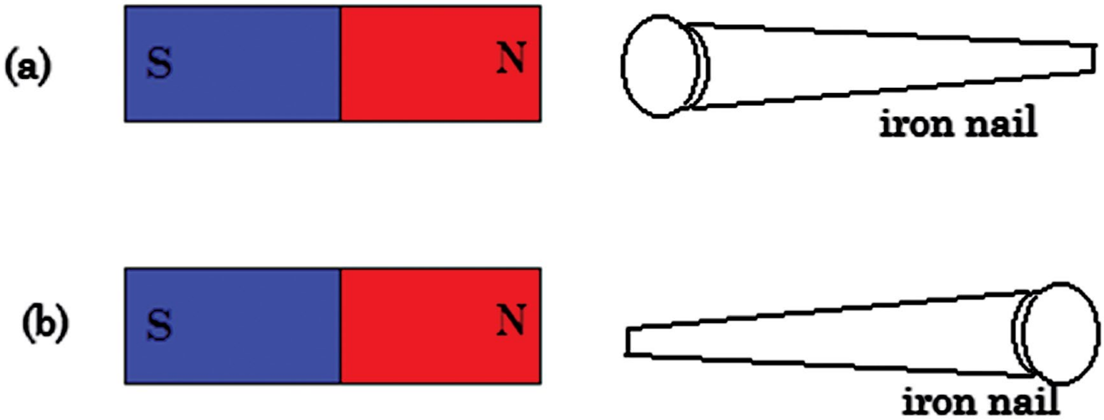

Figure 8.14

4. Magnets are made from magnetic materials.
   a. How many poles are there when a magnet breaks into three pieces
   b. The head of a hammer is made up of steel. Do you expect it to be magnetised? Explain.
5. Draw a bar magnet with its poles well labelled. Draw the magnetic field of the magnet
6. Figure 8.14 are two magnets placed close to each other.

Figure 8.13

   a. Copy and draw magnetic fields between the magnets.
   b. What type of material could be used to make such magnets?
   c. Explain your answer in (b)
7. Magnetism is about domains.
   a. Explain the theory of domains about magnetism.
   b. Give one method of demagnetisation.
   c. Explain how the method works in terms of domains.

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UNIT 9

Electricity and magnetism interact with each other. Their effects are so widely used not only in motors and generators but also associated with production of waves that make radios, cell phones, medical X-rays and microwaves. This interaction between electricity and magnetism is called electromagnetism. In this unit you will learn to describe electromagnetism and explain some uses of electromagnetism.

Electromagnetism

Electromagnetism

Motors are connected to electricity for them to turn around and generators are turned around to produce electricity. Both of them have conducting wire and magnets. You should be asking for explanation. Activity 9.1 will help you to describe electromagnetism.

Activity 9.1

Describing electromagnetism

Materials

- Connecting wires
- Cells
- Plotting compasses
- Switch
- Solenoid

Method

1. Make a circuit of a wire, switch and cells. Let the wire pass near or on top of a plotting compass as shown in figure 9.1.

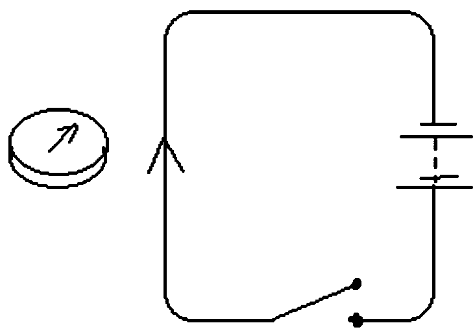


Figure 9.1 Observing effect of electromagnetism

2. Close the switch and observe what happens to the compass needle when the switch is just closed.
3. Open the switch and observe what happens as the switch is opened.
4. Discuss the following.
   a. What is the compass needle made of?
   b. What do you think has happened to the wire when electric current passes through it?
   c. Why is the observation happening only during closing and opening of switch?
5. Make a coil of wire (or use solenoid) and connect it to cells with compass needle placed near the coil as shown in figure 9.2. Switch on the circuit and make observation. Try to reverse the cells and see the effect.

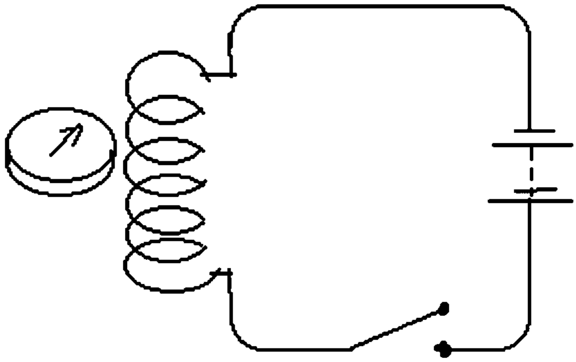


Figure 9.2 Electromagnetism by solenoid

Feedback

A magnet attracts or repels another magnet. A compass needle is an example of a small magnet. When electric current passes through a wire, the wire becomes magnetic by induction and creates its own circular magnetic field as shown in figure 9.3. The induced magnetic field in the wire interacts with the magnetic field of the compass needle to create repulsion and attraction which makes the needle to deflect.

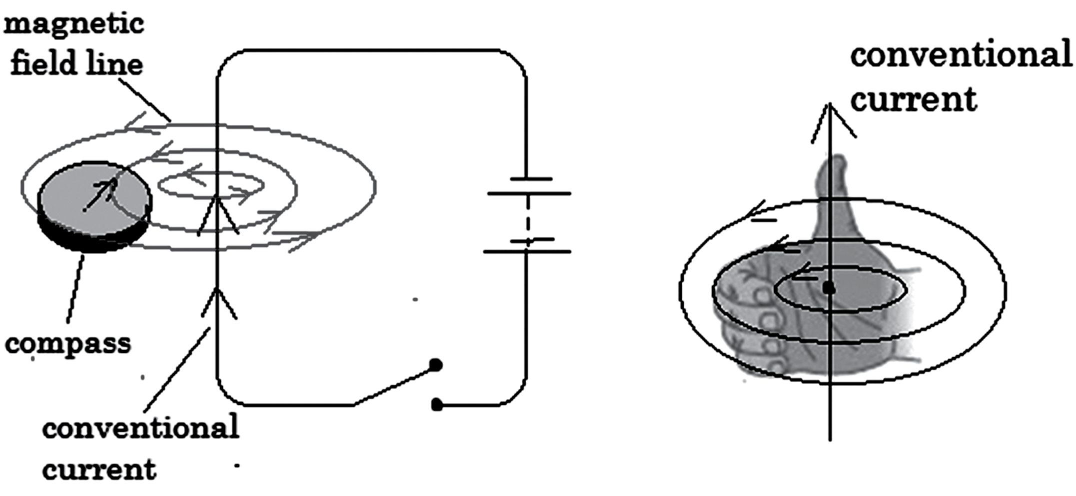
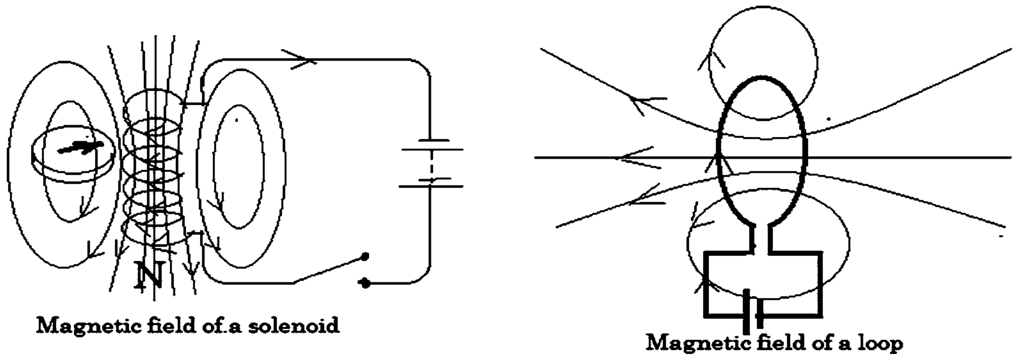


Figure 9.3 Induced magnetic fields around a wire

The direction of the magnetic field follows a right hand grip rule as shown in figure9.3. The rule says "*grip a wire that is carrying electric current using the right hand with the thumb pointing in the direction of conventional current, then the fingers point in the direction of magnetic field*".

When the compass is put near a coiled wire (solenoid) that is carrying electric current, the amount of deflection is stronger than in a straight wire. This shows that induced magnetic field is stronger in a solenoid than in a wire. The shape of magnetic field around a solenoid is like that of a bar magnet as shown in figure 9.4a.



(a) **(b)**

Figure 9.4 Induced magnetic fields in a solenoid

The direction of magnetic field can be deduced using right hand grip rule for a solenoid which says "*grip the solenoid with the right hand with fingers pointing in the direction of conventional electric current then the thumb point in the direction of North Pole of the magnetic field formed*".

When the wire is shaped into a loop form and electric current passed through it the magnetic field created, is similar to that of the solenoid but weaker as shown in figure 9.4.

It can also be shown that when a magnet is moving into a solenoid, which is not connected to any power supply, an electric current flows through the wire of the solenoid, as shown in figure 9.5.

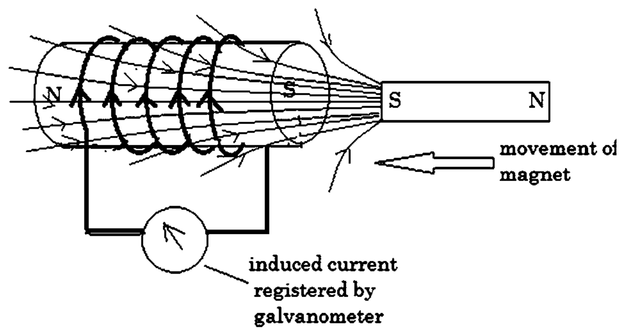


Figure 9.5 induced electric current

Placing a piece of magnetic material like iron inside the solenoid as shown in figure9.6 makes the magnetic field even stronger and a compass placed nearby is deflected very strongly. This is so because the iron itself is induced into a magnet. This induced magnet concentrates the magnetic field lines so that they are closer and near the solenoid.

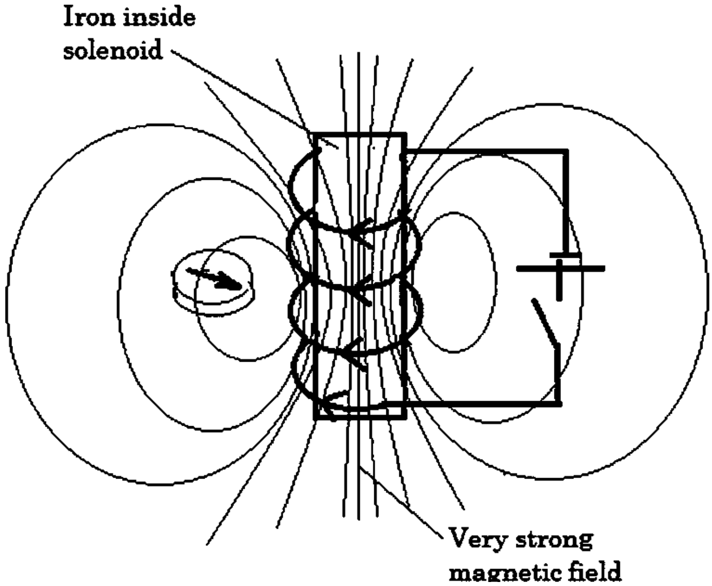


Figure 9.6 Formation of magnetic fields

In conclusion, a wire that is carrying an electric current produces a magnetic field. The magnetism that is associated with electric current passing through a conductor is called *electromagnetism*. The solenoid with a piece of iron inside is called an *electromagnet*. The magnetic field in the electromagnet can be increased by:

i. Increasing number of turns of the coil.
ii. Increasing electric current passing through the coil.
iii. Putting a stronger magnetic material inside the solenoid.

Notice that to have electromagnetism; either a magnetic field has to move near a conductor or an electric current need to move through the conductor.

Key point

Electromagnetism involves magnetic force produced when electric current pass through a conductor

Application of electromagnetism

There are so many applications of electromagnetism. Knowing how they work is very important. In activity 9.2 you will explore some of the applications of electromagnetism.

Activity 9.2

Explaining uses of electromagnetism

Materials
- Electric bell
- Circuit breaker
- Magnetic relay

Method.
1. Study the devices above and discuss how they work using electromagnetism.

Feedback
There are so many devices that work using electromagnetism and some examples are electric bell, circuit breaker, and magnetic relay. In each of them an electromagnet is made magnetic by passing electric current through it. The magnetic force from the electromagnet pulls or pushes a piece of iron near by.

Electric bell

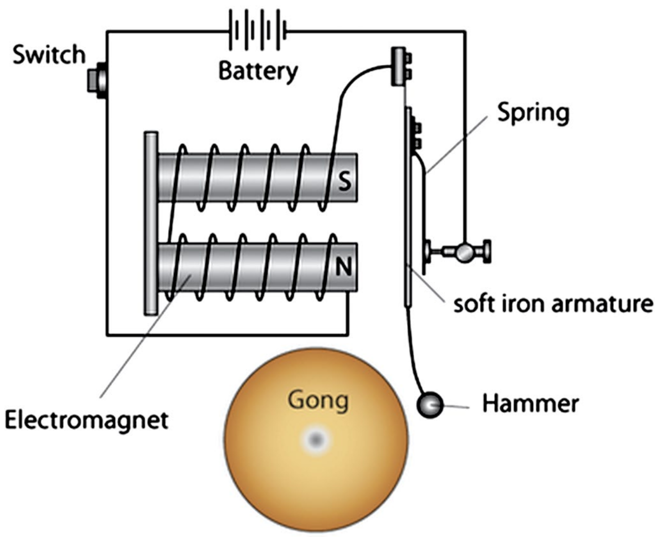


Figure 9.7 Electric bell

Figure 9.7 shows an electric bell which makes sound as long as the switch remains closed.

When switch is on the following processes happen in that order,
i. Electromagnet becomes magnetic and pulls the iron armature and in the process the hammer strikes the gong.
ii. The spring strip contact opens and electric current is switched off which demagnetises the electromagnet.
iii. The spring pulls the strip contact into position closing the circuit and the process repeats.

The process repeats rapidly giving ringing sound of a bell.

Magnetic Relay

Figure 9.8 shows a relay which is a device that acts as a switch using electromagnet. This is important where heavy dangerous current has to be switched on or off without coming too close to the electricity, like current to starter motor of a vehicle.

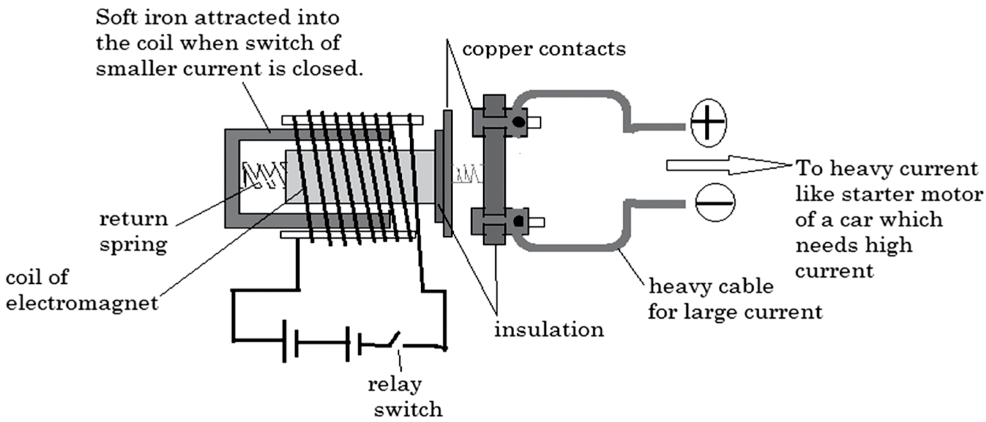


Figure 9.8 a Magnetic relay

When input circuit is switched on, the electromagnet becomes magnetic which attracts iron armature. The armature is attached to a spring which pushes the copper metal into contact, in the process closing the switch of the main heavy current circuit. The return spring pull out the contacts when the relay switch is switched off.

Circuit breaker

Figure 9.9 is a circuit breaker which has an electromagnet that stays magnetic as long as the power is on. When current rises, the magnetic field of the electromagnet also becomes stronger.

When too much current flows the strength of the electromagnet is so strong that it is enough to pull iron out of contact and in the process open the circuit and electric current stops.

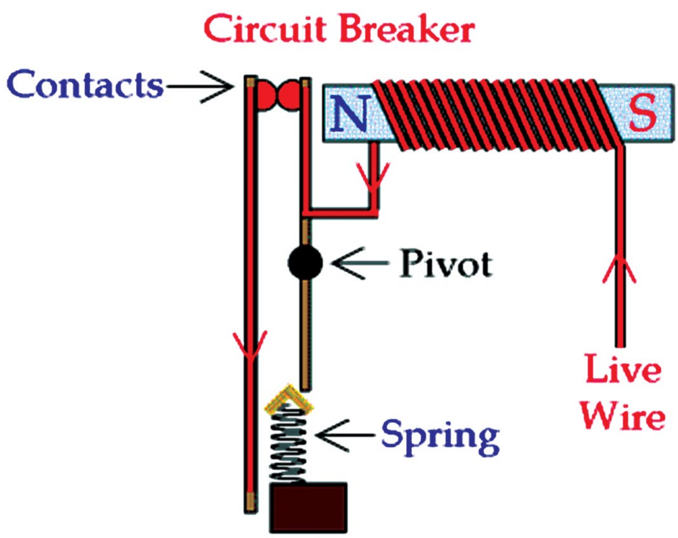


Figure 9.9 Circuit breaker

Exercise 9.1

1. What term is given to interaction of electric current and magnetism in a conductor?
2. Draw magnetic field on
   a. A bar magnet
   b. Solenoid
   c. Straight wire
   d. Loop
3. The Figure 9.10 shows a coil connected to a cell

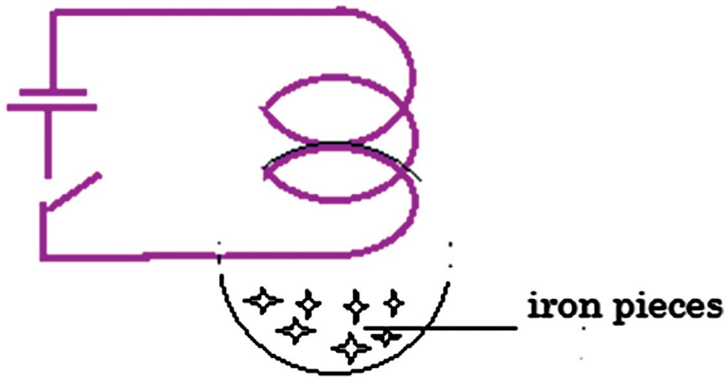


Figure 9.10

   a. What will happen to the iron pieces when switch is closed?
   b. Explain your answer to (a).
   c. In a setup like this one give three ways of increasing magnetic field.
   d. Copy the diagram and show direction of magnetic field formed.
   e. Mention a way of reversing the magnetic field that forms.
4. Explain how a circuit breaker works.

Force on a conductor

It is amazing to see how electricity makes wipers on a car move, make toys move on their own, car windows moved open and huge machines like maize mill run under the influence of electricity. Activity 9.3 will help you to understand origin of forces that make all these events.

Activity 9.3

Discussing the force on current-carrying conductor in a magnetic field

Materials

- horse-shoe magnets
- cells
- switch
- stiff wires
- conducting wires
- iron yoke

Method

1. Attach magnets to an iron yoke so that unlike poles face each other as shown in figure 9.11.

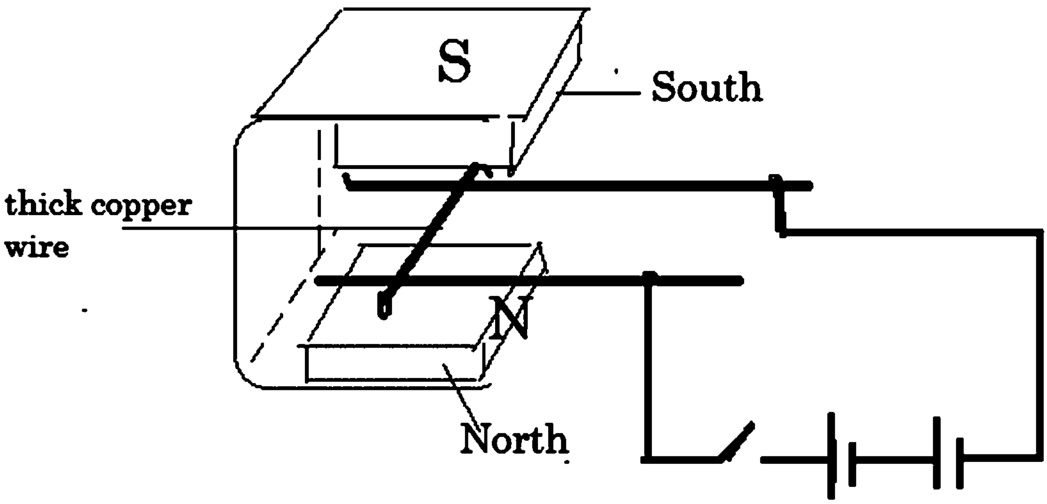


Figure 9.11: Investigating force on a conductor

2. Arrange thick copper wires as shown and place another thick wire on top of the others so that is lies between the magnetic field of the two poles of magnets
3. Close the switch and make observation.
4. Repeat the experiment with current direction reversed
5. Discuss the directions of conventional current and the magnetic field
6. Discuss and explain the observations made.
7. Discuss some of the devices that use the principle that has been observed.

Feedback

When a wire in placed near a permanent magnetic field and then electric current is passed through the wire as shown in figure 9.11, a force is created that can make the wire move. This is so because, there are two magnetic fields, one from the permanent magnet and the other is formed around the wire as current passes. The wire is actually an induced magnet when electric current passes. The interaction of the two magnetic fields (repulsions and attractions) creates a force that makes the wire move.

When electric current or magnetic field is reversed the wire is thrown in the opposite direction.

The amount of force created by the two magnetic fields can be increased by:

i. Increasing the electric current passing through the wire.
ii. Increasing length of part of the wire that is within permanent magnetic field.
iii. using a stronger magnet.

Forces are vectors, with both magnitude and direction. The force on the conductor is at right angles to both the magnetic field and direction of current flow.

In this case the direction of the force can be predicted using Fleming's left-hand rule. The rule says "*hold the Thumb, First finger and second finger of the left hand perpendicular to each other, with the first finger pointing in the direction of magnetic Field and second finger in the direction of conventional electric Current then the Thumb points in the direction of force (or Thrust)*".
Fleming's left hand rule is also called the motor rule because this is the principle which is used in a motor. In the figure 9.12 the wire moves out to the right.

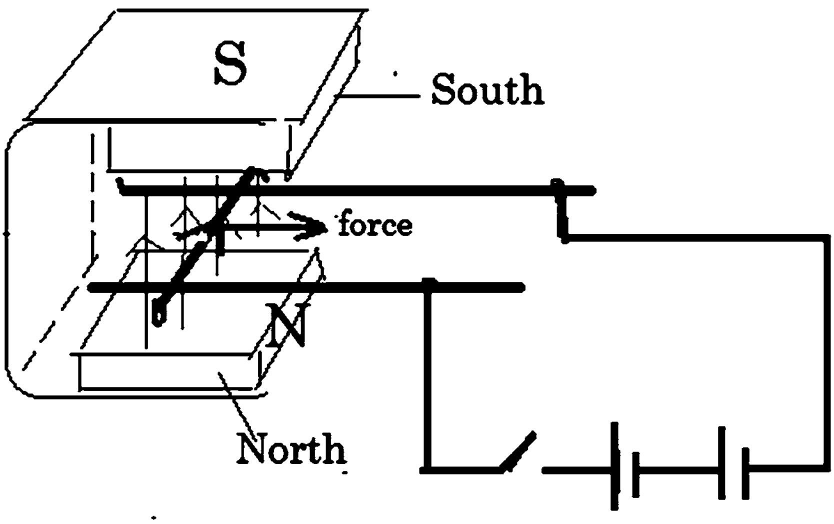


Figure 9.12 Direction of force produced by electromagnetism.

Key point

When a conductor is placed inside magnetic field of permanent magnet and electric current is passed though the conductor, an induced electromagnetism in the wire interacts with magnetic field of the permanent magnet to create a force that can allow movement of the conductor.

The magnitude of the force is a function of

1. amount of electric current
2. strength of magnet
3. length of conductor inside the magnetic field

Uses of force on a conductor in electromagnetism

A number of devices apply this concept of force created on a current-carrying conductor in a magnetic field. All these devices have a solenoid and a permanent magnet near each other to allow their magnetic fields to create a force from their repulsions and attractions. Some of these devices are, meters, loud speakers, microphones, electric guitars, motors and generators.

Loud speaker and microphone are shown in figure 9.13

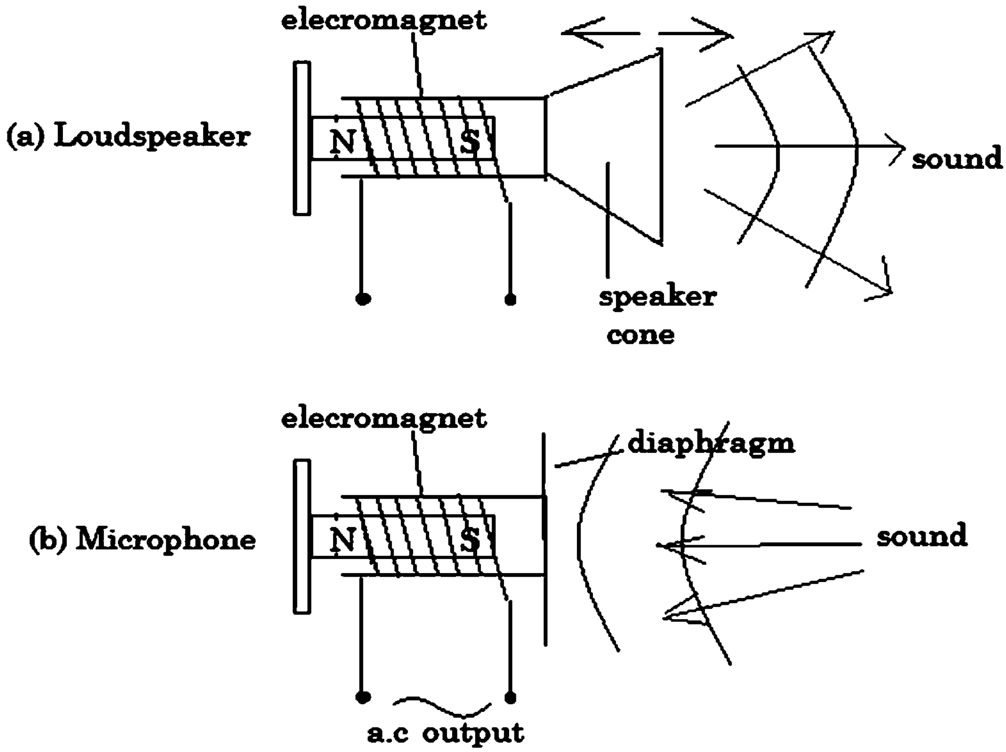


Figure 9.13: Loudspeaker and microphone

A microphone has a magnet inside a coil that is connected to a diaphragm as shown in figure 9.13(b). When sound waves shake the diaphragm, the coil also oscillates around the magnet and induced current forms in the coil. The frequency of coil oscillation imitates the frequency of the original sound. It is also possible to oscillate the magnet while the coil is stationary.

A loud speaker is constructed similar to a microphone as shown in figure 9.13(a). An alternating current is connected to the diaphragm which makes the coils oscillate. The speaker cone then oscillates together with the coil and produce sound wave.

Exercise 9.2.

1. State the Fleming's left hand rule.
2. Draw a diagram of bicycle dynamo and answer the following questions:
   a. Label its parts.
   b. Explain how the dynamo produces electric current.
   c. Mention three things that can increase the amount of current produced.
3. Figure 9.14 shows a wire placed between two magnets.
   a. Under what condition can the wire carry current in it?
   b. What will happen to the electric current if the wire is made into a coil.
   c. If the galvanometer was replaced with a power source and the wire between the magnets is simply placed on the other wire, what will happen to the wire? Explain.

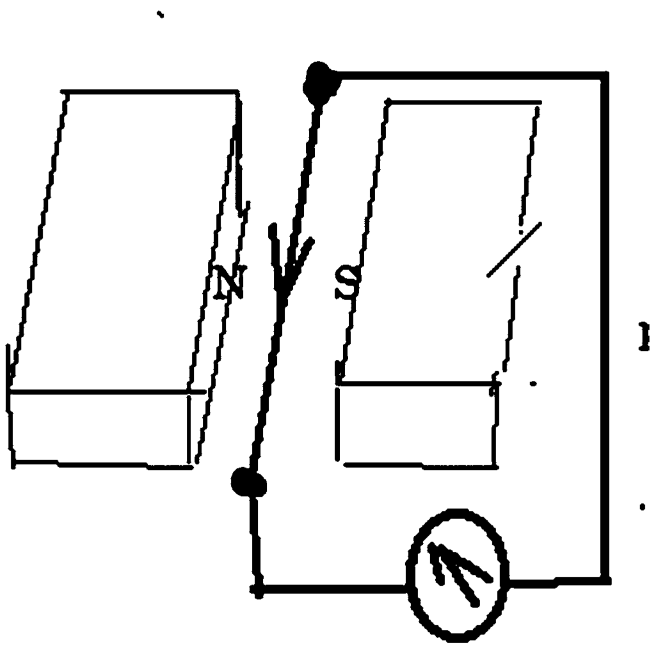


Figure 9.14

Electromagnetic induction

Electromagnetism allows coils to produce and carry electric current even without any power supply. Activity 9.4 shows how electric current can be induced into a conductor by moving magnetic field.

Activity 9.4

Experiments to illustrate electromagnetic induction

Materials

- Coil of wire
- Galvanometer
- Magnet.

Method

1. Make a solenoid and connect it to a galvanometer with a centre zero as shown in figure 9.15.

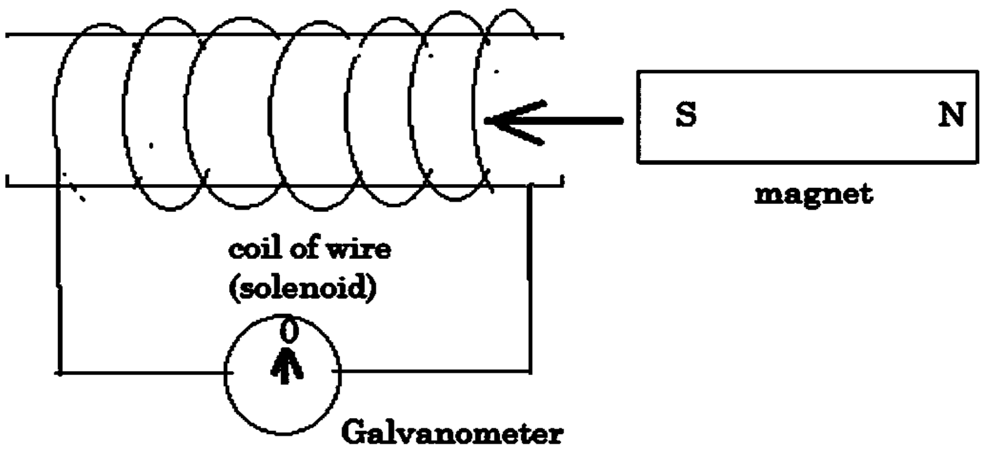


Figure 9.15 Experiment on electromagnetic induction

2. Move a magnet towards the coil and observe the galvanometer while the magnet is moving.
3. Stop the magnet motion and observe the galvanometer again.
4. Move the magnet away and observe the galvanometer again while the magnet is still moving.
5. Move the magnet faster and slower and make observation.
6. Increase the number of turns of the coil and make observation when magnet is moved in and out.

Feedback

When a magnet is moved into a solenoid that is connected to a sensitive galvanometer as shown in figure 9.16 (a), the galvanometer registers an electric current in one direction. When the magnet is moved in the opposite direction the current also changes direction as shown in the figure9.16 (b).

This is also true when the solenoid is moved across the fields of a magnet while the magnet is kept stationary.

When magnet is moved towards the solenoid, its magnetic fields cut across the coil and in the process induces an electromotive force (EMF) which creates induced electric current. This is called *electromagnetic induction.*

The current is zero when the magnet stops moving.

The magnitude of the EMF induced depends on:

i. Speed of moving coil or magnet.
ii. Number of turns of coil.
iii. Strength of magnet. A strong magnet has so many magnetic field lines concentrated around it than a weak magnet.

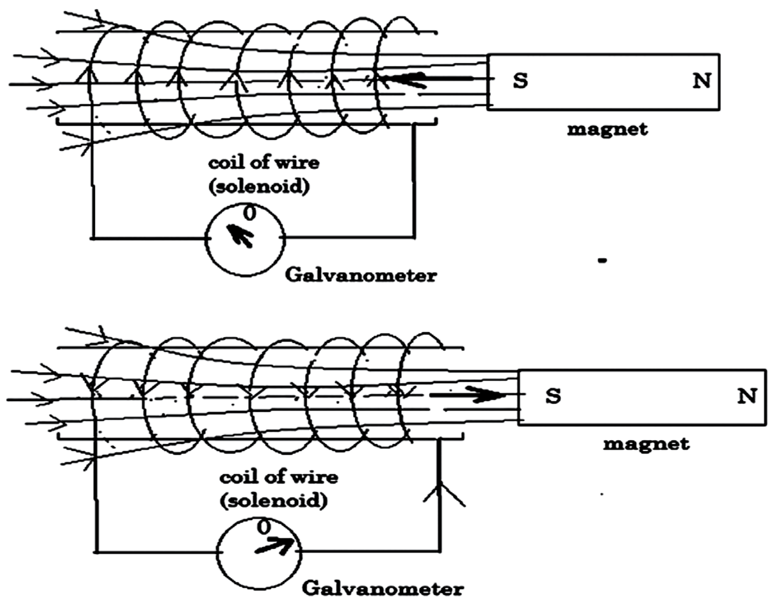


Figure 9.16: Direction of current during electromagnetic induction.

Increasing all the above factors above increases induced EMF by increasing number of magnetic field lines cutting across the coils per unit time. This agrees with Faraday's law which states that

Key point
whenever there is a change in the magnetic flux linked with a circuit an electromagnetic force is induced, the strength of which is proportional to the rate of change of the flux linked with the circuit".

The direction of induced electric current depends on the relative direction of the magnetic field.
Lenz's law states that "*the direction of the induced current is always such as to oppose the change producing it*".

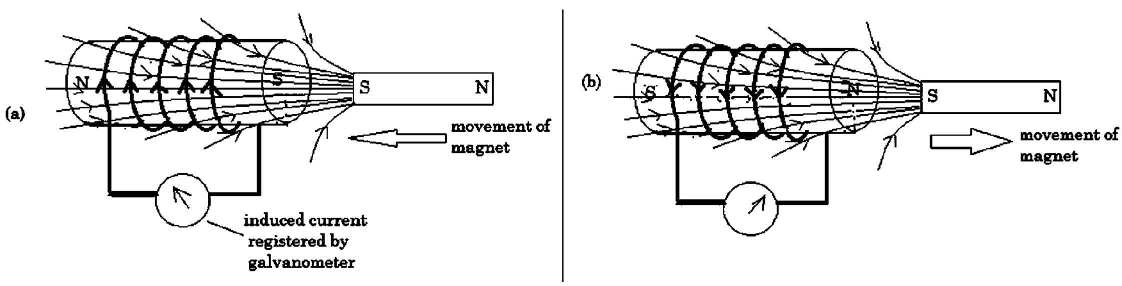


Figure 9.17: Illustrating Lens's Law

In figure 19.17(a), the South seeking pole is moved into the solenoid, the induced electric current must flow in a direction which opposes the direction of movement of magnet. The near end of the solenoid must therefore be south seeking pole. Repulsion will oppose movement of magnet.

In figure 9.17 (b), the south seeking pole is moved away from solenoid, the induced electric current must flow in a direction which opposes direction of movement of magnet. The near end of solenoid must therefore be north seeking pole. Attraction will oppose movement of magnet.

ac and dc Generators.

Generators are machines that convert mechanical kinetic energy into electrical energy. They are made of a free turning rectangular coil, suspended in an axle between two opposite poles of a magnet as shown in figure 9.18.

Generators use the idea of producing an induced EMF by moving a coil which cuts across magnetic field of the permanent magnet. The coil can be turned using moving water, wind, motor engine, steam, and any other mechanical movement. In bicycles the coil of a dynamo is turned by putting the wheel of dynamo against the moving tyre. The coil and the output induced EMF can be arranged in such a way that it can either produce direct current (dc) or alternating current (ac).

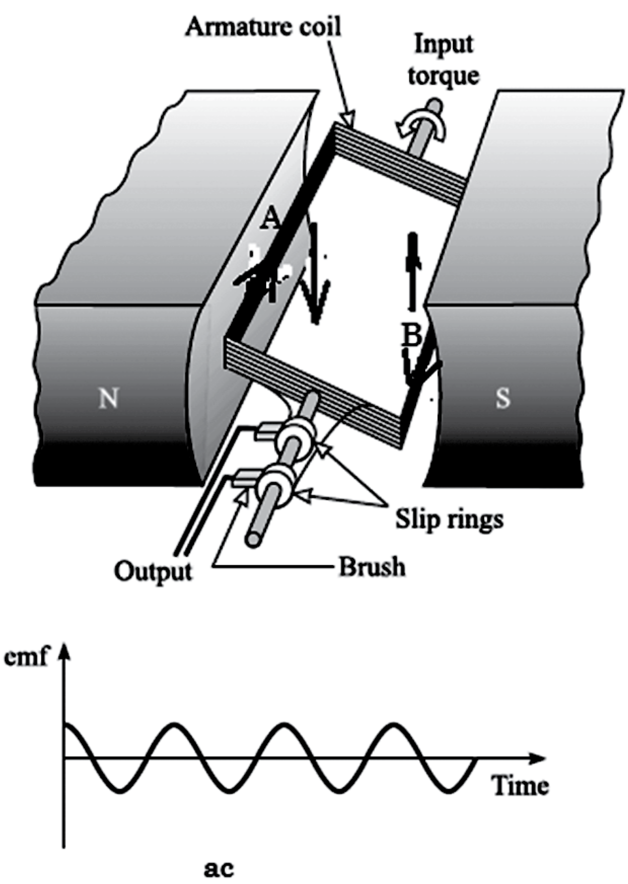


Figure 9.18 a.c. generator

In ac generator solenoid contacts are made of slip rings (as shown in figure 9.14) to allow changes in induced magnetic field only, while contacts remain the same as the coil turns.

In figure 9.18 when the coil is moved into vertical position no current passes. When the coil is horizontal, coils along sides A and B cut across the magnetic field and current in coils passes as shown by arrows in figure 9.18, following the Fleming's right hand rule. Fleming's right hand rule says that *if you point the First finger in the direction of magnetic Field and the thuMb in the direction of Motion then the seCond finger points in the direction of induced Current.*

When the coil changes sides so that A is on the S side while B is on the N side, the direction of current in the coil changes compared to the first. As the coil rotation continues the induced electric current keeps on changing direction and this is called alternating current, a.c.

The electricity at Nkula is generated using water flow to turn big turbines which rotate coils inside magnetic fields. The coils rotate at about 50 times per second or 50Hz. For this reason ac generators are also referred to as alternators. In a car an alternator produces induced electric current which is used to charge the car battery.

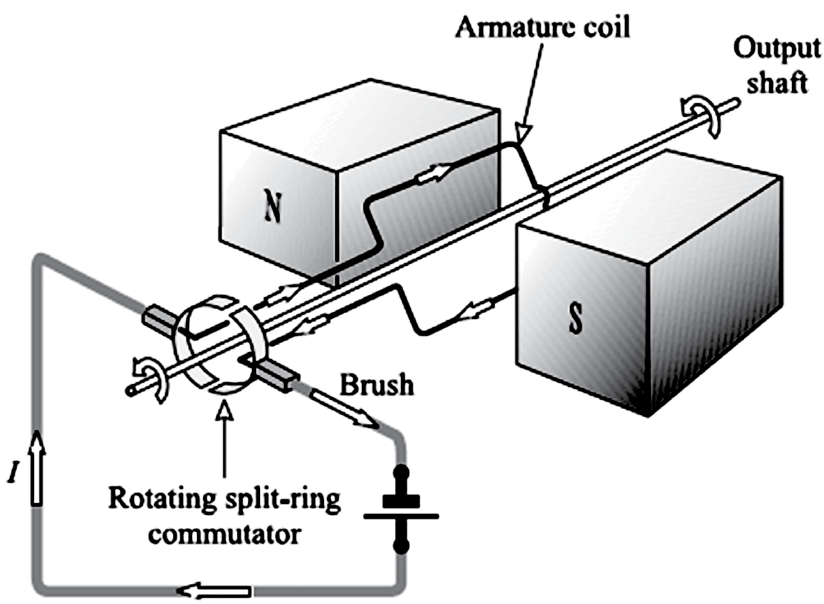


Figure 9.19 dc generator

In a dc generator solenoid contacts are made of split-ring commutator to allow them turn and change over as the coil is turned. Figure 9.19 shows the same generator as above but now connected to commutator.

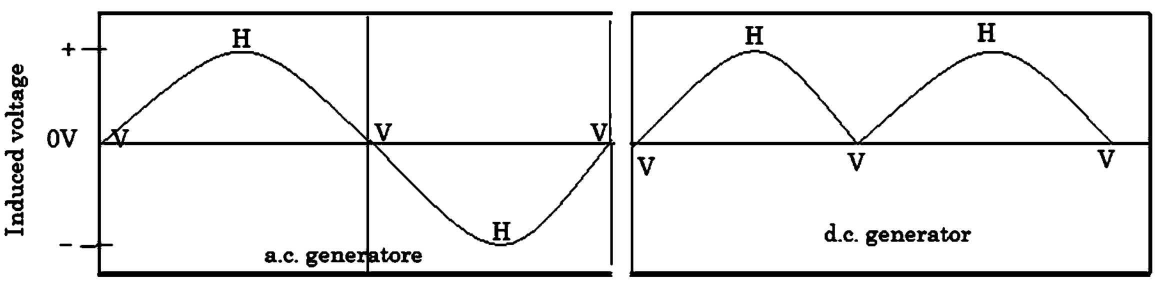


Figure 9.20 Changes in induced emf

In this case when the coil sides A and B change sides, the induced current also changes sides. It is the contacts which reverse but one brush is always positive while the other is always negative creating an output voltage which has one direction.

The graphs in figure 9.20 show how the output induced voltage changes in an ac generator and dc generator.

In both cases maximum voltage is induced when the coil is horizontal (H), when there is maximum number of coils cutting across the magnetic field. There is zero voltage when the coil is vertical because coils are not cutting across magnetic field.

Construction of a motor is the same as a generator. The rotation of coils or magnet in a generator induces electric current, while in a motor it is the current passed through the coils that creates a force to turn the coil.

Project: Constructing a motor

Materials.

- Small wooden frame
- PVC insulated wire (at least 3m long)
- Metal tube
- Insulation tape
- Wire striper or razor knife
- Piece of rubber band
- Two Split pins
- Two Drawing pins
- Two rectangular magnets
- Iron yoke
- 3 cells
- Switch
- Connecting wires
- Wooden base

Method

1. Make or get a wooden frame with a channel and slot cut round its edges as shown in figure 9.21.
2. Insert metal tube into the slot
3. Wrap a short length of PVC insulation tape round the metal tube which sticks out of the wooden frame.

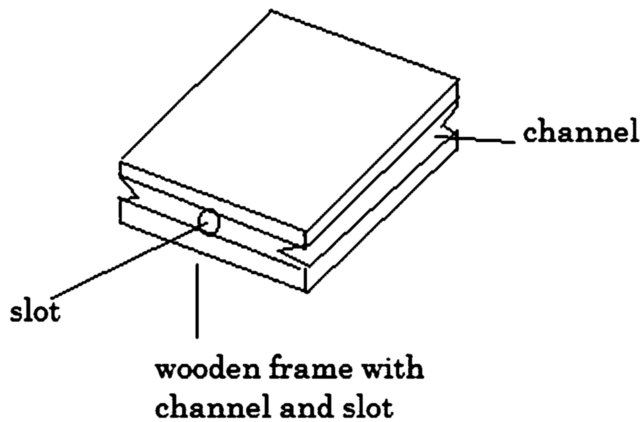


Figure 9.21

4. Wind 10 turns of PVC-insulated wire tightly round a frame, pressing the wires into the slots. Both end of the coil should finish at the same end of the frame as shown in figure 9.22

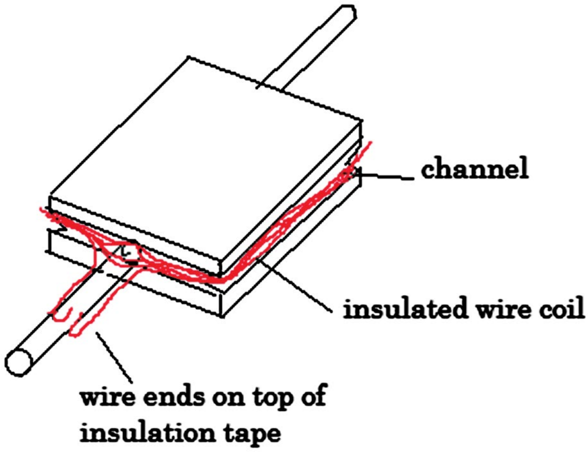


Figure 9.22

5. Make a commutator as follows
   a. Strip about 2cm of insulation from both ends of the wire coil and bend them into a flat U-shape.
   b. Press the two bared wired ends against opposite sides of the insulated tube and fix them using a small rubber band or narrow strip of tape
   c. Fit the frame and coil on the axle, supported by split pins as shown in figure 9.23

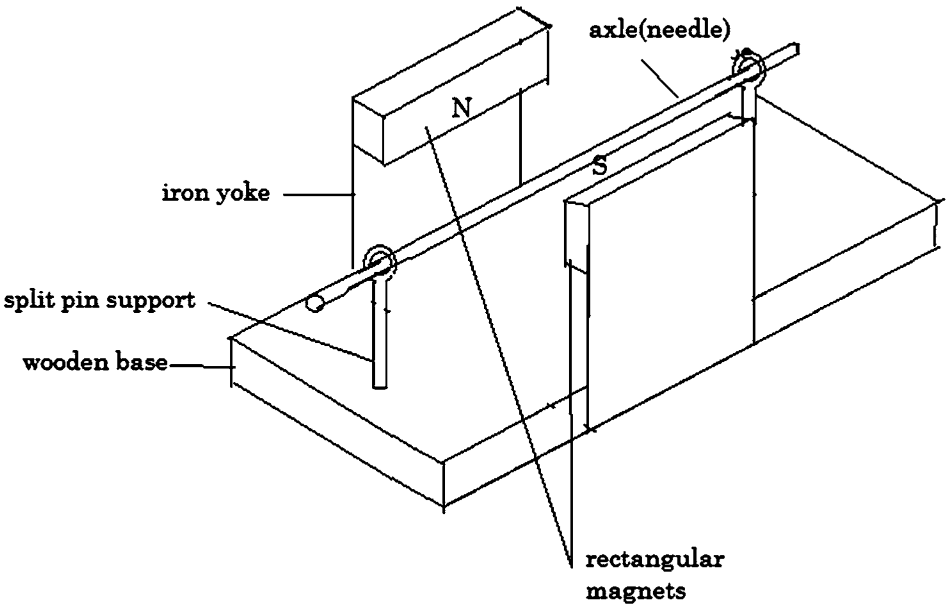


Figure 9.23

   d. Make two wire brushes by stripping about 2cm of insulation from two short lengths of wire, which will form the contacts with the commutator as it rotates.
   e. Fix the wire brushes to the base board with drawing pins so that

they press against the two sides of the commutator. They should make electrical contact when the armature is horizontal.

6. Attach two rectangular magnets with unlike poles facing, to an iron yoke as shown in figure 9.24 making sure that the rotor is free to turn

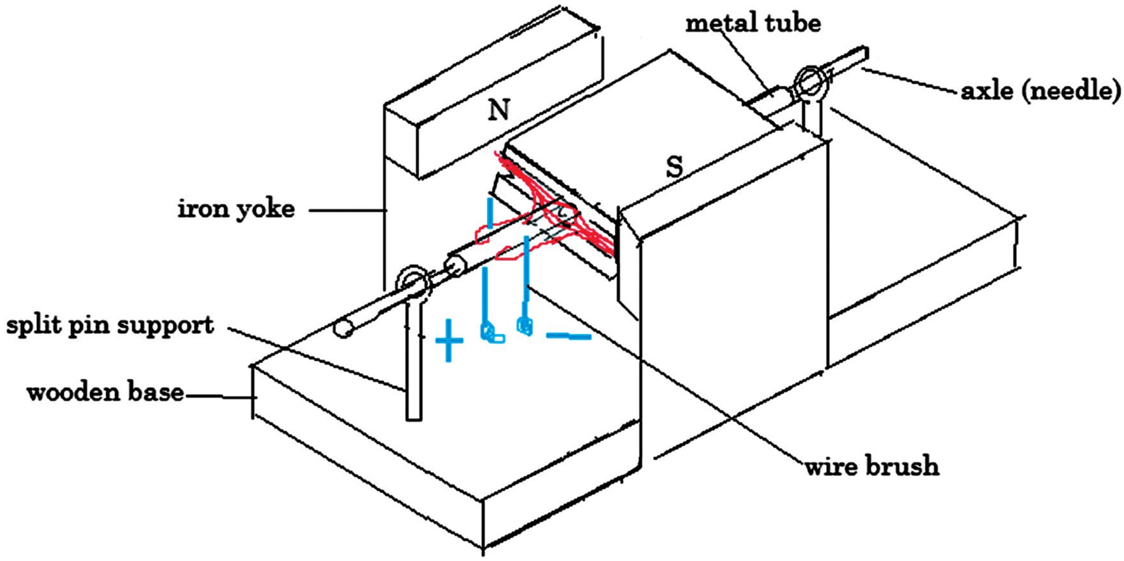


Figure 9.24

7. Connect the brushes to a low-voltage d.c. supply and switch on.
8. Make any necessary adjustment to make the motor run smoothly.

Discussion question after project

1. Why should the two halves of the commutator be on the sides of the metal tube, rather than the top and bottom, when the rotor frame is horizontal?
2. What happens at the commutator when the rotor has turned to vertical position?
3. Work out the directions of the current in the coil and the force on each side of the rotor coil when it is horizontal. What would happen if the direction of the current in the rotor coil did not reverse twice in every revolution?

Exercise9.3

1. List any five devices that use a motor or generator.
2. List down similarities and differences between a generator and a motor.

Transformers and power transmission

Transformers are found in electric is devices like radios, TV andon a large scale in electricity transmission. They are used to rise or lower voltage supplied from a source. Activity9.5 will help you to explore how the transformer works.

Activity 9.5

Explaining the working of a transformer

Materials

- Two pieces of insulated wire
- A piece of iron
- 2 cells
- Galvanometer
- Switch
- Transformer

Method

1. Wind the two pieces of PVC insulated wire around the piece of iron so that they are close together but not touching as shown in figure 9.25

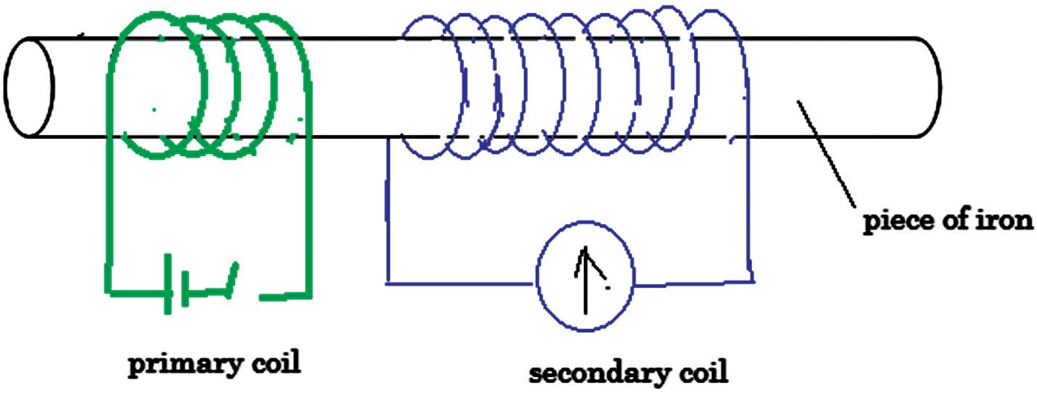


Figure 9.25: sample transformer

2. Connect the primary coil to cells while the secondary coil should be connected to a galvanometer.
3. Close the switch and notice the galvanometer;
   a. as you close the switch.
   b. when the switch is kept on.
   c. as the switch is opened.
4. Reverse the cells and repeat step 2.
5. Exchange the position of galvanometer and the cells and repeat steps 3.

6. Check on the transformer and observe how the winding of the wire is done

Feedback
When two coils are placed near each other as shown in figure 9.26 (a), and electric current switched on the first coil, there is induced EMF in the second coil.

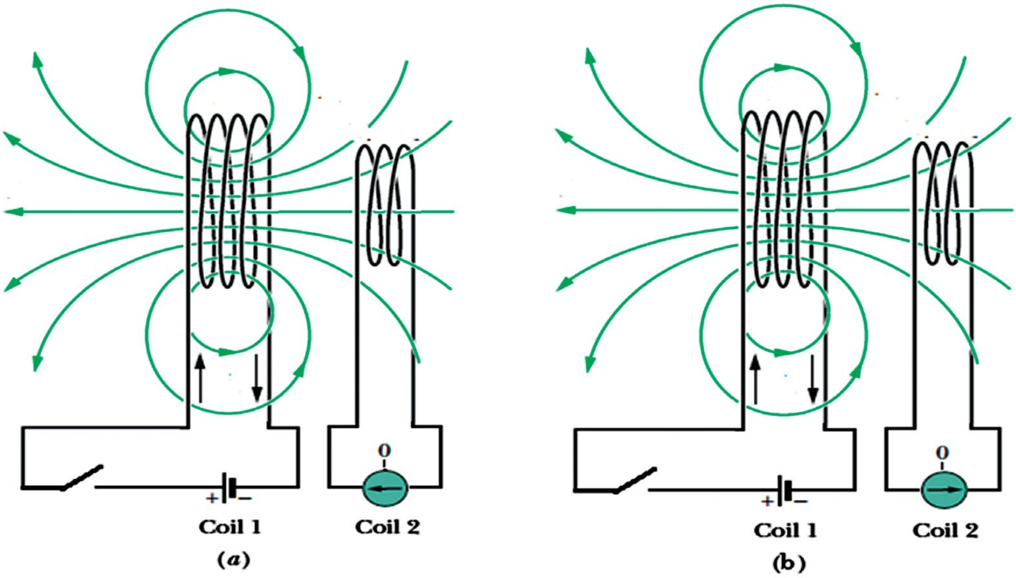


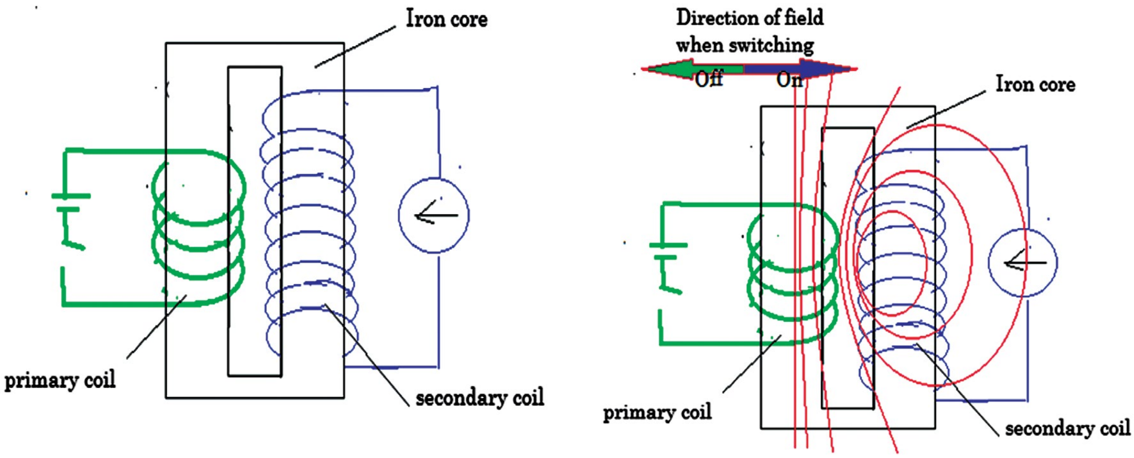
Figure 9.26 principle of transformer

This is so because the making of magnetic field in the first electromagnets, reaches and cuts across the secondary coils. When switching off, the magnetic field moves in the opposite direction as it collapses to zero and in the process cut across the coils again but in the opposite direction as shown in figure 9.26(b). Notice that when the switch is held on, current reduces to zero because the existing magnetic field is not moving to cut across the coils.

Putting an iron core in the coils allows the concentration of magnetic field across secondary coil. Practical transformers are usually arranged as shown in figure 9.27(a) where the two coils share the same iron core. Diagram (b) shows the movement of magnetic field when switching on and off.

If the primary coil is fed with a current that is alternating, its field will also be alternating direction. In turn, the induced voltage is also alternating.
Again the magnitude of induced voltage in the secondary coils can be increased by

i. Increasing the number of turns in the secondary coil (a case of step up transformer).
ii. Using a stronger iron core.
iii. Increasing the speed at which the field moves. In this case the frequency of alternation is very important.



(a) (b)

Figure 9.27 Arrangements of coils in a transformer and movement of fields

Power loss in transformers and in transmission

Transformers are good examples of magnetic induction from one coil to another when they are placed near each other as shown in figure 9.27.

The iron core inside the transformer should be a soft magnetic material so that it can easily be magnetised and at the same time easily demagnetised as the current alternates.

Step up transformers have more turns in the secondary coil and secondary voltage becomes more than input voltage. In step down transformer, the number of turns in the secondary coil is less than number of turns in the primary coil.

Solving mathematical problems involving transformers

In an ideal transformer the energy input in the primary coil is equal to energy output in the secondary coil, as required by the law of conservation of energy.

$$Input\ energy = Output\ energy$$

$$(VIt)_{primary} = VIt_{secondary}$$

Time is the same so the equation can be written as

$$V_p \times I_p = V_s \times I_s$$

Rearranging the equation gives $\frac{I_p}{I_s} = \frac{V_s}{V_p}$

The induced and input voltages are related to the number of turns using the following relationship. $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

The value of $\frac{N_s}{N_p}$ is called turns ratio.

It can be shown that $\frac{I_p}{I_s} = \frac{N_s}{N_p}$

Example.

1. Figure 9.28 shows a transformer 50 turns in the primary, carrying 10A. the primary voltage is 12volts while the secondary voltage is 240 volts

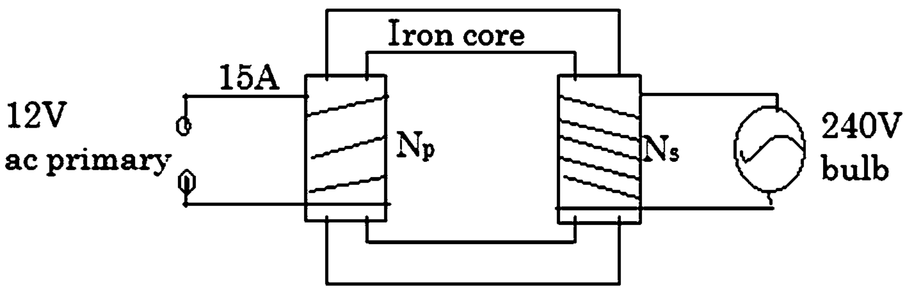


Figure 9.28

a. Work out the number of turns in the secondary coil
b. Calculate the current in the secondary coil
c. Explain why soft iron core is used.

Solution

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

$$\therefore N_s = \frac{V_s}{V_p} \times N_p = \frac{240V}{12V} \times 50 = 1000 turns.$$

b. $\frac{I_p}{I_s} = \frac{V_s}{V_p}$

$$\therefore I_s = \frac{I_p \times V_p}{V_s} = \frac{10A \times 12V}{240V} = 0.5A$$

c. Soft iron core is used for easy magnetisation and demagnetisation each time the electric current in primary coil reverses its magnetic field.

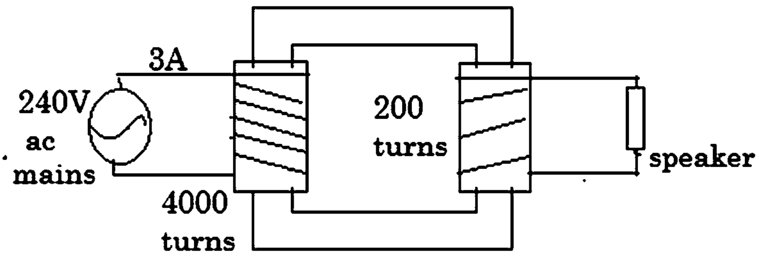


Figure 9.29

2. Work out the following using the information in figure 9.29
   a. Voltage across speaker
   b. Power dissipated by the mains
   c. Current through the speaker

Solution

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

$$\therefore V_s = \frac{N_s}{N_p} \times V_p = \frac{200 \times 240}{4000} = 12V$$

b. $W_p = V_p \times I_p = 240 \times 3 = 720W$

c. $W_p = W_s = 720W$

$$W_s = V_s \times I_s = 720W$$

$$\therefore I_s = \frac{720W}{V_s} = \frac{720W}{12V} = 60A$$

Power losses

No transformer is 100% efficient because some of the input energy is wasted due to two major reasons.

1. Heating of the coils due to their resistance. This is minimised by immersing the coils in oil to cool the down.
2. Eddy currents. These are currents induced in the iron core instead of the secondary coils. To minimise eddy currents, the iron core is made in form of insulated laminates which cut off current paths.

The efficiency of the transformer can be calculated using the formula

$$Efficiency\ (\%) = \frac{output\ power}{input\ power} \times 100$$

$$E = \frac{W_s}{W_p}$$

The other loss in energy is experienced due to resistance of power cables. Although aluminium or copper wire has very low resistance, when it is used in long distance transmission its resistance become considerable enough to lose a lot of power. Consider transmission as shown in Figure 9.30

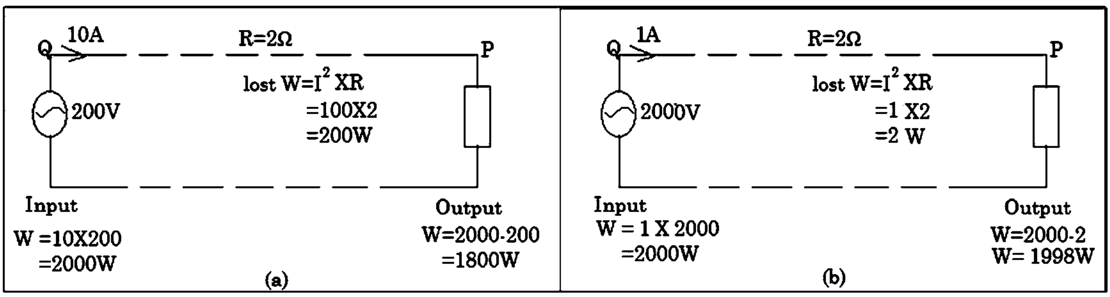


Figure 9.30

In Figure9.30(a) the electricity is transmitted at high current and low voltage. The input power is 2000W, but the output is 1800W making a loss of 200W in the process. This is wasted as heat into the surrounding air.

In figure 9.30(b) the electricity is transmitted at low current and high voltage. With this arrangement only 2W is lost. For this reason electricity is transmitted at high voltage and low current to reduce power losses due to resistance of the cable.

In all cases alternating current (ac) is used to transmit electricity because of two reasons. The first is that ac electricity is easier to generate using generator. The second reason is that using transformers the voltages can easily be stepped up or down to meet required conditions.

Example.

1. Work out the following using the information in figure 9.31if the transformer is 80% efficient.

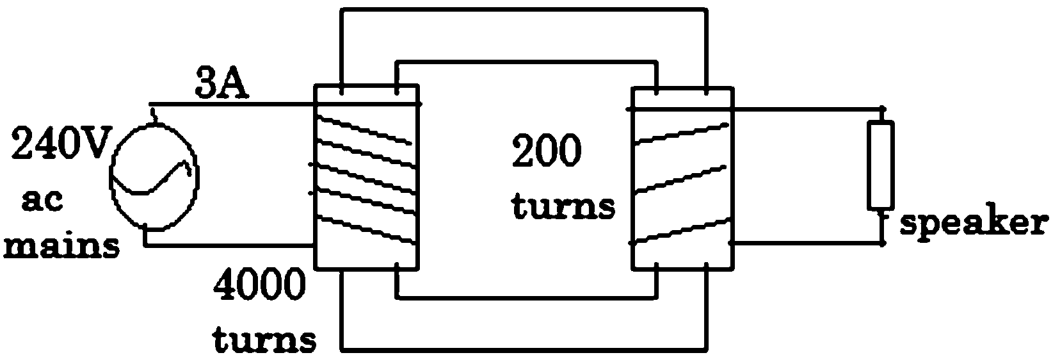


Figure 9.31

a. Power dissipated by the mains.
b. Power dissipated in the speaker.
c. Voltage across speaker.
d. Current through the speaker.

Solutions

a. $W_p = V_p \times I_p = 240 \times 3 = 720W$

b. $W_s = \frac{80}{100} \times 720W = 576W$

c. $E = \frac{W_s}{W_p} \times 100$

$$80 = \frac{V_s \times I_s}{V_p \times I_p} \times 100$$

$$but\ \frac{I_p}{I_s} = \frac{N_s}{N_p} \quad \therefore \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

$$80 = \frac{V_s \times N_p}{V_p \times N_s} \times 100 = \frac{V_s \times 4000}{240 \times 200} \times 100 = 8.3V_s$$

$$\therefore V_s = \frac{80}{8.3} = 9.64V$$

d. $W_s = V_s \times Is$

$$\therefore I_s = \frac{W_s}{V_s} = \frac{576W}{9.64} = 59.8A$$

Environmental impact of power generation and transmission

Generating electricity from generators is very expensive and has impact on the environment. In activity 9.6 you will discuss some of these problems

Activity 9.5

Discussing environmental problems associated with power generation.

Materials
- Chart paper
- Pental markers

Method
1. In small groups discuss some of the environmental problems that come in due to generation of electricity is Malawi.
2. Discuss some of the solutions to the problems that you have listed?

Feedback

To create a hydroelectric power plant, people have to be relocated to other areas which create land problems. Construction of dams requires vast amount of land For example, THE NATION, a local newspaper of Monday, 6th October, 2014 reported that in Malawi a new energy project would displace 3 500 people in Balaka, Phalombe, Lilongwe and Mzimba where transmission lines will pass through.

Other power plants like coal and nuclear plants use a lot of water for cooling.

Erecting overhead power lines may also result into ecological disturbances.

ESCOM in Malawi is having water siltation problems at its generation points due to erosion of soil that is taking place along the Shire River due to deforestation. This affects power generation output.

Unit Summary

- Magnets are made from magnetic materials like iron or steel.
- Magnets can be made by stroking and electrical methods.
- Atoms and molecules in magnetic materials, form tiny magnets called domains which if oriented in the same direction, they form a magnet.
- Magnets can lose their magnetism when heated, hammered all put in ac electricity.
- When electric current passes through a conductor, the conductor becomes magnetic because it develops its own magnetic field, called induced magnetism.
- Induced magnetism can be increased by increasing current, using a solenoid and inserting an iron core in the solenoid.
- When a conductor carries a current while inside a permanent magnetic field, the two magnetic fields produce a force. The direction of the force can be predicted using Fleming's left hand rule. This principle is used in motors and generators.
- When a magnetic field of a magnet is made to move across a wire, an induced current forms in the wire.
- When a coil is made to carry current while placed close to another coil, the magnetic field of the first coil induces and emf in the second coil. This principal is used in transformers.
- Electricity is transmitted at high voltage and low current to reduce power losses due to resistance of the cables.
- Electrical power generation has environmental problems especially the fact that people are displaced when constructing dams and erecting poles.

End of unit exercise

1. Is it possible to locate electric wires located inside the walls of a house using a compass? Explain your answer.
2. Two wires carrying electric current are placed parallel to each other. Explain why the wires exert forces to each other.
3. The figure 9.32 shows an arrangement of two coils of wire with a soft iron inserted into them.
   a. What type of transformer is presented by this diagram?

b. Why is iron needed as a core in the transformer?

c. Why should the iron be a soft magnetic material?

d. Give reasons why a transformer is never 100% efficient.

e. Give two ways of increasing efficiency of a transformer?

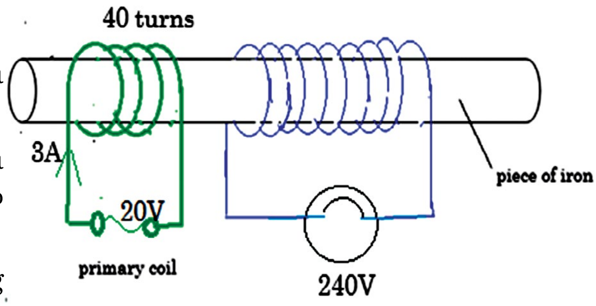


Figure 9.32

f. Calculate the following:
   i. Number of turns of the secondary coil.
   ii. Electric current in the secondary coil.

g. Explain why a transformer cannot work with direct current (dc.)

4. A transformer has a current of 2A and 6V in its secondary coils. If the current in its primary coil is 12A find out the:
   a. Type of transformer this one is.
   b. Voltage in primary circuit.
   c. Power output.
   d. Number of turns in the secondary if the primary had 60 turns.

5. Figure 9.33 shows a transmission line and transformers at its ends

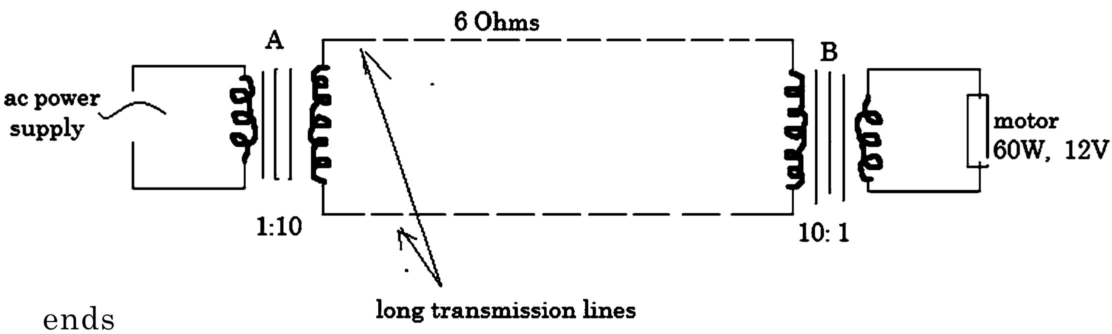


Figure 9.33

   a. How much current passes through the motor?
   b. How much current passes through the cable of the transmission?
   c. How much power is lost in the cables?

6. A long distance cable has a resistance of 3Ω. The input power is 6kW.
   a. Work out the power loss in the cable when the input voltage is
      i. 300V
      ii. 3000V

b. Explain why electricity is transmitted at high voltage, low current?
c. Why are transformers used?

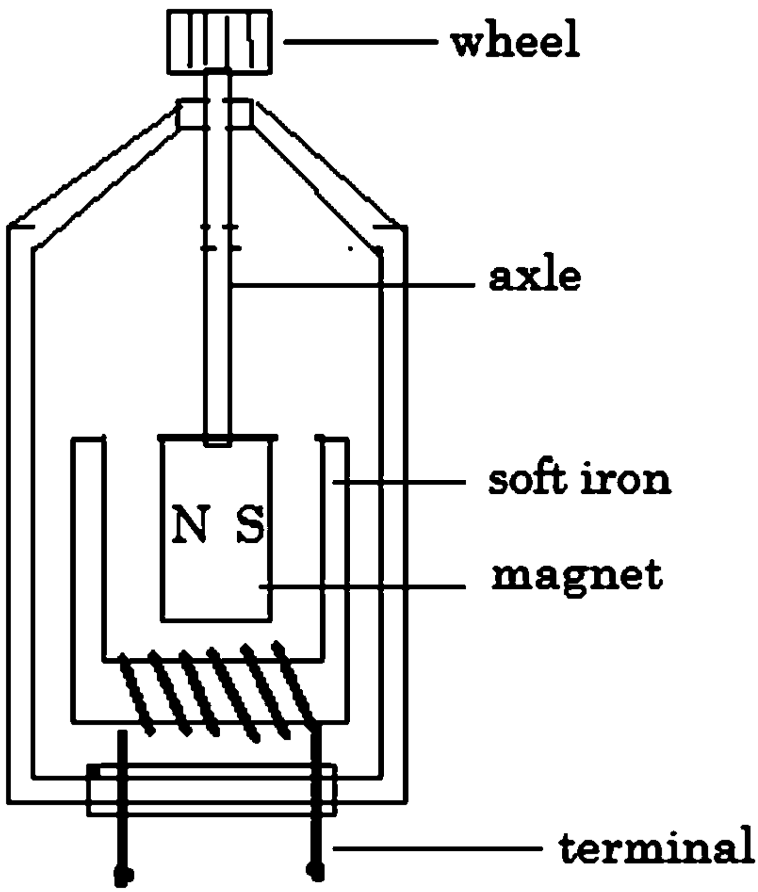


Figure 9.34

d. What is the advantage of ac electricity over dc electricity?

7. Figure 9.34 is a structure of a dynamo.
   a. What happens in the iron core when the wheel turns?
   b. Copy and label a part where voltage is induced.
   c. What three possible changes can be made to produce more voltage
   d. Will this dynamo produce ac or dc current? Explain.

e. Will the bicycle lamp work when the bicycle stops? Why?

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UNIT 10

Which mechanism do materials use to conduct or not conduct electricity? This is a starting point in understanding the world of electronics today which all involvethe use of semiconductors. In this unit you will discuss semiconductor devices and electronic components they use. You will also be introduced to analogue and digital circuits. Finally you will learn to describe the operations of logic gates.

Introduction to digital electronics

Semiconductor devices

Most components in electronic systems like radio, television and computers are made from semiconductors. What are semiconductors? What is the difference between semiconductors and conductors?

Activity 10.1

Discussing semiconductor devices

Materials

- Cathode ray oscilloscope (CRO).
- Semiconductor like Diode.
- Rubber or any other insulator.
- Conductors like copper wire.
- ac. power supply.
- Wires.

Method.

1. Discuss the meanings of insulators, conductors and semiconductors using your previous knowledge.
2. Connect the CRO to power supply.
3. Connect a wire to the oscilloscopeto find nature of signal on the CRO when electric current passes through a wire. Observe how high the signals are on the screen of the oscilloscope to get values of voltage.
4. Reverse the connection of the wire and do the same as in 3.
5. Repeat for other materials like rubber, and diodes.
6. Discuss and describe the difference in the conductivity of the material.

7. Discuss and explain what causes the differences in conductivity between different materials.

Feedback

The experiment above shows that there are three major categories of materials in terms of their conductivities. Materials are either conductors or insulators or semiconductors. Band theory helps to explain why some materials conduct electricity while others do not conduct electricity.

Band Theory

It is well known that electric current use movement of charge, which can be electrons or ions. Electrons are in shells or energy levels. The electrons can only exist in special energy levels not in between. To conduct electricity, the electrons need to move out to higher level, which requires energy that corresponds to energy spacing between the two levels. The band theory says that for a material to conduct electricity, it depends on the energy required to move from one level called valence band, to the next higher level, called conduction band. A material is a good conductor or semiconductor or insulator depending on the ease with which the electrons can go into conduction band from valence band, when subjected to pd voltage. It should also be noted that only the outer electrons in the higher level are moved into conduction band. The core electrons in the inner levels are not used to form electric current.

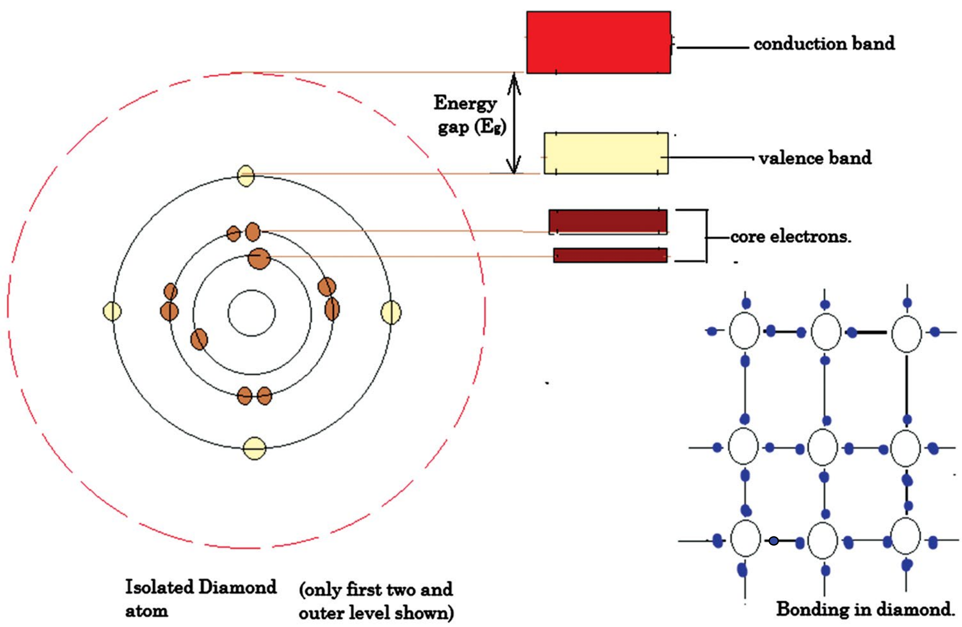


Figure 10.1 Electron shell diagram of atom and bonding in diamond.

Insulators

An insulator is a material in which no electric current exists when it is connected to pd voltage across its ends. For an insulator like diamond, the valence band is filled with electrons due to its covalent bonding. For example diatom atom levels are fully filled in its crystal due to covalent bonding as shown inpart (b) of figure 10.1.

A lot of energy is required for the electrons to manage jumping across the energy gap, E_g(also called forbidden gap). Although the conduction band is vacant of electrons, but thermal energy or photon absorption are not sufficient for the electrons to jump from valence band to conduction band. A very high resistance exists to electric flow.

Conductors

In conductors like metals, the highest energy level (valence band) falls near middle of an energy conduction band as shown in figure10.2

The conduction band is narrow and overlaps the valence band. There are plenty of vacant levels nearby, within same energy so that electrons can easily move into conduction band.
Not all electrons available in the valence band jump into the conduction band. Only those electrons whose energy is close to energy in the conduction band are free to move.

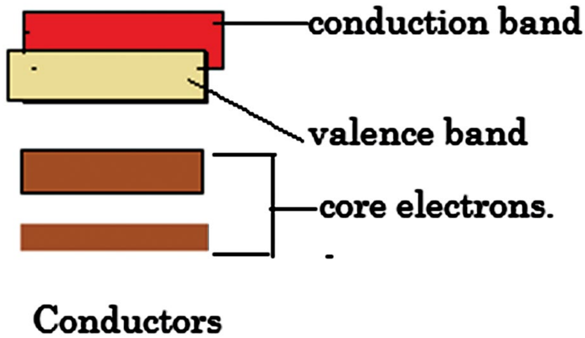


Figure 10.2 Energy gap between valence band and conduction band in conductors.

Semiconductors

The bonding in semiconductors is similar to that of an insulator. Unlike insulators, the energy gap, E_g between conduction and valence band is very small as illustrated in figure 10.3

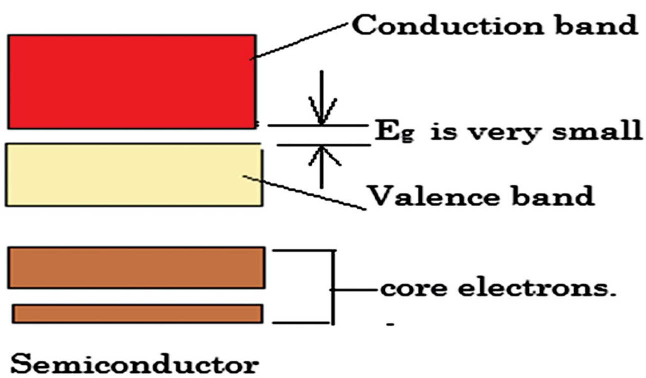


Figure 10.3 Energy gap between valence band and conduction band in semiconductors.

With little supply of heat, at room temperature, the electrons gain enough kinetic energy to move into conduction band.
Relatively, the energy gap, (E_g) in gold is five times larger than it is in silicon, a common semiconductor. The common semiconductors include silicon, gallium arsenide, germanium, indium antimonide, and lead sulphide.

Key point
A semiconductor is a substance whose electrical properties are between a good conductor and an insulator

Charge carriers in a semiconductor

Below absolute zero (-273°C), a semiconductor has its valence band full of electrons while the conduction band is empty so that it cannot conduct electricity. As temperature rises, the electrons gain kinetic energy. At some point of temperature above absolute zero, the kinetic energy is sufficient enough for some limited number of electrons to move from valence band to conduction band. When this happens, a positive gap is created called a positive hole as illustrated in figure 10.4.

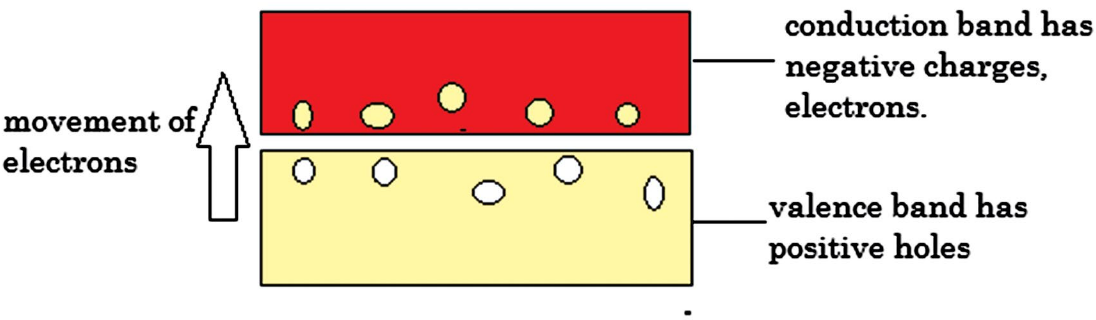


Figure 10.4 Movement of electrons into conduction band creates holes in the valence band

Electrons remaining in the valence band are now free to jump into the positive holes. When an electron fills a hole, it creates another hole where it has moved from and so on. In this way, the holes are also charge carriers like the moving electrons. Imagine that toads are sitting on bars of a small ladder as shown in figure10.5. The way is blocked because the toad sitting on position 4 has not enough energy to move up onto the platform. If the toad on bar four is given enough energy so that it jumps onto the platform, a vacant space is created on bar 4. The lower toad moves from bar 3 to bar 4, while the gap moves from 4 to 3. Every time a toad moves, the gap position moves in opposite direction.

Notice also that because of only one electron moving into conduction band creates freedom of random movement in valence band. This is what happens with holes in the valence band of a semiconductor the moment an electron moves into the conduction band.

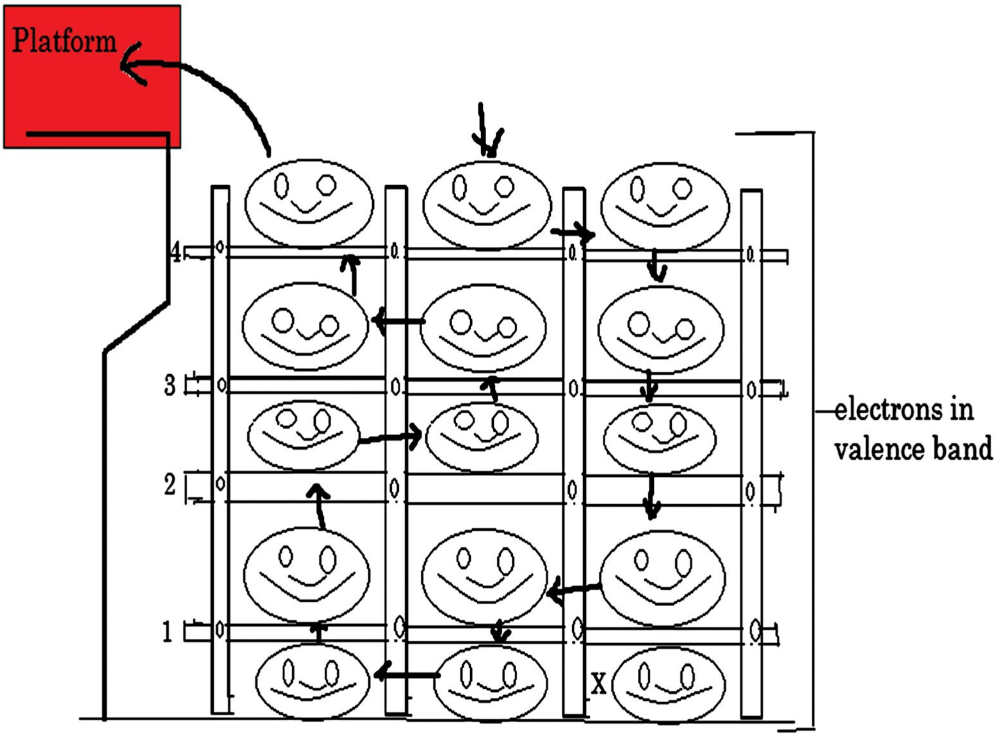


Figure 10.5 Illustrating movement of holes and electrons in a semiconductor connected to pd voltage.

A semiconductor therefore, uses both electrons and positive holes as charge carriers when it conducts electricity. If connected to a pd voltage an electric current is set up where positive holes move in the opposite direction to the flow of electrons.

While solid conductors increase resistance when temperature rises, semiconductors reduce their resistance due to more electrons that move into conduction band due to thermal agitation.

Intrinsic and extrinsic semiconductors

Intrinsic semiconductors can start conducting electricity because of thermal agitation when temperature is raised. It is intrinsic because conductivity is natural since they do not need artificial materials to improve their conductivity.

Extrinsic semiconductors are those which improve their conductivity by addition of another material, called impurity. The process of introducing a small number of suitable replacement atoms in the semiconductor lattice is called doping. In silicon, only 1 atom of impurity is doped per every 10million atoms of silicon. There are two types of extrinsic semiconductors called n-type and p-type.

Key point
The electrical properties of a semiconductor can be improved by heat, light and addition of certain impurities
A semiconductor uses both electrons and positive holes as charge carries to form an electric current

n-type semiconductor

A good example is when silicon is doped using phosphorus. The valence band of a piece of silicon involves those electrons found in its covalent bonds as shown in figure 10.6

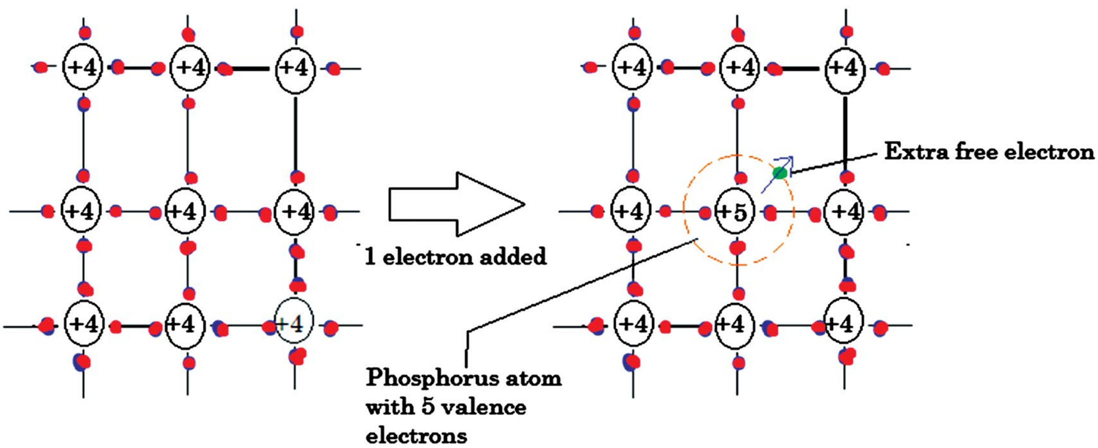


Figure 10.6. n-type doping

The extra free electron moves around by exchanging positions with the other atoms. Each time an electron becomes free to move about in the lattice, means it has moved from valence band to conduction band. In the conduction band electrons are localised on lower energy levels as shown in figure 10.7, where very small amount of energy, (labeled *Ea* on the diagram) will be required to excite

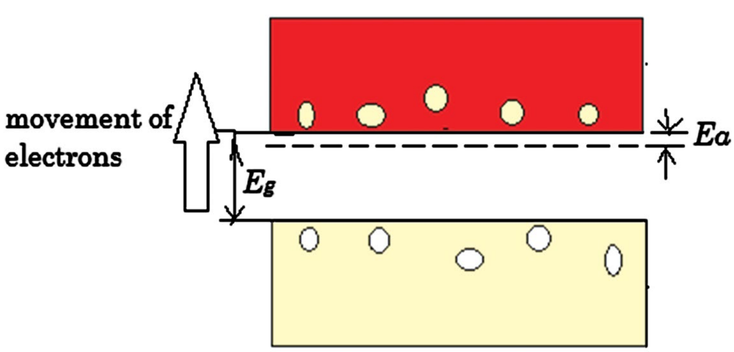


Figure 10.7 Energy gap of electrons in doped semiconductor

them than the larger Energy gap E_g. The electrons will jump from donors at dashed level.

Semiconductors doped with donor atoms are called n-type because negative donated electrons will be in majority as charge carriers than the holes. Other donors to silicon to make n-type are antimony (Sb) and arsenic (As) atoms which are both found in group five of the periodic table.

p-type semiconductor

In p-type semiconductor, silicon is doped with atoms that have only three valence electrons. Figure 10.8 shows aluminium atoms doped into silicon.

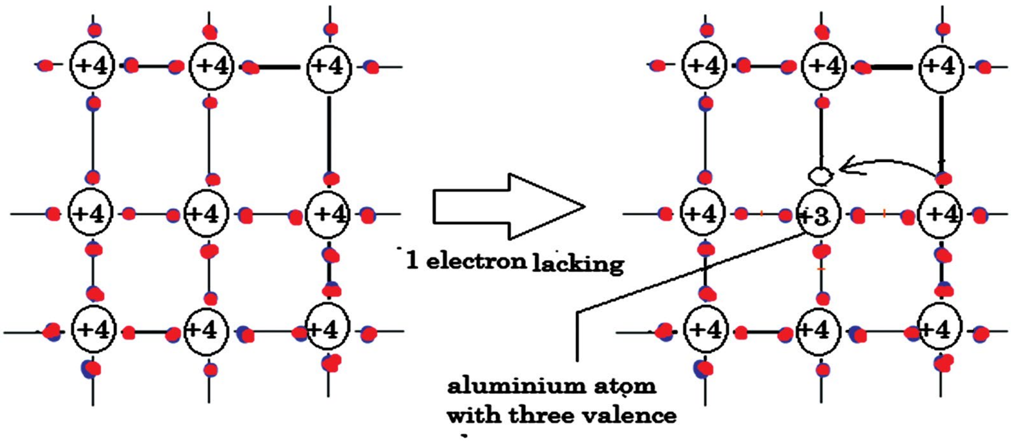


Figure 10.8 p-type doping

There is one electron missing to make four bonds with silicon and that vacancy makes a positive hole. Electrons can be moved from neighbouring bonds to fill that gap with small energy as shown in figure 10.9 where the energy gap is narrow and near the holes. Each time an electron moves in valence band another hole is created.

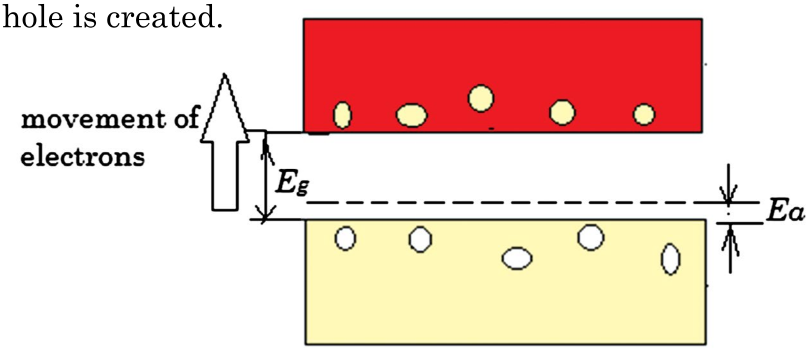


Figure 10.9 Small energy gap in p-type semiconductor.

In this case the impurity is called accepter since it has created a vacancy where electrons can move to. Adding acceptor to silicon increases the number of holes in the valence band. Other impurities used to dope silicon to make p-type semiconductor are gallium and indium.

Key point
n-type semiconductor has electrons as major charge carriers. It is made by doping silicon with group five elements as impurities
p-type semiconductor has positive holes as major charge carriers. It is made by doping silicon with group three elements as impurities

Exercise 10.1
1. What are semiconductors?
2. Describe how band theory explains the difference in conductivity of materials.
3. Explain two ways which can make semiconductor start conducting electricity.
4. Differentiate Intrinsic and extrinsic semiconductors.

Operation of a P-N junction diode

On their own the p-type and n-type semiconductors are not very useful. When a p-type is joined to an n-type, a diode is formed or p-n junction. The symbol for a diode is as shown in figure 10.11, where the arrow is at n-type material. In activity 10.2, you are going to carry out experiment on the behaviour of p-n junction and its uses.

Activity 10.2

Investigating operation of n-p junction.

Materials
- Bulb
- Resistor as load
- Power supply
- Diode
- Switch
- Connecting wires
- Light emitting diode
- Digital calculator

Method
1. Connect a circuit as shown in figure 10.10 using a diode, a small bulb, cells and load resistor.
   Figure 10.10. Behaviour of p-n junction
2. Close the switch for part (a) and notice whether the bulb lights or not.
3. Reverse the terminals of the cells and repeat step 2.
4. Discuss what you have observed and explain what is happening.
5. Repeat steps 1 to 3 using a light emitting diode (LED) and observe

whether it is doing the same as the first diode. Discuss and explain why it gives light while the other diode does not.

6. Discuss and mention some of the applications of such behaviour of a diode.
7. Write the number 8 several times on a digital calculator and observe the seven segments for each 8 digit. Discuss what each of those segments are made up of.

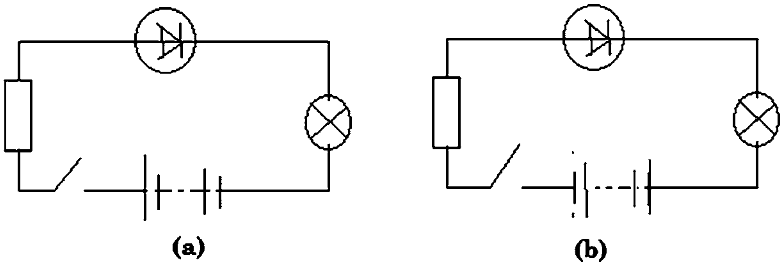


Figure 10.10: Behaviour of P-n juction

Feedback

A p-n junction is made of p-type and n-type semiconductors joined together as shown in figure 10.11.

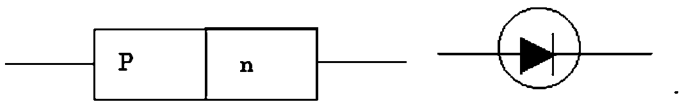


Figure 10.11 p-n junction and its symbol

The majority carriers in the p-type side are holes while the majority carriers in the n-type side are electrons. The vertical line on thesymbol of diode shows the n-type side of the diode.

Isolated p-n junction

In an isolated p-n junction, the major carriers are crossing the junction. The holes are crossing to the n-type while the electrons are crossing to the p-type so that in a moment there is a buildup of charges on either side as shown in figure10.12.

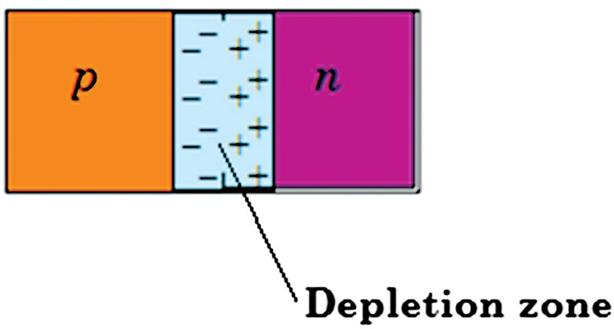


Figure 10.12 Charge distribution in isolated diode

Electron crossing to p-side combines with the acceptor ion and in the process creating a fixed negative charge on the p-side near the junction. Holes crossing to the left have same effect.

The result of this is a creation of space charge called depletion zone as shown in figure10.12.

The movement of holes across the junction balances the movement of electrons across it. Actually these charges are cancelled by movement of minority carriers on either side. Minority carries are small number of holes that exist on the n-type and small number of free electrons on the p-type. Notice that the net current through a junction plane has to be zero to obey the law of conservation of charge. Charges cannot be transferred without limit from one end to the other, where will they come from and where will they go?

Forward biased p-n junction

A p-n junction is also known as a diode or junction rectifier because of its action on electric current.

When the diode is connected as shown in figure10.13 (a), with positive of a diode connected to positive of the cells it is said to be forward biased.

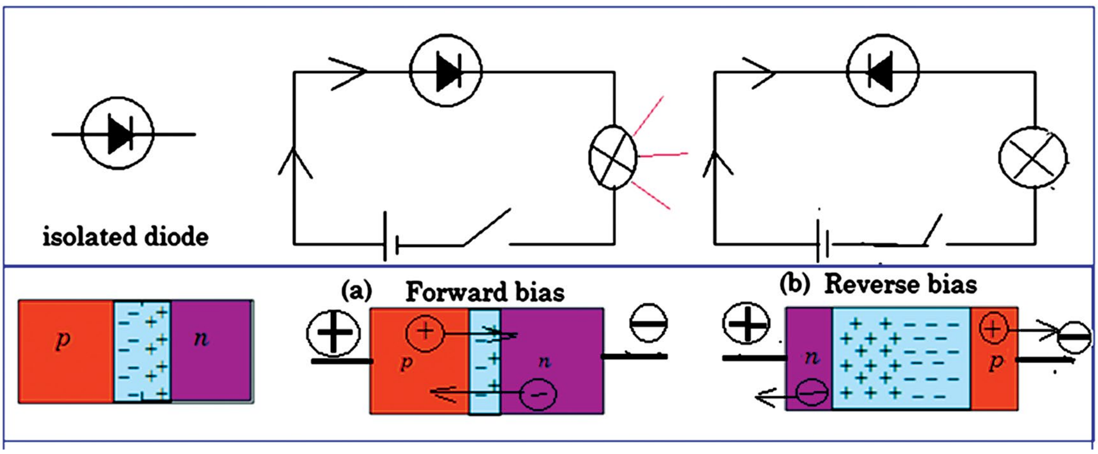


Figure 10.13: Forward and reverse bias of diodes

In the forward biased position, as shown in (a), the p-type becomes more positive while the n-type becomes more negative because of their similar connections to the cells (positive to positive and negative to negative). This makes the highly concentrated positive charges on the p-type to move to the negative n-type region while the highly concentrated charges on the n-type also move to the p-type as illustrated in figure 10.13(a). The two charge carriers cross the junction in opposite directions and then continue through the circuit, forming two way electric current which lights the bulb.

Notice that the depletion zone at the middle which tends to oppose motion is decreased, so resistance decreases.

Reverse biased p-n junction

In the reverse biased position, the negative of cell is connected to the p-type side while the positive of cell is connected to the n-type as shown in figure10.13 (b). The negative terminal of the cell attracts the holes towards it while the positive terminal of the cell attracts the negative major carriers. This is making the barrier zone on the junction wide.Therefore, no current passes.

Current-voltage graph for a diode

A diode allows current to pass only in one direction when connected in forward bias. The conventional current is in the direction of the arrow when forward biased. When a graph of current against voltage is plotted, for a diode, it shows that the junction becomes highly conducting when forward biased and not conducting when reverse-biased as illustrated in figure13.14

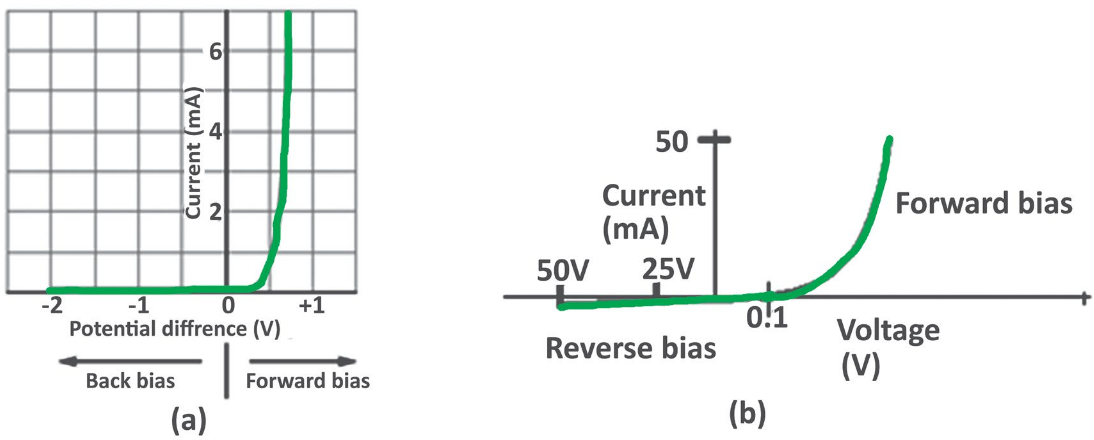


Figure 13.14: Current voltage graph for a diode

Part (a) shows the silicon diode characteristic at low voltage. The diode allows electric current to pass only after the voltage has increased to a certain level, which of course is very small (about 0.1V). If voltage is increased in reverse-biased, the diode does not allow electric current to pass through unless a very large potential difference (as shown in (b)) is applied, which may be 500 times more than what is required in forward bias.

Key point
A p-n junction diode is made by joining a p-type material with an n-type material.
The p-n junction allows electric current to pass through the junction only when it is forward biased. It acts as insulator when reverse biased.

Uses of diodes

Diodes have three main uses. The uses are rectification, light indicators and LED displays.

1. **Half-wave and full-wave rectification**
   Rectification means changing alternating current (ac.) to direct current (dc.). When a diode is connected to an alternating current as shown in figure 10.15, the diode is forward biased at one point and reverse biased at another point and so on, since the electric current is changing direction repeatedly. The diode allows electric current to pass when in forward-biased state and does not allow current to pass when in reverse-biased state. While the input current is ac, the output becomes dc as shown by the wave form of voltages in figure 10.15.

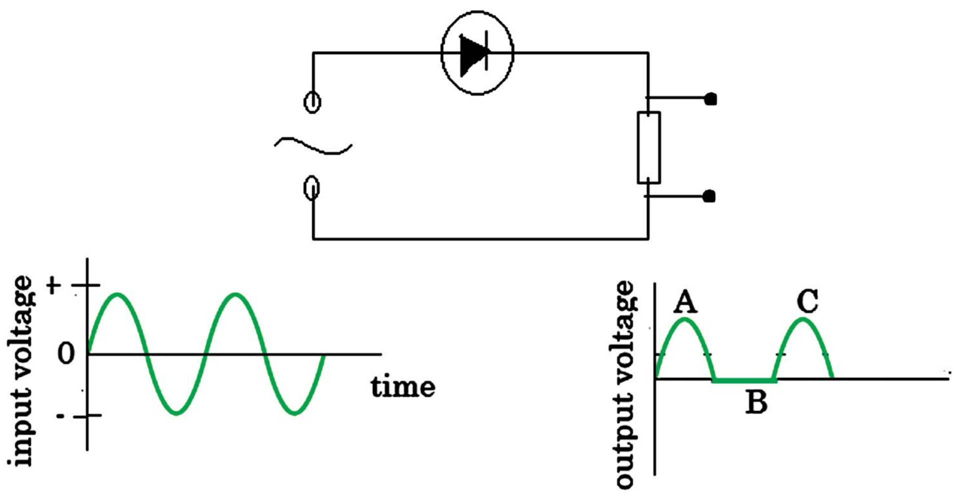


Figure 10.15: Half wave rectification using a diode

Notice that lower half of output wave form is showing zero voltage value during reverse bias. This means the electric current flows with short period of no current at all. This is why it is called half-wave rectification.

Full wave rectification

This is achieved by arranging the diodes so that they form what is called a bridge rectifier as shown in figure10.16

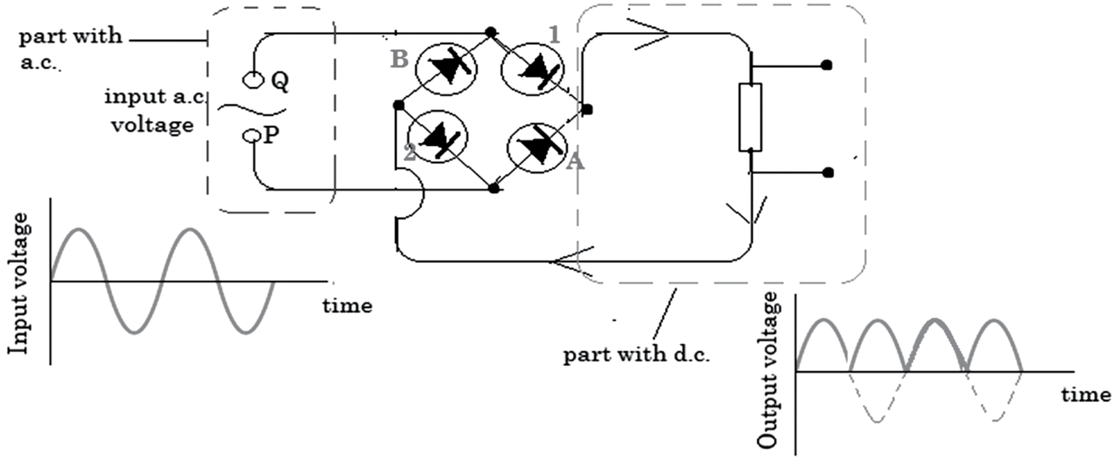


Figure 10.16: Full wave rectification

When positive is at P, conventional current pass through diode A, to output circuit, then through diode B and back to Q to complete the circuit. When positive is at Q, conventional current passes through diode 1, to output circuit, then through diode 2 and back to P to complete the circuit. Notice that on the output side the current has moved through the resistor in one direction and so the wave form is always positive. This is full wave rectification since there is no momentary open circuit. However, there is still a point where the electric current is zero. This is solved by using a capacitor which stores energy. The stored energy in the capacitor is released to compensate for reduction of voltage. This is called smoothing and the wave form of rectified voltage is as shown in figure10.1 where the output voltage and current are steadier.

2. **Light emitting diode**
   Light emitting diodes (LED) give out light when current flows in them. The symbol for LEDs is as shown in figure 10.18.

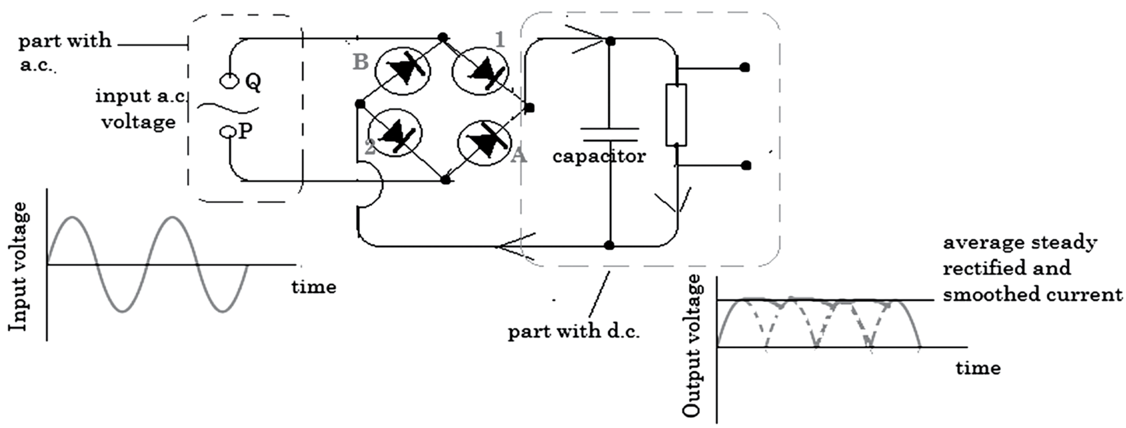


Figure 10.17 Full wave rectifications.

When electrons from conduction band fall into holes in the valence band, energy is given out. For semiconductors like silicon and germanium, most of the energy released is in form of heat. The diode actually becomes hotter but produces no light. In other semiconductors, the energy released is in form of light, for example gallium arsenide. This is achieved because gallium arsenide has a lot of holes in the valence band and lots of electrons in conduction band. When connected to dc voltage, many electron-hole transitions occur making light to be emitted.

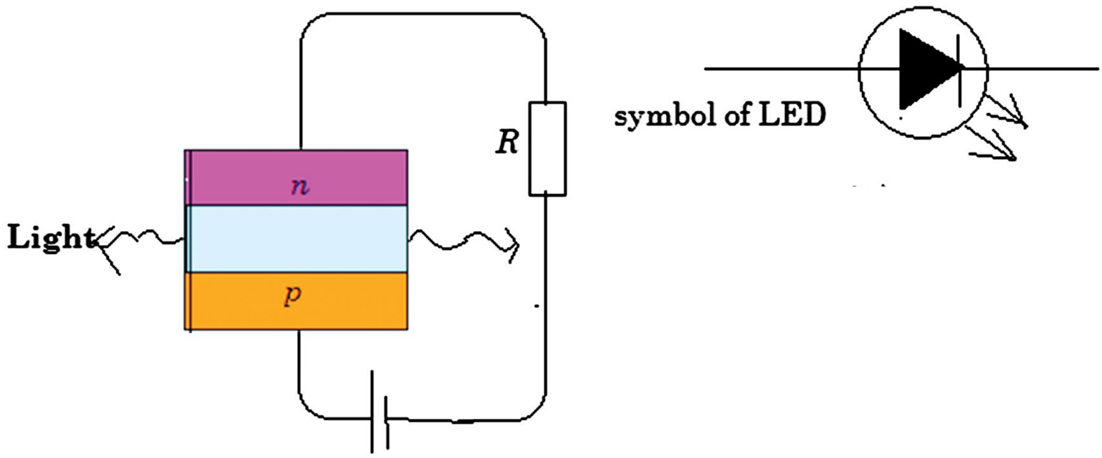


Figure 10.18 Light emitting diode

3. **Digital displays**
   Light emitting diodes are used as indicators in many electronic devices like radios, cameras, electric iron, microwave oven and alarm clocks. In such devices the LEDs are arranged in such a way that they form the seven LED segments as shown in figure 10.19. For example to show a digit 4, LEDs 2, 5 and 7 are off while the rest are on emitting light that one can see as a 4.

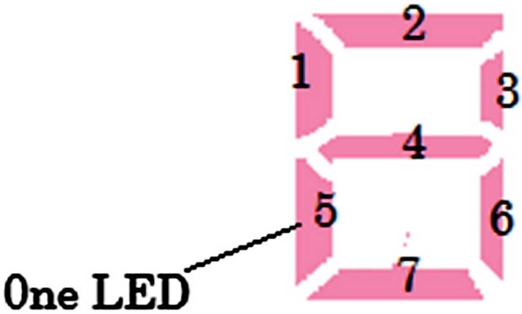


Figure 10.19: Seven LED segment in digital displays

Exercise 10.2

1. One use of diodes is rectification
   a. What is rectification.
   b. Sketch waves to illustrate
      i. Half wave rectification
      ii. Full wave rectification
   c. Why are capacitors used in full wave rectification?
2. The figure 10.20 shows a circuit with a diode in it.
   a. In what state is the diode connected
   b. Will the bulb give light or not? Explain.
   c. Why are diodes connected with a load resistor?
3. LEDs are diodes that emit light when voltage passes through them.
   a. Name any five devices which use LEDs.
   b. Explain how LEDs produce light

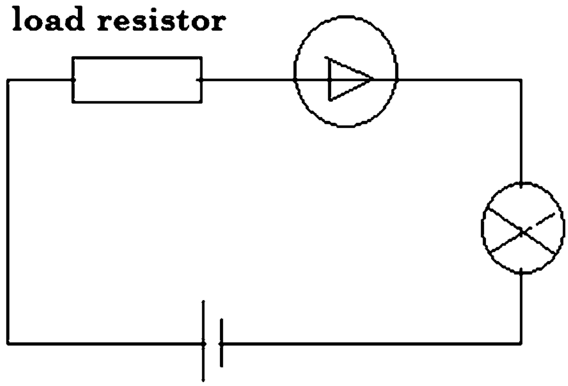


Figure 10.20

Electronic components and their uses

From the p-type and n-type combinations there are lots of components made. The field of electronic is so much dependent on how these materials behave so that they can be used in various applications.

Activity 10.3

Discussing electric components and their uses.

Materials

- A radio or TV motherboard (or any motherboard preferably out of use)
- Capacitors
- Inductors
- Light dependent resistors
- Diodes
- Transistors
- Light emitting diodes
- Photovoltaic cells
- Logic gates

- Thermostats
- Breadboard
- Component holders

Method

1. Identify the electronic components above from what you are given and from any mother board.
2. Discuss and describe the uses of each.
3. Explain how each one works

Feedback

Photodiode

A photodiode is also a p-n junction which works opposite to a LED. In photodiode, electricity flows when light falls on them. The light is energy which promotes the electrons and holes to move and form electric current. The symbol for a photodiode is the reverse of a LED as shown in figure10.21. Photo diodes are mostly used as detectors of light in light and other electromagnetic waves like Ultraviolet or X-rays

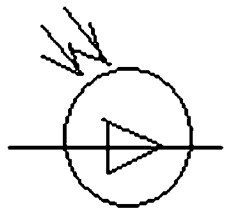


Figure 10.21 Symbol for photodiode.

Transistors

A transistor is made of either n-type semiconductor placed between two p-type semiconductors or a p-type semiconductor placed between n-type semiconductors and they bear the names pnp or npn respectively as shown in figure 10.22

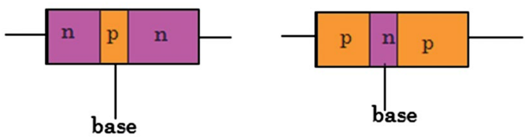


Figure 10.22: p-n-p and n-p-n transistors

Each transistor has three terminals one from each piece of material. The central material connection is called a *base*. One of the other two is called *emitter* while the other is called *collector*. By using the three terminals, one current going into an electrical device can be used to control the amount of another current.

In both types the emitter will send charges through the base to the collector. Figure10.23 shows symbols for the two types of transistors. In an npn transistor, the emitter (n-type) sends its major carriers, the electrons, to the collector through the base. The conventional current is opposite to the flow of electrons. In a pnp transistor, the emitter sends its major charge carriers, the positive holes, to the collector through the base. Notice that in both symbols, the terminal with an arrow is an emitter. The conventional

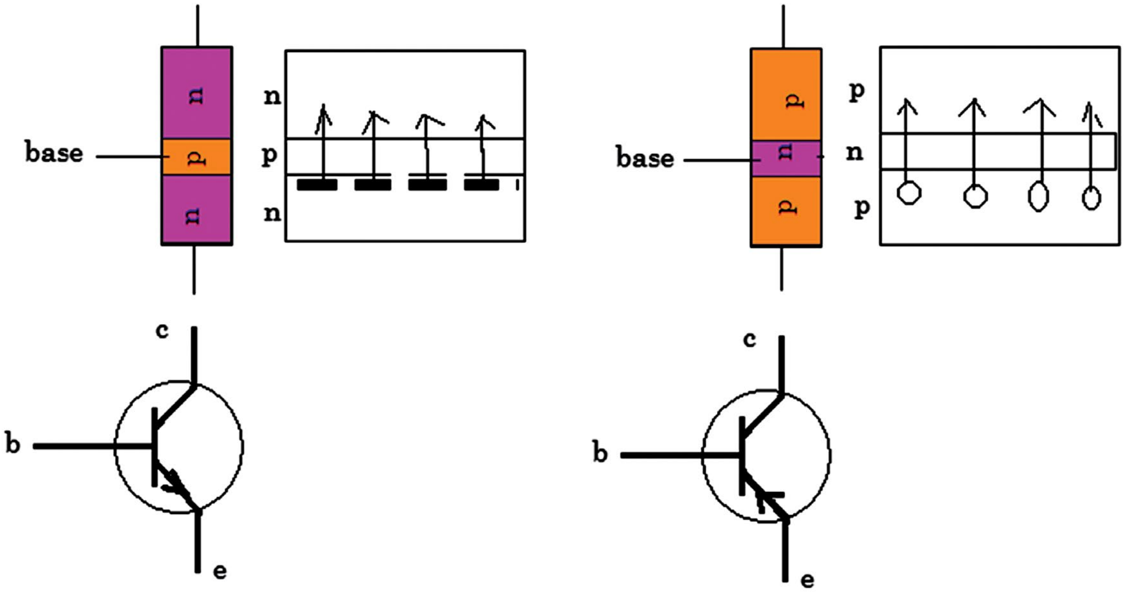


Figure 10.23: Movement of charge carriers in transistors.

current flows in the direction of the arrow as shown on the symbol.

The relationship of current in the emitter, I_e, the collector, I_c and the base I_b is always $I_a = I_b + I_c$.

The transistor works when a small current, I_b passes through the base so that this small current controls the much larger current through the emitter and collector. When input base current changes, the output collector current changes over a hundred times. In this case the transistor is used as **amplifier**. It can also be used as **switch**.

Transistor as a switch

Consider circuit in figure10.24 (a) which is the same as (d). In diagram (a) when S_1 is closed while S_2 is open, bulb B_1 does not give light. This is because the collector (n-type) and the base (p-type) are reverse biased as shown in diagram (b). When S_2 is closed and S_1 is open, bulb B_2 gives light. This is because the base (p-type) and the emitter (n-type) are forward biased as shown in (c) and current flows.

When both switches are closed as shown in (d), both bulbs give light.

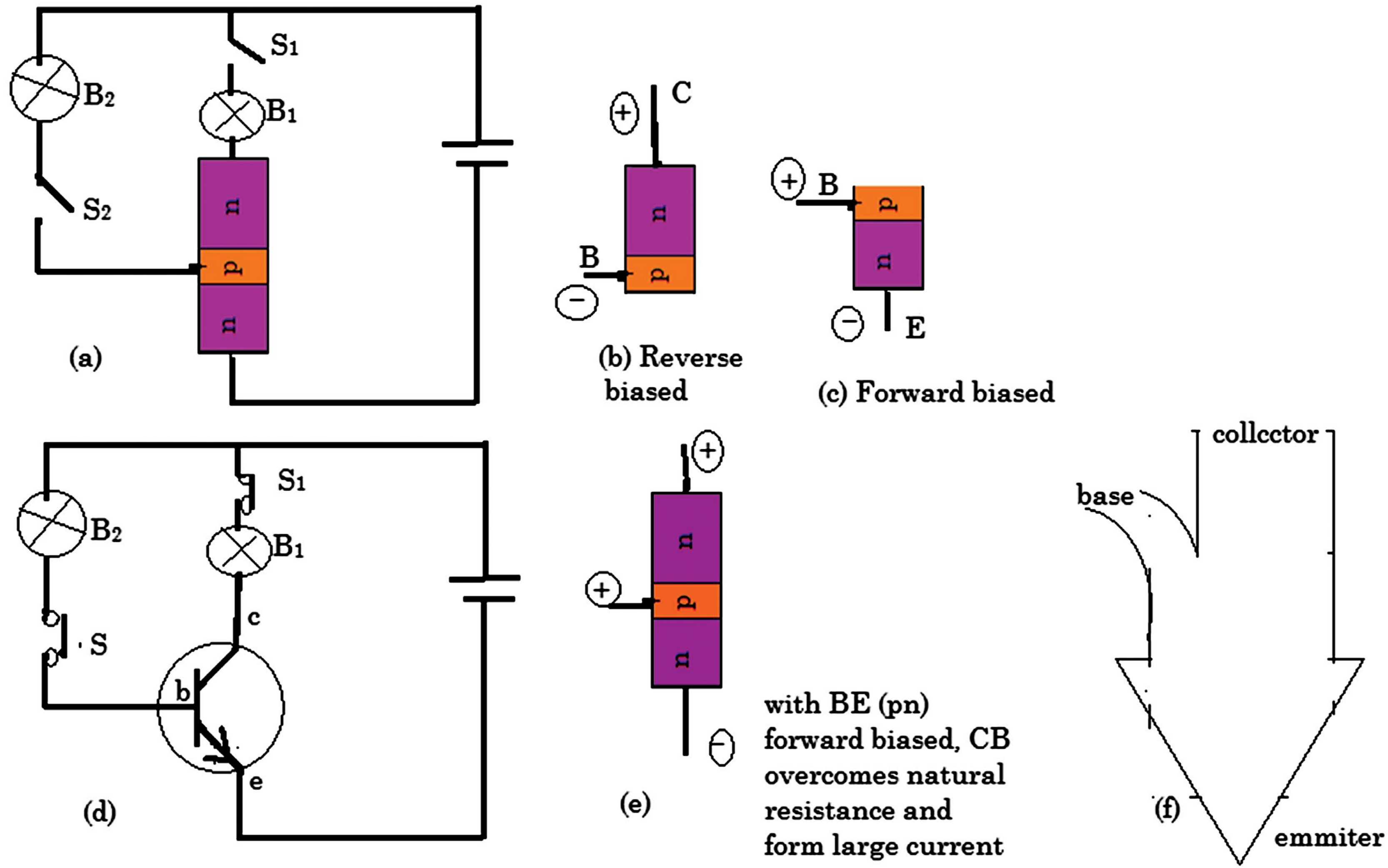


Figure 10.24 Using a transistor as a switch and amplifier

This shows that the collector base current is switched on by the base emitter current and also acts as amplifier of electric current to collector as shown in (f) , where $I_a = I_b + I_c$. .

Light operated switch

The switching and amplification effect of transistors is used in so many electronic devices. Figure 10.25 shows a circuit which is used to open and close a bulb using light.

The light dependent resistor (LDR) has low resistance when sunlight shines on it. During the day, LDR has very low resistance so that most of the current at junction X, pass through LDR, and very little pass through R_2. The current and voltage through R_2 is too small to create a base emitter current. The minimum voltage should be about 0.6V in most transistors.

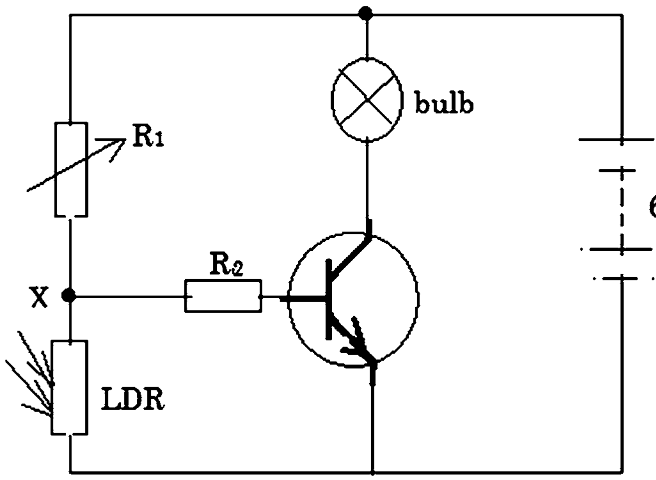


Figure 10.25: Transistor as light operated switch

When dark in the evening, the resistance of LDR picks up sharply. At junction X most of the current will take a lesser resistance path to base of transistor. Once the voltage rises beyond the 0.6V in the transistor, the bulb gives light because the whole transistor is now conducting electric current.

Such switching processes are also used to operate a temperature operated switch using thermistor, time-delayed switch and smoke detectors using nuclear ionising effect.

Figure 10.26 shows circuit for temperature operated switch using thermistor, time-delayed switch.

In (a), when under normal temperature, resistance of thermistor is too large so that a small current passes not enough to switch on the transistor. Resistance of thermistor reduces when temperature rises allowing more current to reach the base and switch the transistor. Bulb or alarm is then switched on.

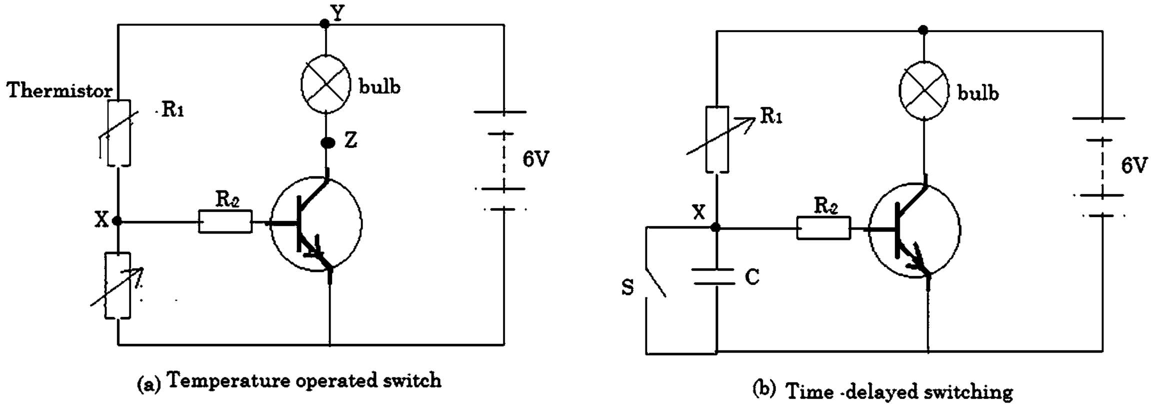
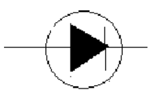
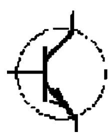
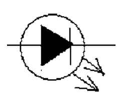
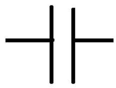
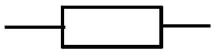
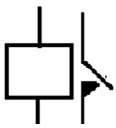
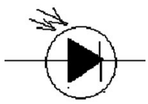
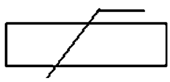
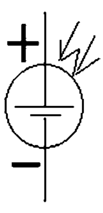


Figure 10.26 Transistors as a switch

In (b), battery charges the capacitor, C. When capacitor is fully charged it produces high voltage at X and transistor is switched on. The period of delay depends on the size of capacitor, since larger capacitors take more time to charge to full capacity. It may also depend on the variable resistor, since low resistance allows more current and capacitor charges faster than when resistance is large.

Table showing some of the electronic components and their uses.

Electronic component	**Symbol**	**Description and uses**
Diodes		Semiconductors that are mostly made from silicon and gallium. Since they allow electric current to pass in one direction they are used as rectifier.
Transistors		Made of semiconductor material. They are mostly used to switch and amplify signals.
Light emitting diodes (LEDs)		Diodes which give out light when electric current flows in them. They are used as indicators and also work as digital displays like in a calculator.
Capacitor		Stores charge which is used when it discharges. Used in tuning circuits and smoothing of surging rectified

		voltage. They can also pass electricity from one circuit to another.
Integrated circuits (IC's)	None. Consists lots of components together	They are a form of circuits containing the other components, put on a very small chip. They are also called microchips.
Resistor		Used to keep current to a component at required level.
Relays		They are switches which use electromagnetism. They are used to control remote high power.
Photodiode		Converts light energy to electricity.
Thermistor		Changes its resistance significantly with temperature.
Logic gates	Depends on type	Used as digital thermometers, in cars to measure oil and coolant temperature, ovens, refrigerators and anything that needs cooling and heating control
Photovoltaic cell		Commonly assembled into what is commonly known as solar panel. Converts light energy to electricity. Its advantages include: • Limited environmental impact. • Can easily reach remote. • Easy to install and maintain. • Can be used as alternative to fossil fuel.
Inductors		Use as filters for analogue circuits, Signal processing, Contactless or inductive sensors, As transformers, as Motors, Energy storage.

Basic blocks for electronic circuits

Electronic circuits contain microchips and other semiconductor devices. All electronic systems have three major building blocks and these are, input, processor and output as illustrated in figure 10.27. Sometimes the processor needs energy for processing like amplifying. This energy is given from power pack.

The input and output is what connects the system to outside world. Input changes different kinds of energy into electrical while output changes electrical into other forms like sound, or heat. The input and output are therefore transducers since they change energy forms. The input has a sensor for differences in surrounding like sound, light, pressure, magnetic field or temperature. The output could be a bulb, or fire alarm.

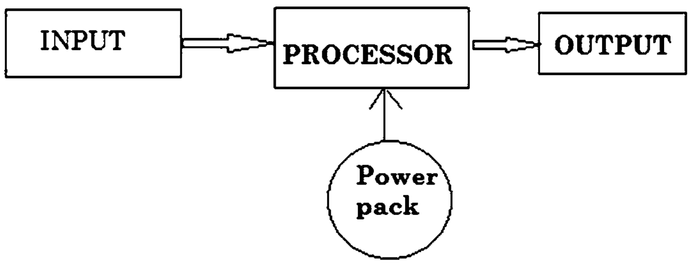


Figure 10.27 Basic electronic building blocks

Examples of sensors are thermistor, microphone and light dependent resistor. The examples for output are Light emitting diodes, bulb and loudspeakers.

Example of electronic system could be a TV where the inputs are the radio waves that reach the aerial. The processor amplifies and interpret the signal and sends it to the output which is the screen, energy is supplied from power source for the processer to amplify the signal.

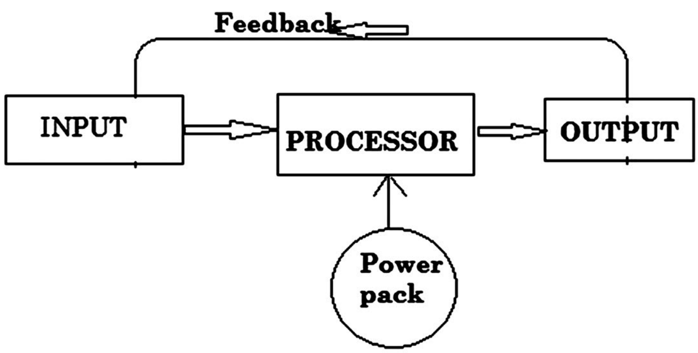


Figure 10.28: Building block for electronic system that involves feedback

In some cases, the output is sent back to the input and this is called feedback. A good example is operation of a geyser with a thermostat.

When it is cold the thermostat switches on the geyser. When the water is too hot the signal goes back to the thermostat which switches power off. In this case the building blocks will look like in figure10.28.

Feedback is all or some of the output being directed back into the input of a system in such a way that its output is controlled if changed. Feedback is used in automatic control systems.

Some of the electronic components that are used in electronic circuits of systems are shown in the table below with their uses. Some act as input while others act as output.

Exercise 10.3

1. Which electronic component is involved with the following:
   a. Made of p-type semiconductor sandwiched between n-type.
   b. Converts light energy to electricity.
   c. Can be used for smoothening surging electric voltage.
   d. Can be used as indicator.
2. All electronic systems have three basic blocks.
   a. Name the blocks.
   b. Which blocks are transducers?
   c. Name any four devices that can act in the first block.
3. The figure 10.29,shows a circuit of an electronic system.
   a. What type of transistor is used in the circuit?
   b. What is the difference between diode 1 and 2?
   c. What is a thermistor?
   d. Under which conditions of the thermistor will the Diode 2 givelight.
   e. Suggest one application of this circuit.

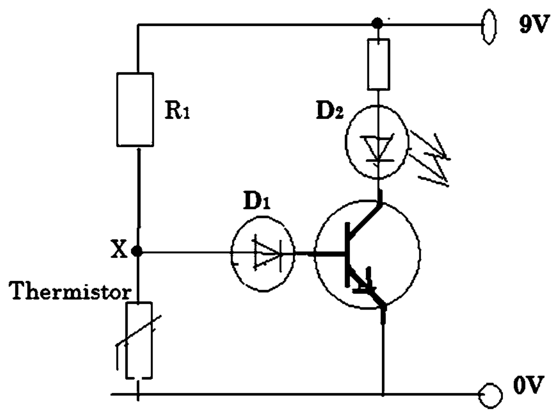


Figure 10.29

Analogue and digital circuits

Many systems today are being changed from analogue to digital. What are they in electronic terms? What is the advantage of one above the other? These are some of the question you will answer after learning this section.

Activity 10.4

Describing analogue and digital circuits

Materials
- Charts
- Pental markers

Method
1. List as many things as you can which are digital and those that are analogue used in day to day life.
2. In groups discuss and explain the meaning of digital electronics which has helped you to answer step 1. Record your findings so that you can share with others later.
3. Discuss and list the characteristics of analogue and digital signals.
4. Share your findings with peers in class.

Feedback

Difference between analogue and digital electronics

Two people went to the market and bought melons. The first person reported and said "we bought two water melons from the market". Later the second reported about the same and said "we bought 23kilograms of water melons from the market". Between the two who is right? Well, they could both be right, only that they have used two different ways of presenting quantity. The first is using digital while the second is using analogue.

Figure10.30 shows some of the digital and analogue instruments. The word digit is to do with counting while the word analogue deals with measuring. Counting gives exact result while measuring gives an approximate result. As seen from the figure10.30, one has to approximate from position of moving handle to get quantity of analogue instrument.

Analogue ammeter **Digital ammeter** **Analogue stop watch** **Digital stopwatch**

Figure 10.30:Examples of analogue and digital instruments.

In digital the exact amount is given using numbers or digits, hence called digital.

As has been said, there are two types of electronic circuits, namely analogue and digital. In analogue circuit information is in the form of voltages and electric currents which varies smoothly and continuously in the same way as the information which it represents. On the other hand, digital information has limited number of values and can change only suddenly from one value to another.

A. **Analogue circuits.**
Just like all electronic circuits, they have input, processer and output plus power supply to active components in the processor.

Example of analogue system

System	Input	Processor	Output
moisture operated switch in a granary of maize	moisture sensor and micro switch	electronic switch to electronic latch	alarm

Inputs and outputs are transducers since they change one form of energy into another. Examples of transducers in analogue are as shown in table below.

Transducer	Where used	Signal conversion	
		From	**To**
Microphone	Sound input	Sound	Electricity
Loudspeaker	Sound output	Electricity	Sound
Thermistor Thermocouple	Electronic thermometers	Heat (temperature)	Electricity
Photodiode	Light meters	Light	Electricity
Aerial	Both output and input from radio systems	Radio (electromagnetic)	Electricity
Voltmeter	measurement	electricity	Mechanical (pointer movement)

In a good analogue system, the output varies in the same order as the input with changes only in amplitude. The output is an exact representation of the input variations but in another form.

Building blocks for analogue systems

A complete system like a studio is very complex but it is only built by a small number of building blocks. Some of these may include the following:

1. Power pack: Gives input power to all active components.

2. Amplifier: Increases amplitude of signal.
3. Rectifier: Converts ac to dc.
4. Filter: Allows only waves of certain frequency to pass.
5. Oscillator: Generates ac voltage of certain controlled frequencies.

A. **Digital systems**

They also have input processor and output as building blocks. The input and the output are usually numbers in *decimal form*. The processor does calculations using digital information in *binary code*.

The main building blocks are as shown in figure 10.31.

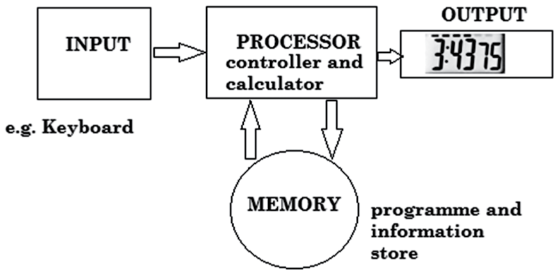


Figure 10.31: Building block for digital system

Some of the building blocks in digital electronic systems are shown in the table below;

Input	**Processors**	**Output**
Switches Keyboards	Arithmetic (adding, counting, dividing)	Displays (LED, monitor,printer)
Magnetic sensors (read magnetic tape or disc)	Decision making (logic gates)	Monitor or screen
Optical sensors (read optical and compact discs)	Signal processing: amplifying,	Warning and control devices

In digital electronics only two values are used “high” or “low”. A high is 5V while a low is 0V. To use binary code, each 0V is taken as logic 0 while each 5V is taken as logic 1. Figure10.32 shows the same information being represented using analogue and digital values. Notice that the wave form for analogue is continuous at any point. On the other hand the signal for digital is in digit form, counting a value at a certain period interval

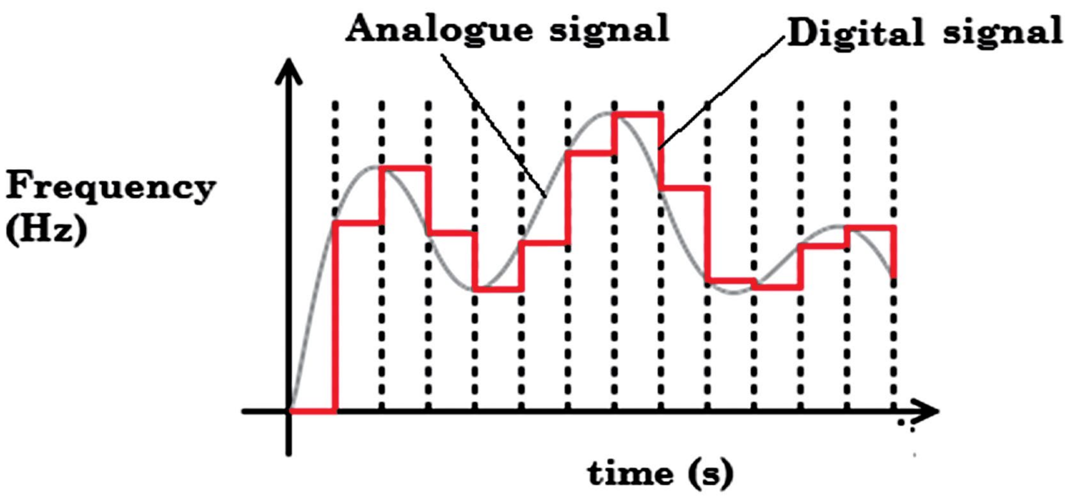


Figure 10.32 Analogue and digital wave form

Similarity between analogue and digital

1. Both are used to transmit information through electric signals.
2. Both use building blocks such as input, processer and output.

Differences between analogue and digital

Analogue	Digital
Information is in form of electronic pulses of varying amplitude.	Information is in form of binary form (1 and 0), where each bit represent two different amplitude
Use continuous signal to present physical measurement.	Signals are discrete time signals
Use sine wave	Use square waves
Examples could be human voice in air using analogue electronic devices	Examples are CDs, DVDs, computers
Records wave form as they are	Samples analogue waves forms into a limited set of numbers and record them
Data transmission is subject to distortion	Not easily deterred
Memory stored in wave signal	Memory stored in binary bit
Uses large power	Use very little power
Low cost and portable Give considerable observational errors	High cost and not easily portable. Free from observational errors

Key point
Analogue refers to circuits in which quantities (x) vary continuously with time (t) (analogous to input).
Digital refers to circuits in which the input quantities are discrete with time i.e. quantities are counted (in digit form) at particular time (t)

Exercise 10.4

1. Name any two devices that use digital technology.
2. The figure 10.33 below shows a wave to present voice of a singer as amplified and seen on an oscilloscope.

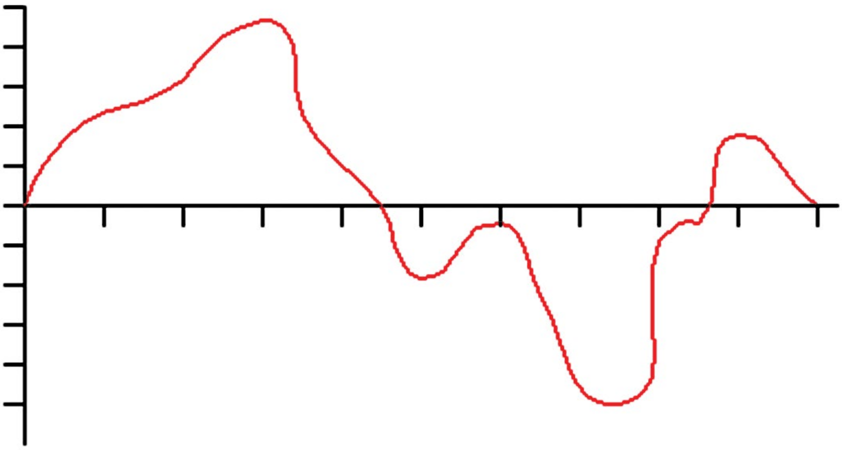


Figure 10.33

   a. What type of electronic system does this wave present?
   b. Copy the wave form and draw a similar wave form of the other type.
   c. Give any two disadvantages of such type of electronic systems.
3. Give three characteristics of digital systems that are different from analogue system.

Logic gates

Logic gates are very important in making electronic decision in a device. Do activity 10.6 which imitates how logic gates function.

Activity 10.5

Operation of basic logic gates

Materials.

- bulb
- two switches
- two cells.
- Connecting wires

Method.

1. Make a circuit of a bulb, two switches and cells as shown in figure 10.34 (a).

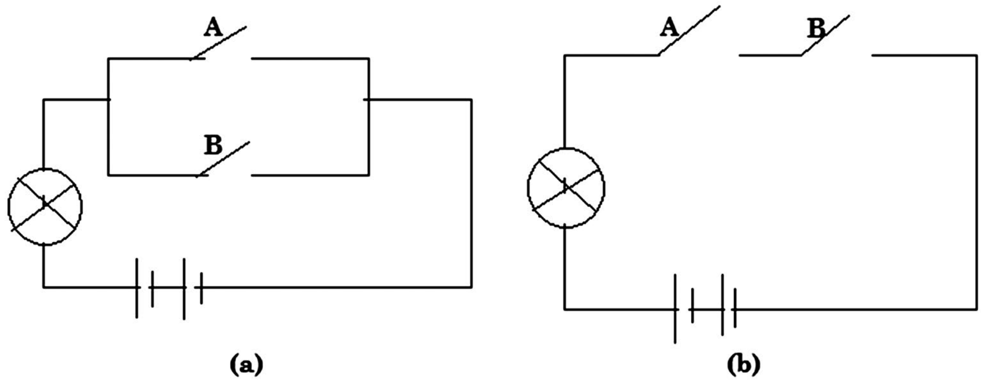


Figure 10.34 Analogy of logic gate operation

2. Close switch A and leave B open. Record whether bulb will be ON or OFF. Record your result inform of condition of A, B and bulb status.
3. Do the same with switch B closed only, and finally the both switches closed at the same time.
4. Rearrange the circuit so that it is like (b).
5. Repeat steps 2 and 3.
6. Discuss the results and find out which setup can use the word AND and which one can use the word OR to make the bulb give light.

Feedback

The circuits that you made in this activity are not logic gates, but they represent how logic gates work.

In circuit (a) possible combinations of the two switches so that the bulb lights on or off as shown in table below:

Circuit (a)			Circuit (b)		
Switch A	**Switch** B	**Bulb** status	**Switch** A	**Switch** B	**Bulb** status
Open	Open	Off	Open	Open	Off
Open	Closed	On	Open	Closed	Off
Closed	Open	On	Closed	Open	Off
Closed	Closed	On	Closed	Closed	On

This is exactly the way logic gates work. They are electronic blocks with transistors and switches which function as gates or switches in electronic systems. The gates use binary code to get and give output. Unlike decimal system which used 10 digits (dec-means 10), binary systems use only two digits, a 1 and a 0. If the above circuits were digital the ON could be presented as 1 and the OFF could be presented as 0. The 1 means voltage is high and allowed to pass (usually 5V in electronic components) and 0 means low or 0V of voltage. The table above is called truth table and using digit 1 and a 0, It can look as follows:

Circuit (a)			Circuit (b)		
Switch A	Switch B	Bulb status	Switch A	Switch B	Bulb status
0	0	0	0	0	0
0	1	1	0	1	0
1	0	1	1	0	0
1	1	1	1	1	1

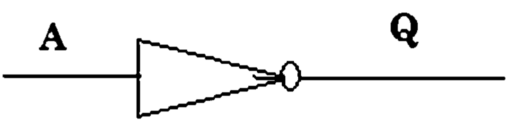
Several logic gates may be put in one integrated circuit (IC), on a small chip.

Key point
In conclusion logic gates are computer circuits with several inputs but only one output that can be activated by particular combinations of inputs.

Types of logic gates

There are five basic types of logic gates and each gate has a truth table which gives all possible input combinations and their possible output. These are shown below. The name of the gate describes how the logic gate makes its decision. The name tells which combinations of NOT high inputs (0) produce output signal. It is easier to remember by taking note of one odd combination in the truth table.

1. NOT
   This gate gives output 1 when input is 0 and vice versa. It is called inverter.



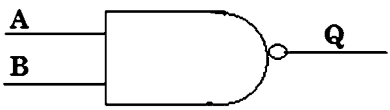
Input (A)	Output Q
0	1
1	0

2. AND

This gives output 1 only when both inputs are 1

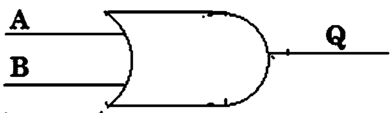
A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

3. NAND
   This gate gives output 1 unless both inputs are 1. The outputs are a reverse for all combinations of AND gate. The symbol has a small circle to show that it is inverting an AND symbol.



A	B	Q
0	0	1
0	1	1
1	0	1
1	1	0

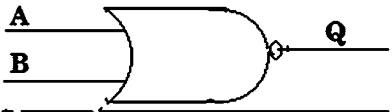
4. OR
   This has output of 1 when either A or B is 1, OR both are 1. This means output is 1 when at least one input is 1.



A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1

5. NOR

The output of this gate is only 1 if neither A NOR B is 1. It is the opposite of OR. It is like saying Not OR hence it has a small circle on its symbol.



A	B	Q
0	0	1
0	1	0
1	0	0
1	1	Q

Examples of systems that may use logic gates

Example 1
There is a security flood light at your school for security lighting at night. The lights should be on automatically when it gets darker and off when sunshine is enough in the morning. It should also be possible to switch off the lights manually when there is a fault. Which gates should be used to help make decision and how should they be combined?

Solution
The light should be on either by manual OR by light

The light should NOT be on when sunlight has gone.

These two statements, if true suggest that we should use the OR and NOT gates as shown in figure 10.36
Example 2

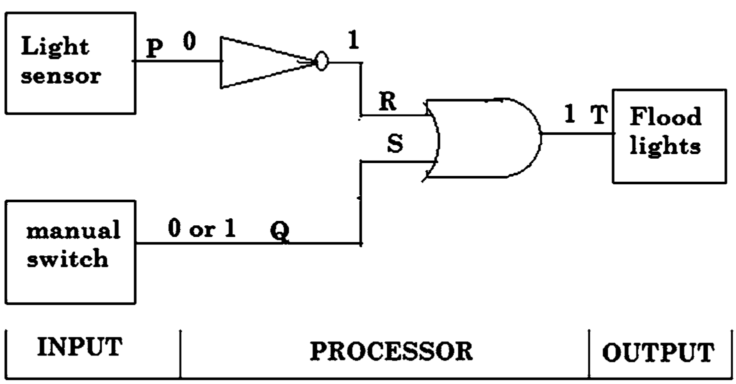


Figure 10.36

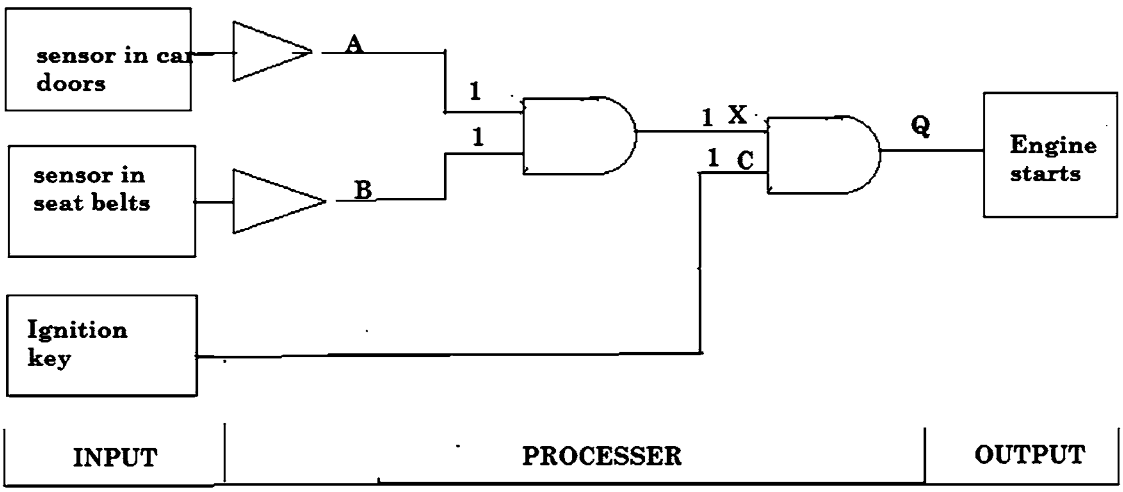
Your parents have bought a car which can only start when all seat belts are worn and all the doors are closed. Which logic gets can be used and in what combinations.

Solution

The Inputs are:

1. Seat belts use strain or pressure sensor. To get a signal from the seat belt the input must be 0 so that output is 1. Seat belts should be ON when not used (and indicator on the dash board will warn you) and OFF when used. Proper logic gate is NOT.
2. Door lock electronic sensor to get a signal 1 from the door, it must be off when closed (0) proper gate is NOT.
3. The starter key
   For the key to work the combination of 1 and 2 should be combined with 3. 1 and 2 use AND logic gate to combine. Then using that combination use another AND with the key. The diagram will be

Exercise 10.5



1. Construct a logic get grid for a geyser in a house which should be on when water is cold and it is day light.
2. Design and draw block diagrams for logic control system for a money chest box that can only be opened when there are two keys inserted to it.
3. Draw block diagram for logic control system that can alert you every morning to go for exercise when it is not raining.

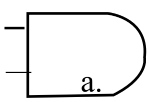
Unit Summary

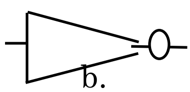
Semiconductors are materials which are solid substances which have conductivity between that of an insulator and that of most metals.

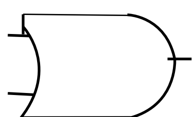
- Band theory describes states of electrons in solid materials as to have values of energy only within specific ranges called bands. The ability to conduct electricity depends on the ability of electrons to move from valence band to conduction band.
- Insulators have a larger energy gap between valence and conduction band so that it is difficult to conduct electricity while the energy gap between semiconductors is narrow so that electrons can easily be moved to conduction band by thermal agitation. In metals the bands overlap so that electrons are free to change to conduction band.
- The most common semiconductor is silicon.
- Intrinsic semiconductors can start conducting electricity due to thermal agitation alone without adding other impurities to their crystal structure.
- Extrinsic semiconductors improve their conductivity by adding other materials called impurities.
- N-type material has extra free electrons in the structure used as major charge carriers.
- P-type materials have positive holes used as major charge carriers.
- A diode is a p-n junction which allows electric current to move in one direction when forward biased. Their uses include rectification.
- Light emitting diodes (LEDs) produce light when current pass through them
- Transistors are made of one type of semiconductor materials sand-witched between two pieces of the other type of materials. Their uses include switching and amplifying current.
- Electronic circuits are electric circuits composed of individual electronic components such as resistors, transistors, capacitors, inductors and diodes
- The building blocks for electronic circuits are input, processor, and input plus power pack to supply energy used for processing.
- Analogue circuits operate with electric current and voltage that vary continuously with time while digital circuits use electric and voltages that have discrete values between sets of time period.
- The building block of digital circuit includes memory for programmes and storage of information.
- Logic gates are electronic circuits with several input signals but only one output that can be activated by particular combinations of inputs. Some of logic gates are NOT, AND, NAND, OR and NOR.

End of unit review questions

1. Name two types of semiconductors and explain their difference
2. Name the following gate symbols


a.

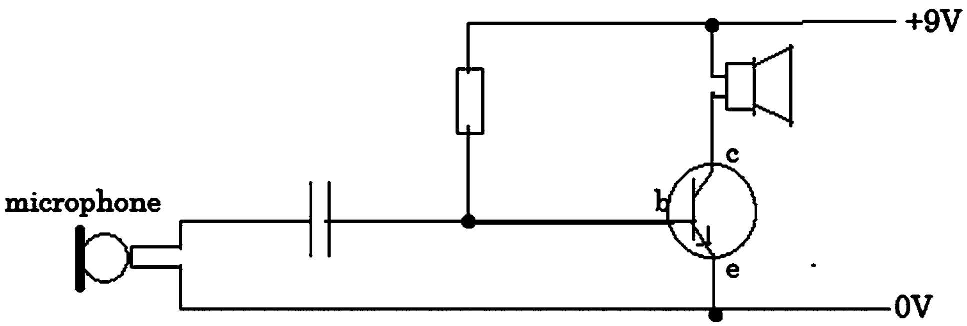

b.


c.

3. Which of the electronic components has the following functions? Draw the symbol for each of the following;
   a. Changes light energy into electricity.
   b. Stores electric charge.
   c. Allows current to pass in one direction.
   d. Switches and amplifies electric current.
4. A truth table for a logic gate with two input signals shows a “1” output only when both inputs have a “0”.
   a. Name this logic gate.
   b. Draw its truth table in full.
   c. Draw symbol for the gate.
5. The truth table below shows three types of logic gates P, Q and R.

Inputs		Output		
		P	Q	R
0	0	0	0	1
0	1	1	0	1
1	0	1	0	1
1	1	1	1	0

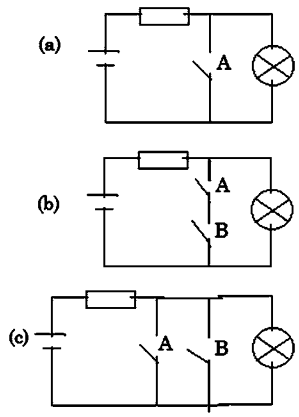
   a. Name each logic gate, P,Q and R.
   b. Which logic gates are opposite to each other?
   c. Draw a symbol for logic gate Q.
6. Design and draw a block diagram for logic control systems to shut off a machine that is used to bake bread when temperature inside its oven is beyond required level manually and automatically.
7. The circuit below shows an amplifier



   a. State the energy changes that take place in the
      i. Microphone.
      ii. Loudspeaker.
   b. Name the type of transistor that you can see.
   c. Explain how the transistor works to make the loudspeaker give sound when someone speaks onto the microphone.

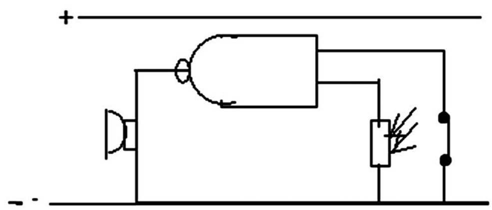
d. Sketch draw two sign waves to show the difference in input wave at the microphone and output wave at the loudspeaker.

8. The following are circuits which demonstrate how some logic gates function.



a. Why are the circuits above not logic gates.
b. Name the type of gate that each circuit stands for.
c. Draw circuit symbols for each type of gate.

9. Figure below shows a circuit for burglar alarm which gives sound when switch is closed or burglar uses torch.



a. What type of resistor is used in this circuit?
b. What type of logic gate is shown?
c. Draw truth table for this logic gate.

10. One function of diodes is rectification.
a. What is rectification?
b. Draw an arrangement for half wave rectification.
c. Draw waves forms for input and output for half wave rectification.

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UNIT 11

Today so many devices use electromagnetic waves including radios, televisions, microwaves and x-ray machines. What makes electromagnetic waves different from other mechanical waves like sound and water waves? In this unit you will learn the nature and properties of electromagnetic waves and their applications. You will also learn to apply wave equation in solving problems concerning electromagnetic waves.

Electromagnetic waves

Electromagnetic spectrum

An electromagnetic spectrum is a band of a special group of waves arranged in order of their frequencies as shown in figure 11. 1

Activity 11.1

Describing the electromagnetic spectrum

Materials

- Chart paper
- Pental markers
- Radio
- Scientific calculator

Method

1. Study the electromagnetic spectrum shown in figure 11.1 and discuss the following questions.
   a. Define wavelength and frequency of a wave?
   b. Which part of the electromagnetic spectrum has longest waves?
   c. Which part of the spectrum has waves with highest frequency?
2. What is the major cause of waves on the electromagnetic spectrum?
3. Name the sources of various waves found on the electromagnetic spectrum?
4. Suggest some of the uses of the following waves found on the electromagnetic spectrum.
   a. Visible
   b. Microwaves
   c. Infrared
   d. X-ray

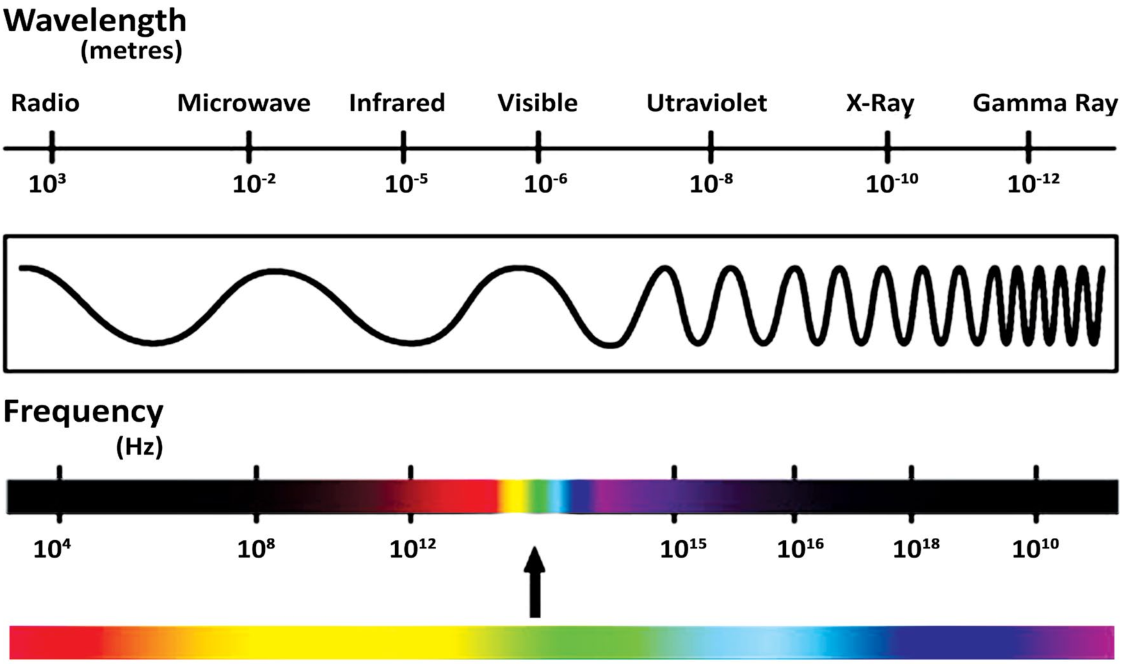

Figure 11.1: Electromagnetic spectrum

5. Look at the band on a radio.
   a. What is the range of frequencies written on the band of the radio?
   b. Are the radio frequencies close to that on the electromagnetic spectrum?
6. Name detectors of the different waves on the EM spectrum

Feedback

All waves have velocity, frequency and wavelength. Frequency is a measure of number of waves happening per second measured in units called Hertz, Hz. Generally waves on the EM spectrum are oscillating very fast. Radio waves have lower frequency and the gamma rays have highest.

Wavelength is a measure of distance covered by one complete wave measured in units of length, metres. On the EM spectrum, radio waves have longest wavelength while gamma rays have very short wavelengths.

The waves on the electromagnetic spectrum are called electromagnetic waves arranged in continuous order of their frequency. Different sections of the EM spectrum are classified into bands given special names. In order of increasing frequency the bands on the spectrum are radio, microwave, infrared, visible light, ultraviolet, x-rays and gamma rays.

These waves have various uses in our everyday life. For example, the eye use visible light for vision, microwaves are used for keeping food hot, infrared is used for cooking and warming while x-rays are used to take pictures of bones and body organs. The radio and television in the home use waves that have frequencies of radio waves on the EM spectrum.

The EM spectrum is continuous with no distinct boundaries between one band and next. Each band is also a spectrum on its own, For example visible light is a spectrum that ranges from a low frequency red light to high frequency violet. The visible light can be broken further into red, orange, yellow, green, blue, indigo and violet as shown in figure 11.1.above.

The radio waves are also a spectrum of waves. In terms of frequency the radio waves are classified and given names like ELF (extremely low frequency), VHF (very high frequency) and UHF (ultra high frequency). In terms of wavelengths the radio waves can also be classified into long, medium and short waves.

Just like all waves, EM waves carry energy which increases with frequency. The gamma waves are therefore the most energetic waves while the radio waves have lowest energy.

The common sources and detectors of different bands of electromagnetic wave are listed in the table 11.1 below:

Table 11.1: Sources and detectors of various electromagnetic waves.

Name of wave band	Sources	Detectors
Radio	Television and radio transmitters using electric circuits and aerials	• TV and radio aerials
Microwaves	Microwave oven	
Infrared (IR)	The sun, warm and hot objects	• Semiconductor devices like LDR and photodiode • Skin • Certain photographic films
Visible light	Sun, lamps, lasers	• Eyes • Photographic films • Photocells
Ultraviolet light (UV)	Sun, arcs and sparks, mercury vapour lamps, very hot objects	• Photo cells • Photographic films • Fluorescent chemicals
X-rays	x-ray tubes	• Photographic films • Fluorescent screen
Gamma (rays	Nuclei of radioactive atoms, cosmic rays	• Geiger Muller tube • Spark counters • Photographic films

Exercise 11.1

1. What is electromagnetic spectrum?
2. Arrange the following EM waves in order of increasing frequency; *microwave, blue light, VHF and x-rays.*
3. By studying the spectrum explain the following:
   a. Micro waves sometimes interfere with radio waves.
   b. Microwaves can also be used for cooking just like infrared.
   c. A hot metal giving out infrared glows and give visible light which is usually red or orange in colour.
   d. Arc welding gives very bright ultraviolet light.
4. Arrange the following wavelengths in increasing order all in metres; 10^{-12}, 10^{3}, and 10^{-4}.

Electromagnetic waves

What makes electromagnetic waves a class of waves on its own? Activity 11.2 will help you to learn properties of electromagnetic waves, and methods used to detect them.

Activity 11.2

Stating the properties of electromagnetic waves

Materials

- Pen
- Paper
- Chart of electromagnetic spectrum

Method

1. Look at the electromagnetic spectrum and note approximate frequency and wavelength at any one position of each band. Using your previous knowledge about wave equation (*velocity = frequency x wavelength*), work out the velocity of each type of waves. Use scientific calculator.
   a. Gamma rays
   b. X-rays
   c. Radio waves

   What do you notice about the values of velocity of waves in different sections of electromagnetic spectrum?

2. Radio and visible light are both electromagnetic waves.
   a. Can radio waves pass through walls and glass panes of houses in and out?
   b. Can light pass through window panes ?
   c. Does sunlight pass through vacuum in space from the sun to the earth?
3. There are two types of waves, namely longitudinal and transverse.
   a. What is the difference between longitudinal and transverse

waves?

b. Are electromagnetic waves longitudinal or transverse? Give an explanation.

c. All waves are caused by oscillations. What causes electromagnetic waves?

Feedback

Just like all other waves, electromagnetic waves carry energy from one point to another, can be reflected from obstacles, can refract when passing through different media, can diffract as they emerge out of gaps and go round corners and interfere with other waves. Electromagnetic waves also follow the wave equation $v = f\lambda$ where v is wave velocity, f is frequency and λ is wavelength.

The special properties of electromagnetic waves are as follows:

Electromagnetic waves are transverse waves.

As the name suggests, electromagnetic waves are a combination of oscillating electric and magnetic fields of electric charges. Remember that matter consists of atoms with charged particles like protons and electrons. You should remember that a moving charge always produces a magnetic field in addition to its electric field. When the electric field is made to oscillate, its accompanying magnetic field also oscillates. The two oscillating waves travel together away from the oscillating charged particle covering a lot of distance and producing a lot of phenomena when they interact with matter on their way.

Electromagnetic waves are transverse because both fields oscillate perpendicular to direction of travel as shown in figure 11.2.

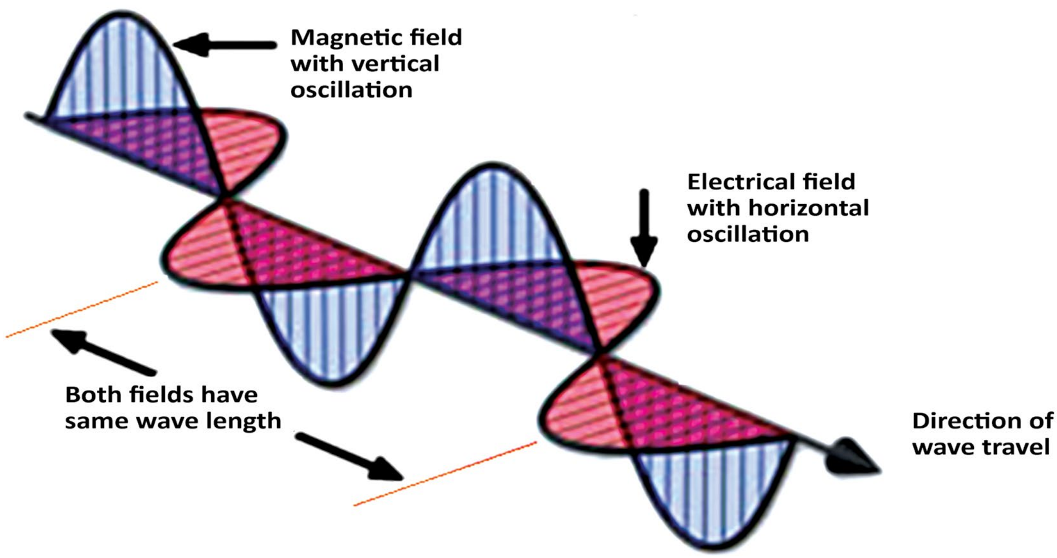

Figure 11.2 Transverse electromagnetic waves

Electromagnetic waves travel at the same speed. In a vacuum the speed is 299, 792, 458m/s. This value is normally approximated to 300 000 000m/s or $3x10^8$m/s and is called speed of light because it was first measured using light.

Electromagnetic waves can travel through both vacuum and matter. They do not need a medium like sound waves. It is for this reason that x-rays and gamma rays can pass through your body and radio waves can pass through walls. Light can pass through glass at the same time it can pass through vacuum in space as it travels from the sun. In some cases, however, the electromagnetic waves are either absorbed or reflected from material surfaces. For example, microwaves are absorbed by water in foods and in the process generate heat which cooks them. Light is reflected from mirror surfaces.

Source of electromagnetic waves

To produce electromagnetic wave at a particular frequency charged particles are forced to oscillate at that particular frequency. The accompanying oscillating electric and magnetic fields from the charge produces the electromagnetic wave.

Since electromagnetic waves carry energy, the source provides that energy and it can be gained by anything that absorbs them. For example, visible sunlight is an electromagnetic wave that changes into heat energy when absorbed by matter.

Key point

Logic gates are computer circuits with several inputs but only one output that can be activated by particular combinations of inputs.

Exercise 11.2

1. Give the difference between transverse and longitudinal waves.
2. Explain why electromagnetic waves are transverse waves.
3. A radio station in Lilongwe transmits radio waves with a frequency 95.1MHz.
   a. What is the wavelength of such waves?
   b. If it is required that the minimum length for an efficient dipole aerial is half wavelength, what should be the aerial length of radio to get good signal?

Applications of electromagnetic waves

There are various uses of electromagnetic waves due to variety of ways in which they interact with matter. Activity 11.3 will help you to explore some of the uses of various electromagnetic waves.

Activity 11.3

Describing the applications of electromagnetic waves

Materials
- Paper
- Pens
- Chart paper
- Pental markers
- Internet

Method
1. In groups find out from the library, internet and people in various fields of communication, medicine, engineering, and industry about how electromagnetic waves are used.
2. Record your findings on a chart paper and share your findings with others in class.

Feedback
Each band of electromagnetic waves has uses. The uses depend on the amount of energy carried by the waves which directly correspond to frequency. It also depends on whether the waves are absorbed or reflected from surface or pass through matter. The oscillating electric field can generate alternating current in conductors, make molecules vibrate, cause ionization of atoms and even interact with nuclei of atoms.

Radio waves
These have lowest energy due to low frequency. They are produced using electricity whose electric current alternates at a particular frequency. Their major use is communication in radio, TV, telephone and satellites. Radio waves easily diffract round hills and buildings by diffraction due to their long wavelengths.

Microwave
These are EM waves with frequencies that are above radio waves but below Infrared waves.

Communication: Blue-tooth and Wi-Fi signal use microwaves to connect computers and cell phones.
Radar (radio detection and ranging): Also uses microwaves to locate ships and aircraft and missiles by sending the waves and detect reflected waves. Radar is used for air traffic control and monitoring severe weather
Cooking: Foods are cooked when microwaves penetrate the food and raise the energy of the food molecules.
This is achieved by making the polar water molecules in the food to

vibrate by twisting to and fro following the oscillating electric field of microwave. Food cooks faster due to direct cooking that uses conduction.

Infrared

These are emitted by any warm or hot object as it is actually heat radiation. Person's body, fire, and electric bulbs are examples of emitters of infrared waves. People feel warm when they are near fires and electric heaters because they absorb infrared radiation which causes rotation and torsion of molecules hence raising the temperature. On the electromagnetic spectrum infrared waves are above the microwaves but below (infra-) the red part of visible light.

Uses of infrared include the following:

Communication: Wireless remote control for TV and short distance data transfer between computers.

Lasers: Lasers are used to read audio and video information on CDs and DVDs. They are also used to read bar codes on product identification labels in supermarkets.

Heating: Fires emit radiation that can be used to heat things during cooking.Infrared radiation makes molecules vibrate, and the energy transfer involved causes the radiated energy to be absorbed very quickly in solid and liquid materials and raise their temperature.

Infrared thermography: Human body emits infrared waves therefore image of the human body (called thermograph) can be formed using sensitive infrared detectors. A thermograph is a display of temperature variations of the skin since a brighter infrared image in a given region shows that the region is at a higher temperature.

- **Uses of thermographs:**
  - Early detection of breast cancer since temperature of tumour is often 1 to 2°C higher than that of normal tissue.
  - Examination of burns and frostbite.
  - Analysis of the vitality of various types of skin grafts.

A thermograph receiver is a sensitive IR detector which scans and converts the IR intensity into electrical signal which is amplified and displayed on an oscilloscope screen or colour printed on paper.

Visible light.

It is the band of electromagnetic waves that can be detected by cones and rods in the human eyes. In vision, the higher frequencies are perceived as violet while the lowest as red.

Uses of light include the following:

Vision: Our eyes receive and detect light waves which the brain interprets into various colour perceptions.

Photosynthesis: Plants are a major source of food for humans. The green plants manufacture the food using water and carbon dioxide with the help of sunlight as a source of energy for that process to take place.
Communication: Light is also used in communication systems using lasers and fibres.

Ultraviolet light

This is a band just above (ultra) violet of visible light and below x-rays. Very hot objects emit very bright light in the range of UV. They are very energetic waves so that when they fall on matter they may;

- o Excite electrons in atoms from lower to higher levels and in the process get absorbed.
- o Eject electrons from atoms or molecules to form ions.
- o Dissociate molecules into their constituent atoms.
- o Produce instantaneous chemical changes.

Some uses of UVs include the following:

- — *Fluorescence.* Fluorescent tubes and plasma TVs are coated with substances which convert UV waves into visible light and this is called fluorescence. Invisible ink use same principle when subjected to UV light. Some washing powders have same effect so that clothes look clean and bright when washed
- — *Medicine.* In medicine UV have various uses like;
    - o Treatment of skin conditions like psoriasis, acne and certain cosmetic effects.
    - o Killing fungi and bacteria on the skin.
    - o Sterilisation of the air in operating rooms and instruments in laboratories.

Dangers of UV

The sun is a very strong source of UV radiation but very little of it reaches the earth because atmospheric gases like ozone absorb it before it reaches the earth.Depletion of ozone layer by atmospheric contaminations allows the dangerous UV light to reach the earth. This has very serious consequences like sunburns and skin cancer.
The eye is most susceptible to UV light damage; therefore welders must wear shields to avoid acute inflammatory conditions of the eyes. In countries with snow, UV light reflected from snow causes 'snow blindness'

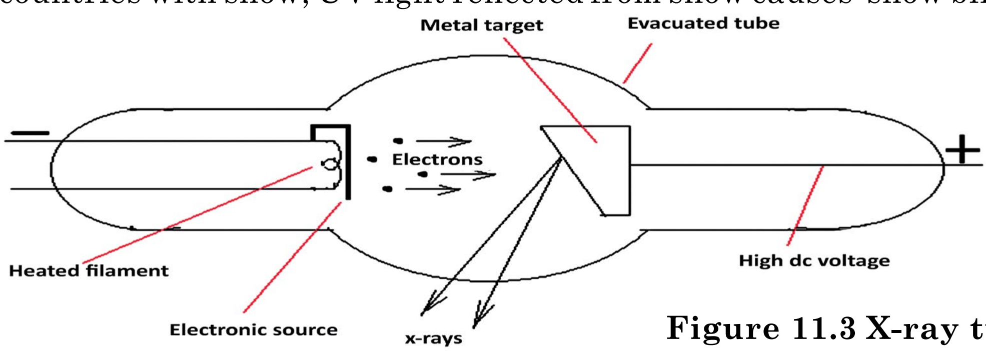

Figure 11.3 X-ray tube

X-rays

X-rays are produced by accelerating electrons through high voltages and allowing them to strike metal target as shown in figure 11.3. When the high speed electron approaches a metal target, it is strongly repelled and decelerated by the electron cloud of the atoms, thereby losing kinetic energy. Most of this energy raises temperature of the metal target, but 1% of it is given off in the form of X-rays.

X-rays are very penetrating and dangerous because they ionise atoms.

The common uses of X-rays are:

— *Take pictures of bones and body organs*. Soft tissues are more transparent to X-ray than body structures therefore can be used to form a shadow when the body is placed between X-ray source and the film as shown in figure 11.4. to take pictures of organs contrast is increased by introducing air or another gas into cavity normally filled by fluid or more opaque substances like barium sulphate

— *Treatment*. X-rays can be used to treat certain skin disorders.

— *X-ray crystallography*. Used to study crystal structures since they are partially reflected by the regular array of atoms in a crystal.

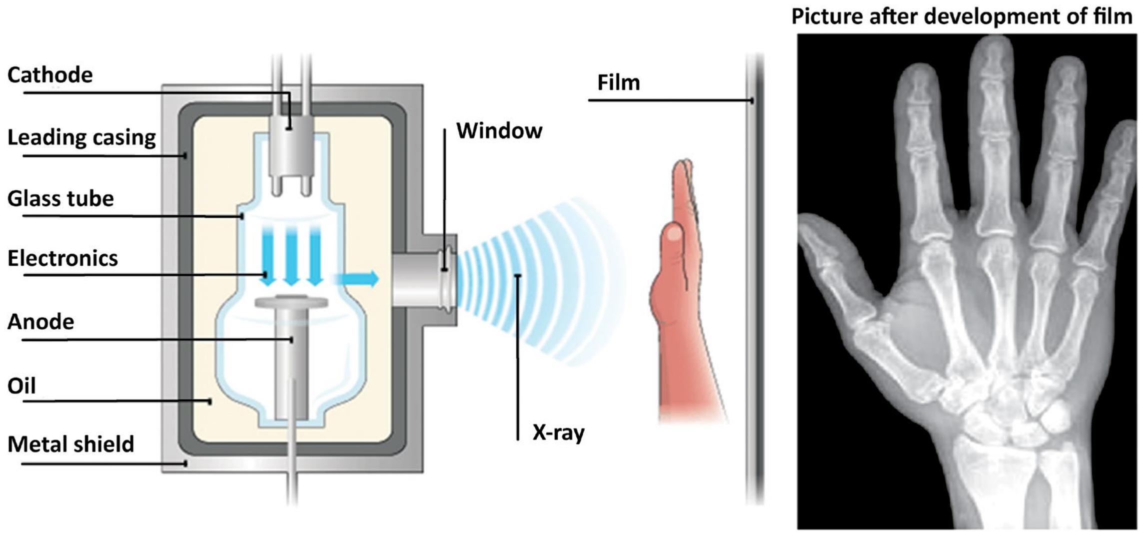

Figure 11.4 Getting image using X-rays

Gamma rays

This is an electromagnetic wave band with highest frequencies therefore very energetic. Most matter is transparent to them and they mostly involve ionisation. They are emitted naturally from radioactive decay of unstable nuclei in some isotopes and may artificially be produced using nuclear fission and fusion.

Some uses of gamma rays include the following:

— *Radiotherapy*. They are used to kill cancerous cells.

— *Sterilisation.* Used to sterilise packed foods and surgical tools.
— *Tracing.* They are used to trace flaws in metals and pipes.

Unit Summary

- Electromagnetic spectrum is a continuous arrangement of electromagnetic waves in order of their frequencies.
- Electromagnetic waves on the spectrum are classified into bands. In order of increasing frequencies the bands are radio, microwave, infrared, visible, ultraviolet, X-rays and gamma rays.
- Electromagnetic waves carry energy which increases with frequency.
- Electromagnetic waves are transverse waves.
- Electromagnetic waves are produced when charged particles oscillate creating equally oscillating electric and magnetic fields. These fields move away in form of a wave perpendicular to direction of travel.
- In a vacuum all electromagnetic waves move at the same speed of light, equal to $3x10^8$m/s.
- Electromagnetic waves do not need a medium for their travel, they can move through both vacuum and matter.
- Different bands of electromagnetic waves have various applications in communication, medicine, industry, agriculture and domestic setting.

End of unit exercise

1. List three properties that are common about electromagnetic waves.
2. Name electromagnetic waves that have the following:
   a. Have longest wavelength of all.
   b. Produced by passing electrons towards a metal target in a evacuated tube.
   c. Cause fluorescence.
   d. Emitted from nuclei of atoms.
   e. Emitted from a warm body.
   f. Emitted from a very hot body.
3. All waves are produced from oscillating particles.
   a. Describe how electromagnetic waves are produced.
   b. Explain why direct current would be difficult to create electromagnetic waves.
4. Electromagnetic waves have so many uses. Name the following;
   a. Two waves that are used to cook food.
   b. A wave used for air traffic control.
   c. Waves used to make a thermograph (a temperature dependent picture).
   d. Two waves that are used for communication.
5. What type of electromagnetic wave is emitted by your body most?
6. An electromagnetic wave has a wavelength of 600m.
   a. What is the frequency of the wave?
   b. Name type of electromagnetic.
7. What is the frequency of electromagnetic waves with wavelength of 160m, and name the band of the wave?

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UNIT 12

Light is an electromagnetic wave. Its path of travel through lenses produces interesting and important effects to our day to day life. Most important of all is their ability to form images of objects when light passes through them. In this unit you will learn description of lenses and the images that they form. You will also learn how to solve problems that involve the lens and magnification formula so that you can understand application of lenses in various optical devices. Lastly, you will look at formation of image in the human eye and common defects of vision.

Light and lenses

Converging and diverging lenses

Lenses are all glass blocks made in different shapes. The lenses are classified as converging and diverging depending on their actions to light that passes through them. Activity 12.1 will help you to learn action of lenses on light so that you can appreciate why they are given such names.

Activity 12.1

Describing converging and diverging lenses

Materials

- Metal plate with multiple parallel slits
- Barriers
- Holders for slits and barriers
- Cylindrical lenses (preferably plano-convex and plano-concave)
- Plane mirror
- Power supply, 12V
- Ray box, with vertical filament or lamp stand
- Lamp with vertical filament
- Housing shield
- Retort stand

Method

1. Fix the lamp to a retort stand and hold it inside a housing shield with a vertical opening. Place a mirror inside the shield to reflect all light towards the hole.
2. Stand a metal plate with multiple slits on white paper using holders. Switch on the lamp so that it shines its light

towards the slits and make rays on the paper. Raise or lower the lamp until the rays continue well across the paper as shown in figure 12.1.

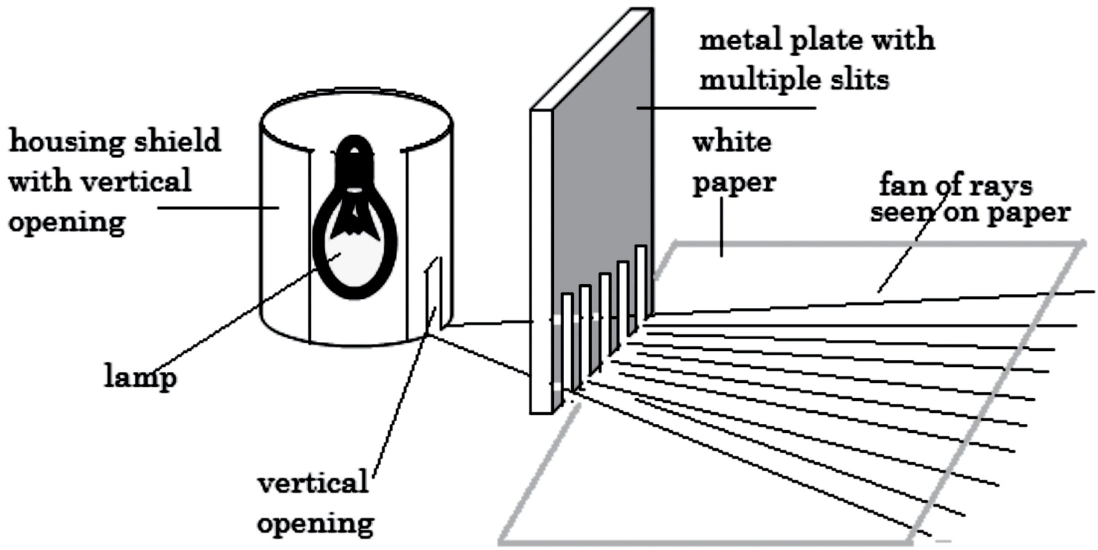


Figure 12.1

3. Stand a plano convex lens vertically in various positions on the fan of rays on paper as shown in figure 12.2 and observe what happens. The plane surface of the lens should face the light.

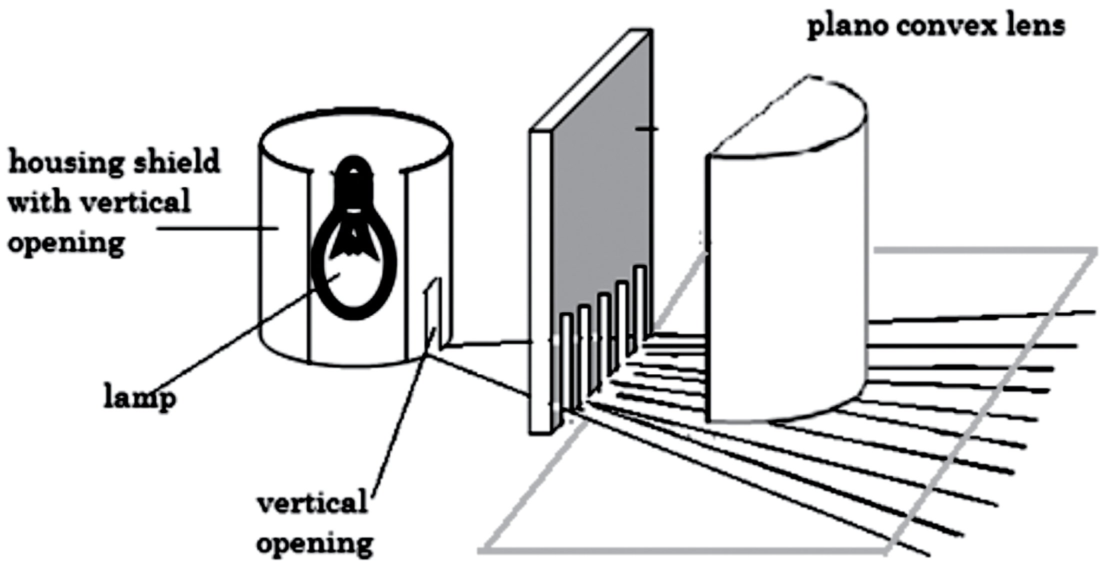


Figure 12.2

4. Adjust the lens position carefully to make sure that its face is perpendicular to the centre ray. What do you notice? Try to move the lens away and closer to the light and each time make observations. Try to use different plano convex lens if any and make observations.
5. Repeat step 3 and 4 using plano concave lens and make observation.

Feedback

Convex lens has its surface curved outwards while concave lens has its surface curved inwards. The figure 12.3 shows lenses of different shapes and their names.

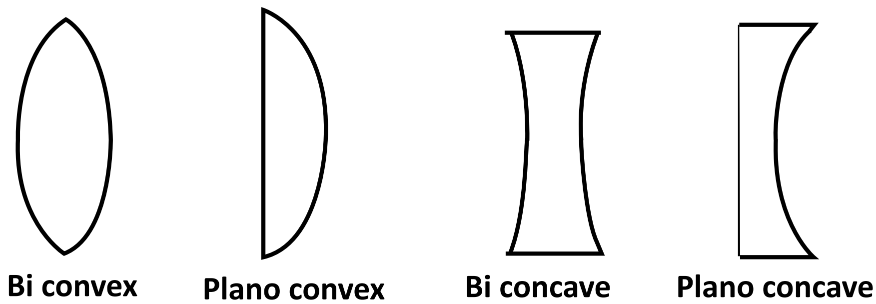


Figure 12.3: Names of lenses according to their shapes

When light rays pass through a convex lens they refract in such a way that they come closer together as shown in figure 12.4 hence they are called converging lens.

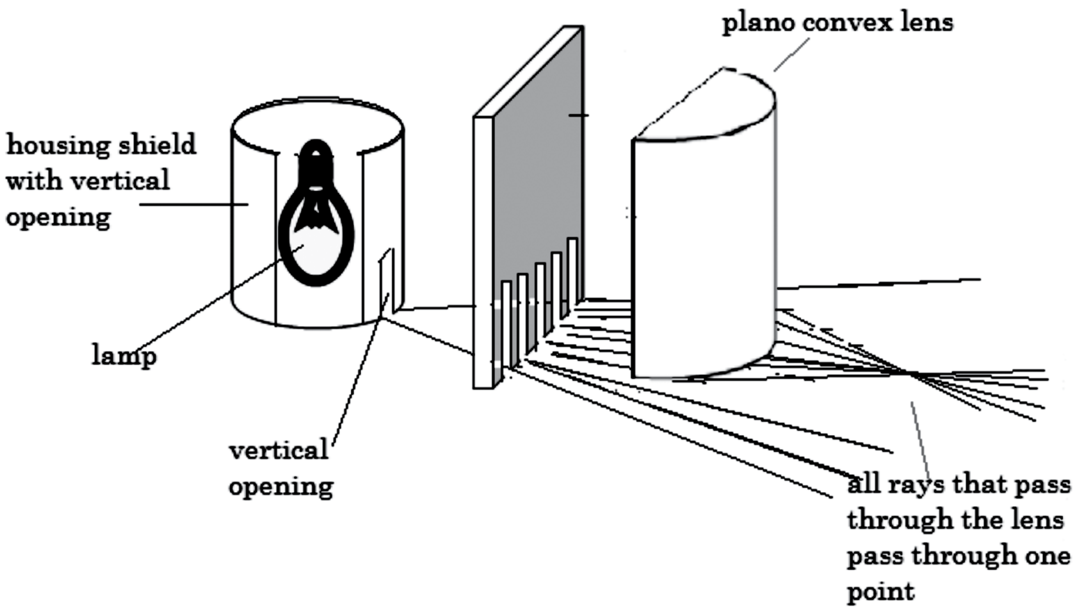


Figure 12.4 Action of convex lens

Remember light travels in a straight line and an object is seen only when light from that objects enters the eyes. The lens bends the rays from an object and forms its image at the position where they meet. Such image is real, meaning it can be put on a screen. Light through a biconvex lens would refract and pass through one point as shown in figure 12.5(a)

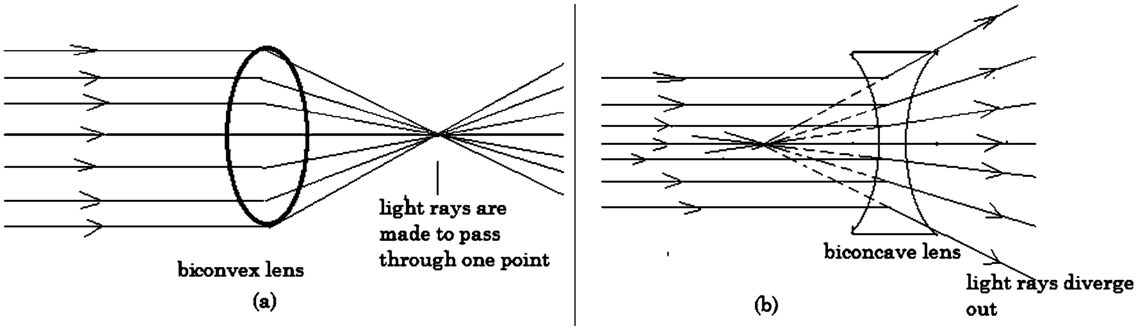


Figure 12.5: Light rays through a convex lens and convex lens

When the light rays pass through a concave lens, the rays refract in such a way that they move further apart as shown in figure 12.6. This is why a concave lens is called a diverging lens.

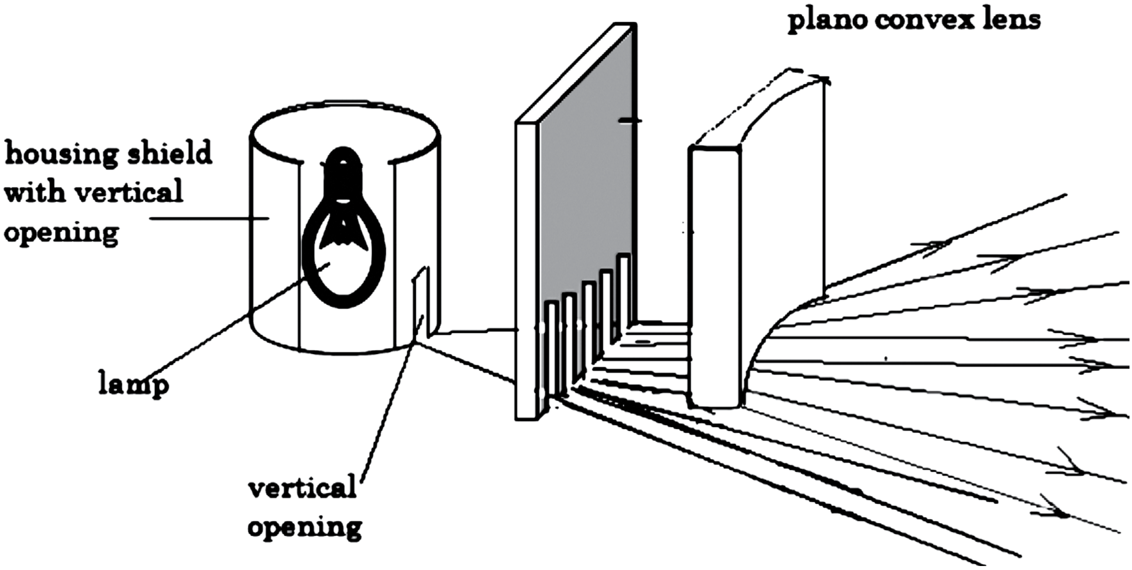


Figure 12.6: Action of concave lens

In this case an image is formed at a position where the refracted rays appear to come from. Such image is said to be virtual meaning it cannot be put on a screen. In a biconcave lens the rays would diverge as shown in figure 12.5(b)

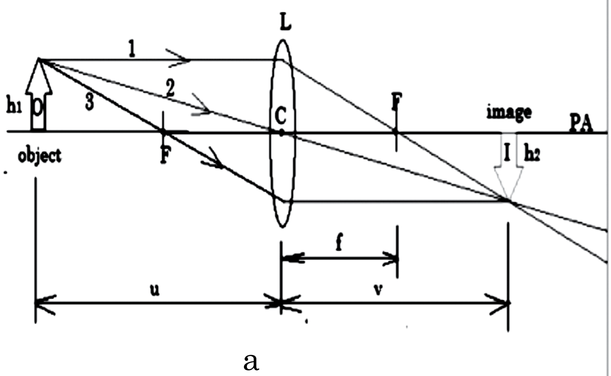
Key point

A converging lens is a convex lens that make light rays to come together to a focus

A diverging lens is a concave lens that make light rays to move apart from each other

Terms associated with lenses

Study figure 12.7 to familiarise yourself with terms associated with lenses and the images that they form.



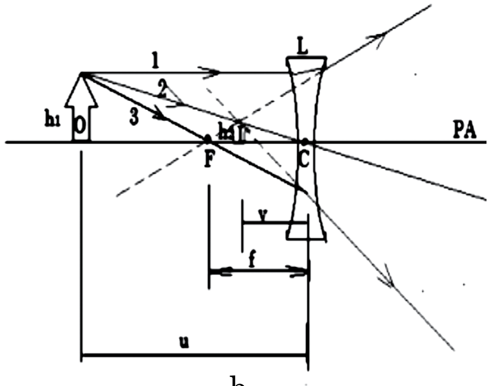


Figure 12.7 Lens terms

- The letter *O* represent position of object and letter *I* represent position of image from the lens.
- *C* is optical centre of the lens *L*.
- *PA* is a line that passes through optical centre and runs perpendicular to the plane of the lens.
- *F* is a point on the principal axis where rays from a distant object always meet and is called Focal point or Principal focus.
- *f* is called focal length of the lens. It is distance along the PA from the optical centre O to focal point F.
- *u* is object distance from the lens.
- *v* is image distance from the lens.
- h_1 is the height of object while h_2 is the height of the image from the PA.,

All horizontal distances (*f*, *v* and *u*) are measured from the lens and all vertical distances (h_1 and h_2) are measured from the PA.
Each point on an object has countless number of light rays spreading into all directions.

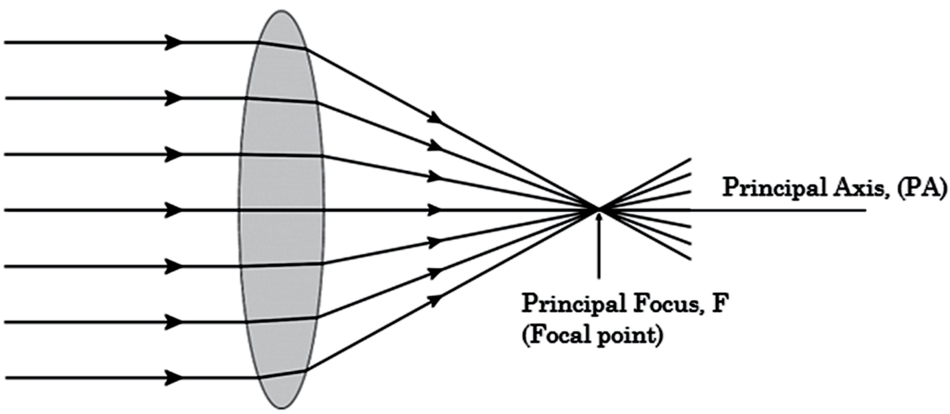


Figure 12.8: Focal point of convex lens

However, three rays called principal rays are enough to describe light propagation through a lens as shown on figure 12.7. Constructing any two of the three rays can give the position where the rays meet, which is also the position where a sharp image of object forms.

Take note that the image is not at the focal point of the lens. Focal point is where parallel rays (rays from a distant source) pass through as they emerge out of the lens a shown in figure 12.8

The principal rays are:
1. Ray drawn from a point on object (usually top), and running parallel to the PA refracts and emerges to pass through focal point F on the other side of the lens.
2. Ray drawn from the same initial point passing through the optical centre C continues without bending.
3. Ray drawn from same point as the other rays and passes through F before the lens emerge out of the lens, refracted in such a way that it is parallel to the PA.

Where the rays meet is the position where the image forms. The point of intersection represents the position on the object where the rays were drawn from.

Note: When drawing light ray diagrams, make sure that the object, lens and image stand perpendicular to the principle axis. Use protractors or set squares to get right angles.

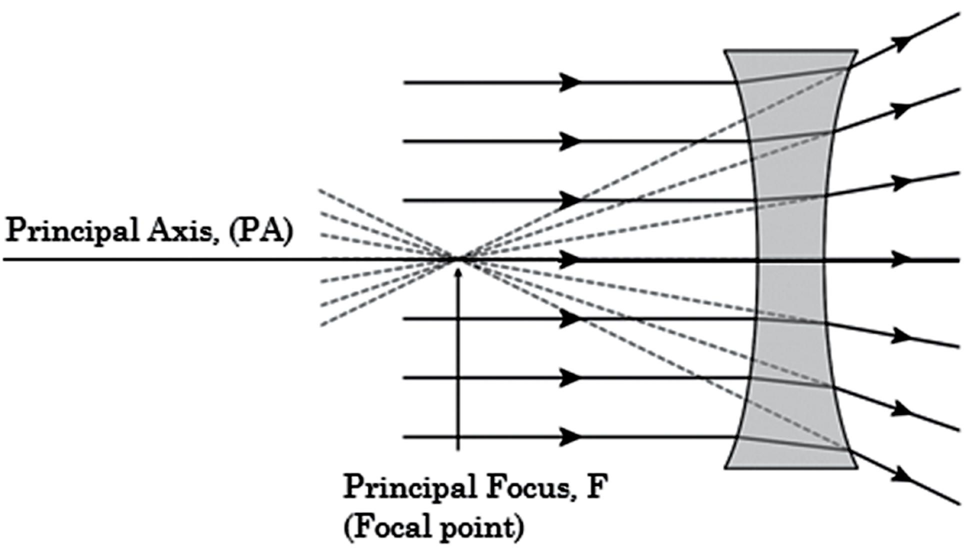


Figure 12.9: Focal point of concave lens

Similar terms are used for diverging lenses as shown in figure 12.7(b).The same rule of drawing the rays apply. In this case the position of virtual image is located by producing the refracted rays backward using dotted lines. The focal point is where incident parallel rays meet on the PA when extrapolated. As shown in figure 12.9. Focal length f is the distance from the optical centre of the lens to the focal point.

Focal length of a converging lens

The amount of refraction through a lens is so much dependent on the focal length of the lens. It is very important for you to know how to find focal length of a lens. Activity 12.2 will help you to know how to find focal length of a convex lens.

Activity 12.2

Determining focal length of a converging lens

Materials

- Lens holder
- Convex lenses of different thickness
- 1 metre ruler (preferably with wide base like chalk board ruler)
- Wires
- Cello tape
- Light box
- Mirror
- Screen
- 2 graph papers
- Pencil
- Eraser

Method.

A. **Approximate method.**

1. Put a convex lens in a lens holder and place it on a 1 metre ruler. Use the lens to focus image of a window across the room onto a wall as shown in figure 12.10
2. Adjust position of the lens by sliding its holder to or away from the wall, until a sharp image of the window forms on the wall.
3. Measure distance from the centre of the lens to the wall by reading values on the ruler. This gives the approximate focal length of the lens.
4. Repeat steps 1 to 3 using lenses of different thickness.
   a. Which lens is stronger in refracting light?
   b. Which lens has shorter focal length between the thick and thin lens?

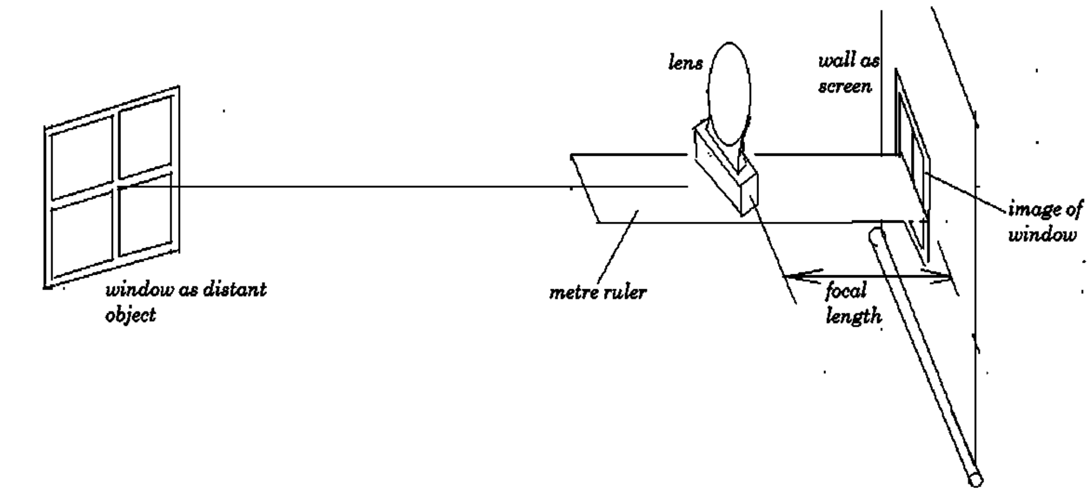


Figure 12.10: Measuring approximate focal length of a lens

B. **Accurate method**

1. Put a cross wire across an opening of a light box to act as object using cello tape.
2. Place the light box in front of a lens at any distance and screen behind the lens so that the three lie in a straight line as shown in figure 12.11.

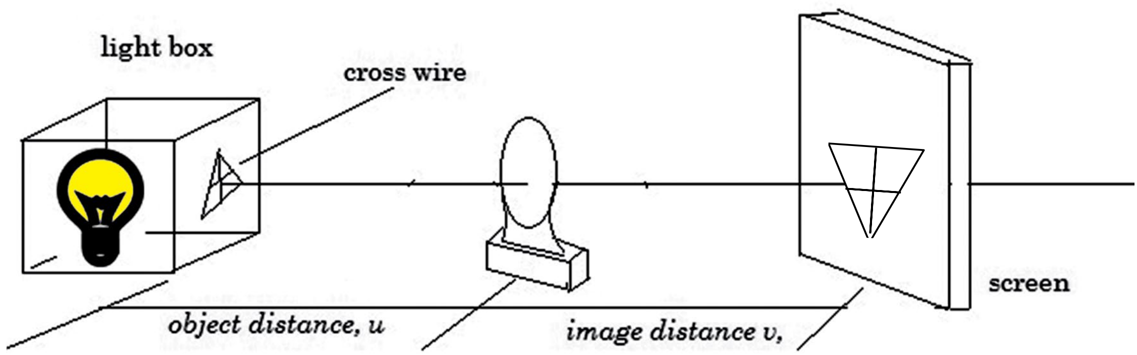


Figure 12.11: Measuring focal length of lens

3. Switch on the light box. Adjust the position of the screen from the lens until a clear focused image of the cross wire forms on the screen. Measure both object and image distances from the lens, using a ruler and record in the table of results like one seen below.
4. Change the distances of the lens from the object and each time adjust the distance from the lens to the screen to get a sharp image. Measure both object and image distances. Use values of object distances in the table of results below.

Object distance, *u* (cm)	**Image distance, *v* (cm)**	***u* + *v* (cm)**
?		
22.5		
25		
30		
35		
40		
45		
50		
55		
60		

5. Fill the last column of the table by calculating the sum of object distance and image distance.
6. Using suitable scale plot a graph of $u+v$ against u on the graph paper.
7. Using the graph line find the minimum value of u and work out focal length of the lens using the relationship $2f = u$
8. Compare your findings with the one you got using the approximate method.

Feedback

The graph line from this experiment has a u shape like the one shown in figure 12.12

Point X is the minimum point. The value of u at this point is equal to twice the focal length of the lens, $u = 2f$. The value of the focal length is therefore,

. $f = \frac{u}{2}$

Alternatively, f can also be calculated using values on the vertical axis. In this case the value of u=v at point X is equal to four times the value of focal length, $u+v = 4f$. The value of focal length is therefore $f = \frac{u+v}{4}$

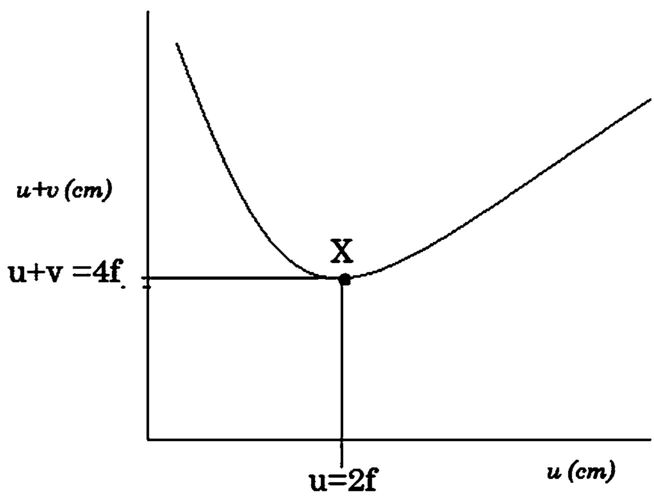


Figure 12.12: Working out value of focal length from graph

Alternative approach

Using the same data, the focal length can also be obtained using a different approach.

Example.

Let us assume that the values obtained from the experiment are as shown in table below

Object distance, u (cm)	**Image distance, v (cm)**
?	
22.5	90
25	81
30	72
35	49
40	40
45	36
50	32
55	30
60	28

What to do

1. Create two columns labeled $\frac{1}{u}$ and $\frac{1}{v}$. Fill these two columns by calculating their values. Limit the values to three decimal points as shown in table below:

Object distance, u (cm)	Image distance, v (cm)	$\frac{1}{u}$ (cm^{-1})	$\frac{1}{v}$ (cm^{-1})
?			
22.5	90	0.044	0.011
25	81	0.040	0.012
30	72	0.033	0.014
35	49	0.029	0.020
40	40	0.025	0.025
45	36	0.022	0.028
50	32	0.020	0.031
55	30	0.018	0.033
60	28	0.017	0.036

2. Decimal numbers are difficult to plot on a graph. It is better to write them in standard form. All the values will be raised to x 10^{-3} hence they can be shown

once by writing it at the top of the column as shown in table below:

Object distance, u (cm)	Image distance, v (cm)	$\frac{1}{u}$ x 10^{-3} (cm^{-1})	$\frac{1}{v}$ x 10^{-3} (cm^{-1})
?			
22.5	90	44	11
25	81	40	12
30	72	33	14
35	49	29	20
40	40	25	25
45	36	22	28
50	32	20	31
55	30	18	33
60	28	17	36

3. Using values of origin as (0,0) plot a graph of $\frac{1}{u}$ against $\frac{1}{v}$. Extend the graph lines so that they intersect the y and x axes. The graph intersects y-axis at point A as shown in figure 12.13.

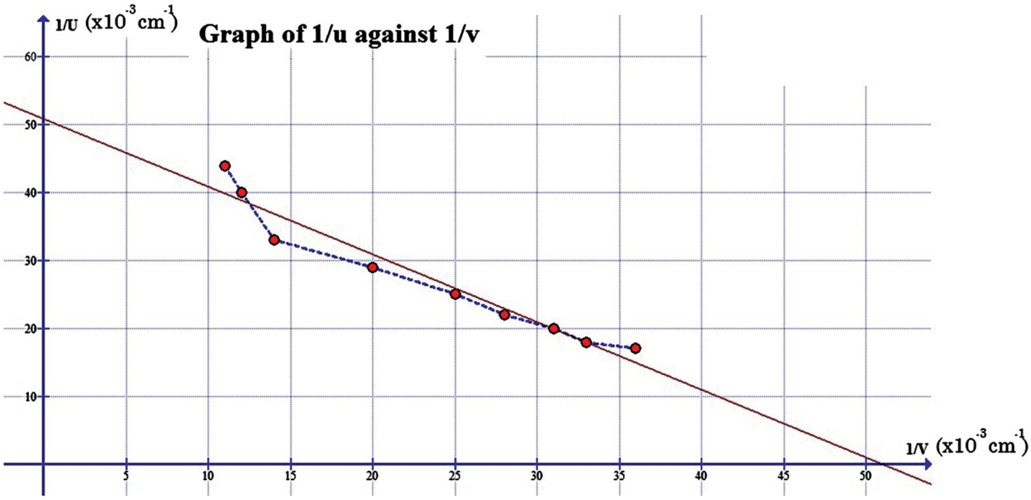


Figure 12.13

4. At y-intercept, the value of u = f. This is also true at x-intercept. To find focal length f you will have to find the value of u.

In the above example the y-intercept,

$$\frac{1}{u} = 50 \times 10^{-3}$$

$\therefore u = \frac{1}{50\times10^{-3}} = 20$

$\Rightarrow f = u = 20cm$

A similar answer is obtained when using the x-intercept where $v = f$.

Exercise 12.1

1. An experiment to find focal length of a lens was done by measuring image distances for different object distances from the lens. The results obtained were as shown in table below:

Object distance, u (cm)	22.5	25	30	35	40	45	50
Image distance, v (cm	57.5	45.5	30	27	25.1	23.6	22.5
$u + v$ (cm)							

   a. Find the values of $(u+v)$ in the last row
   b. Plot a graph of $(u+v)$ against u
   c. Using the graph find the focal length of the lens.

2. A graph of $u+v$ against u was plotted to find focal length of a lens as shown in figure 12.14. What is the focal length of the lens?

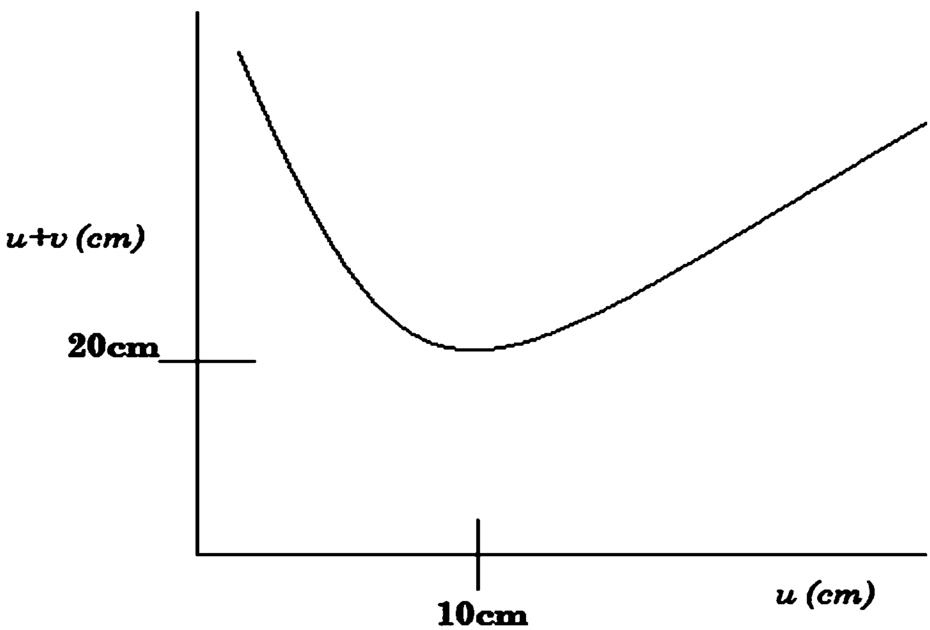


Figure 12.14: Graph of $u+v$ against u

3. In an attempt to work out focal length of a lens the following values of object and image distances were measured.

Image distance, u (cm)	30	40	50	60	70	80	90
Object distance, v (cm)	150	67	50	43	39	36	35
$\frac{1}{u}$ (cm^{-1})							
$\frac{1}{v}$ (cm^{-1})							

a. Fill the table by working out the values of $\frac{1}{u}$ and $\frac{1}{v}$.

b. Plot a graph of $\frac{1}{u}$ against $\frac{1}{v}$.

c. Use the graph to find the focal length of the lens.

Key point
Focal length, f is the distance from a lens to image position of a distant bject.

Image formation using ray diagrams

The light ray diagrams are very important in the study of lenses and the images that they form when light passes through them. The rays are constructed. This means accuracy is very important. Use sharp pencils, good rulers and protractors. Use proper scale to draw the lines.

Activity 12.3

Explaining image formation by converging lens using raydiagrams

Materials
- Paper or exercise book
- Sharp pencil
- Ruler
- Eraser
- Protractor or set square

Method
1. Read and understand the problem below:
   An object 4cm tall is put in front of a lens of focal length 10cm at a distance of 25cm.
   a. Find by scale drawing, the position, height, magnification and nature of image.
2. The distances should be drawn to scale. Use two scales, one for vertical distances and the other for horizontal distances. Sample scales are shown in the table below. Sometimes the scales can be the same but need not to be.

Vertical distances	Horizontal distances
Object height and image height, h_1 and h_2	u, v and f
Scale 2:1	Scale 5:1

3. Draw a horizontal straight line on paper using a sharp pencil and ruler to represent the principal axis.
4. Mark a point C, on the principal axis where the lens will be drawn.
5. Draw a vertical line on point C using a set square so that it stands perpendicular to the principal axis.
6. The focal length is 10cm. Using the scale of 5:1 the focal length should be drawn as 2cm on paper. Mark two points , 2cm from each side of the lens and label each one F.

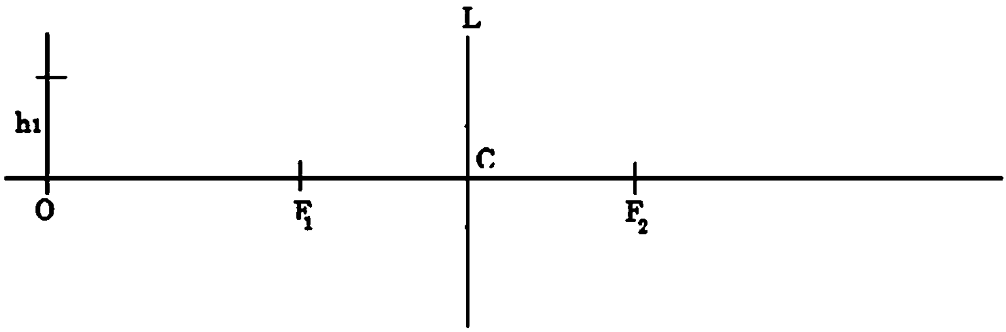


Figure 12.15: Constructing a light ray diagram

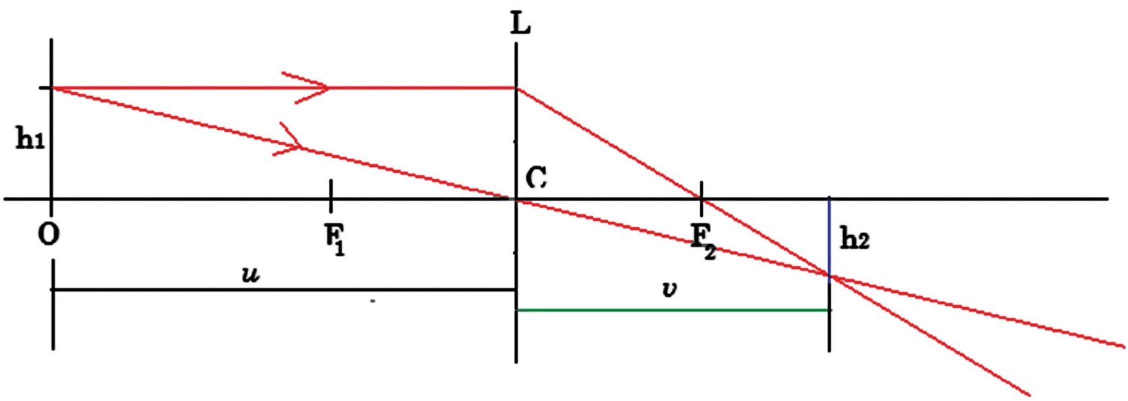


Figure 12.16: Complete light ray diagram

7. The object is 25cm from the lens. Using the scale of 5:1 this is 5cm on paper. Draw a line vertically using setsquare at a position of 5cm from the lens (it can be at any side but it is better if put on the left.

8. What should be the height of your object? The object is 4cm tall. Using a scale for vertical; distances of 2:1, 4cm is 2cm on paper. Mark a point 2cm from the principal axis. Your diagram should look like figure 12.15 below:
9. Draw a straight line from the top of the object with height h_1, parallel to the principal axis up to the lens L. At the lens join the line with another straight line that passes through the focal point F_2.
10. From the same point of object draw another line that passes through the optical centre C without bending until it crosses the first line.
11. Using a set square draw an image perpendicular to the principal axis, where the two rays meet. Your diagram should now look like figure 12.16:

Feedback

a. To get image position you measure image distance v and multiply it with the scale (*v* x *5*) *cm*
b. To get image height measure distance h_2 and then multiply it with the vertical scale (h_2 x *2*)cm
c. Magnification is the ratio of image size to object size. The formula for calculating magnification is therefore,

$$m = \frac{h_2}{h_1}$$

Using the shaded similar triangles, as seen in figure 12.17,

$$\frac{h_2}{h_1} = \frac{v}{u}$$

so that magnification can also be calculated using formula

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

Magnification is a ratio of similar quantities therefore it has no units.

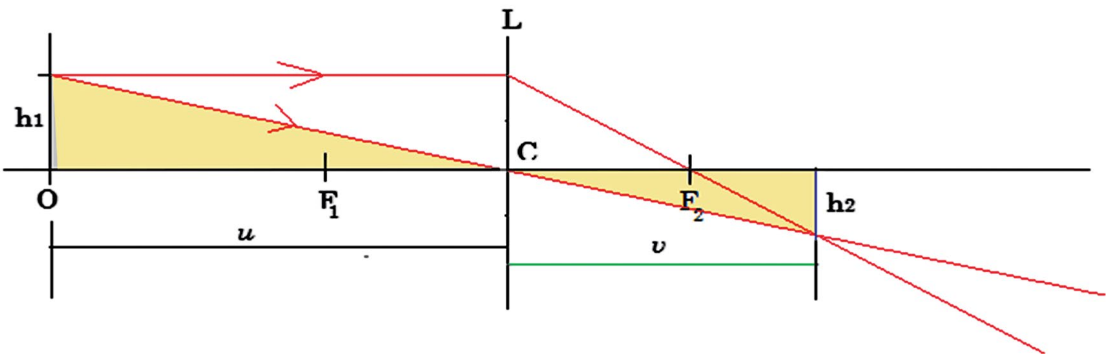


Figure 12.17: Similar triangles used to calculate magnification.

d. Images are erect or inverted, real or virtual, magnified or diminished.
   i. Real images are formed when rays are able to meet on the other side of the lens. Virtual images do not.
   ii. Real images are all inverted. Only virtual images are erect.
   iii. An image is magnified when $m > 1$ and diminished when $m < 1$. If $m = 1$ then the size of image is the same as that of the object.

In the case of our example the image is real, inverted and diminished. If your construction is accurate, the image position v is 16.7cm, height of image is 2.8cm and magnification is 0.7.

When rays do not meet on the other side of the lens, produce the rays backward. The point where the rays meet is where a virtual image forms.

Exercise 12.2

1. A candle light is 8cm high and placed 24cm in front of a convex lens. The lens has a focal length of 10cm.
   a. Construct a ray diagram to produce an image.
   b. Use the ray diagram to find;
      i. Image distance, height and magnification.
      ii. Nature of the image.
2. An object 5cm high is focused by a lens of focal length 20cm. If the object is placed at 15cm from the lens, find by graphical method the following:
   a. Image position
   b. Image height
   c. Magnification
   d. Nature of image.
3. A thin lens with focal length 10cm produces a real image its size twice that of object. By graphical method find the following:
   a. Object distance
   b. Image distance.

Image formation by converging lenses

What happens to the image as object distance changes? This is very important because optical instruments are used to capture images of objects at various distances from the lens. Activity 12.4 will help you to investigate the nature of image at various distances from the lens.

Activity 12.4

Describing image formation using ray diagrams

Materials

- lens holder
- Convex lens
- 1 metre ruler
- Two Wires
- Cello tape
- Light box
- screen

Method

1. Use approximate method to find focal length of a lens and record its value. (hint. the approximate method is done by focusing a sharp image of window across room on a wall and then measure distance from the lens to the wall)

2. Stick a cross wire to the hole of light box to act as object.
3. Place the light box in front of a lens at any distance which is more than twice the focal length but less than three times focal length. Place a screen behind the lens so that they lie in a straight line. Adjust position of screen until a sharp image forms on the screen. Record image position and nature of image.
4. Repeat step 3, with the light box at a distance twice the focal length of lens.
5. Repeat step 3, with the light box at a distance more than the focal length but less than twice the focal length.
6. Repeat step 3, with the light box at a distance equal to focal the length of the lens.
7. Repeat step 3, with the light box at a distance less than the focal length.
8. Discuss and describe the image as object moves near the lens at various distances in relation to the focal length of the lens.

Feedback

The nature of the image changes as the object moves closer to the lens. In the activity above you observed image changing size, position and orientation. In some cases you could not see the image on the screen.

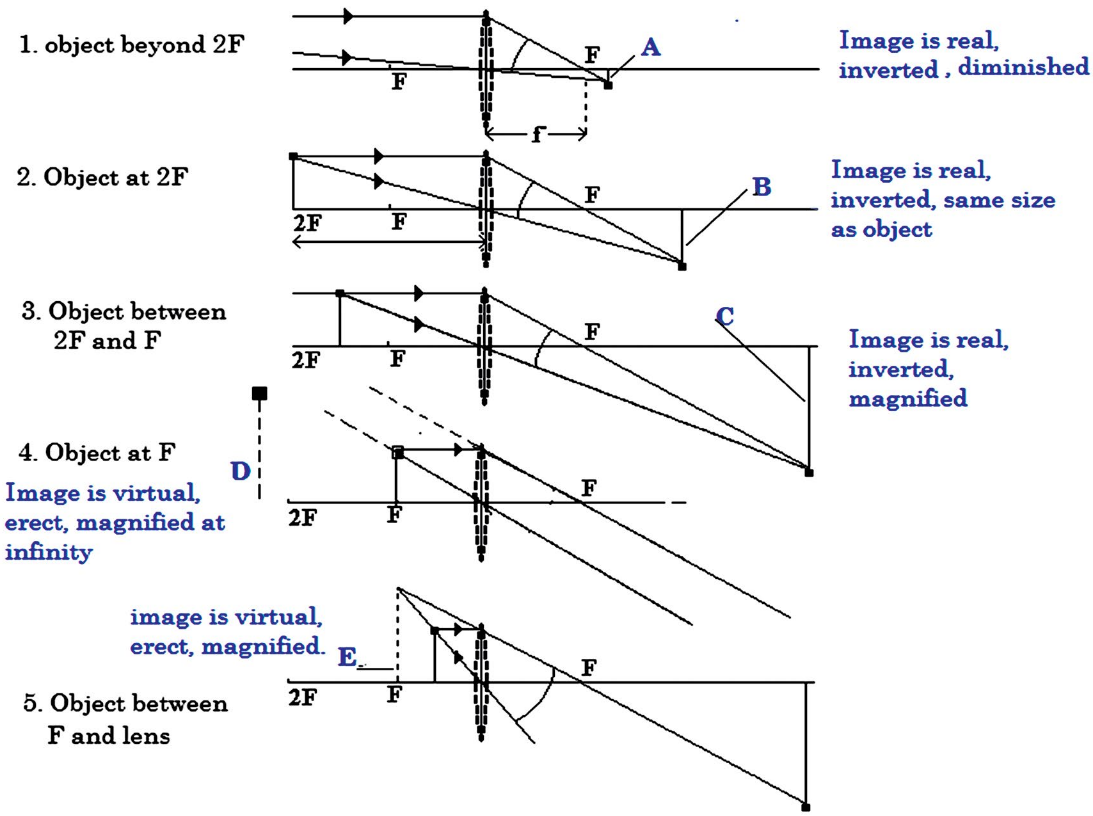


Figure 12.18: Image of object at various object distances in relation to focal length.

In that case, it means a virtual image is formed and is normally on the same side as the object from the lens. Figure 12.18 shows ray diagrams and nature of images produced as object distance varies.

Lens and the magnification formulae

Construction is not the only way to solve problems that involve lenses. An equation called lens formula can be derived from the light ray diagrams that you have constructed in this unit.

Activity 12.5

Deriving lens formula and magnification formula, and use them in the problem solving.

Materials
- Plain paper
- Pencil
- Ruler

Method
1. On a plain paper construct a light ray diagram like the one shown in figure 12.19 below where the object is placed between 2F and F. Use any value of focal length and label as shown.

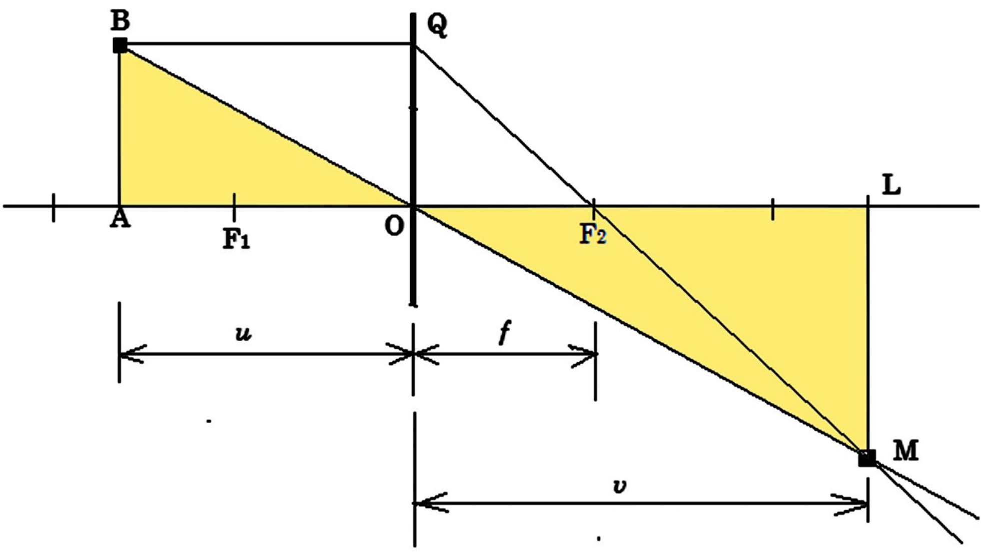


Figure 12.19: Deriving lens formula.

2. Triangle OLM is similar to triangle OAB

So we write

$\frac{LM}{AB} = \frac{OL}{OA}$ --- equation 1

Similarly as seen in a copied figure 12.20 triangle OQF_2 is similar to triangle F_2LM

So we can write

$\frac{LM}{OQ} = \frac{F_2L}{F_2O}$

But OQ = AB, therefore the equation becomes

$\frac{LM}{AB} = \frac{F_2L}{F_2O}$

............equation 2

In equation 1 and 2, $\frac{LM}{AB}$ is common therefore we can write

$$\frac{LM}{AB} = \frac{OL}{OA} = \frac{F_2L}{F_2O}$$

Discarding first part gives

$\frac{OL}{OA} = \frac{F_2L}{F_2O}$

But $F_2L = OL - OF_2$

Hence $\frac{OL}{OA} = \frac{F_2L}{F_2O}$

becomes $\frac{OL}{OA} = \frac{OL - OF_2}{F_2O}$

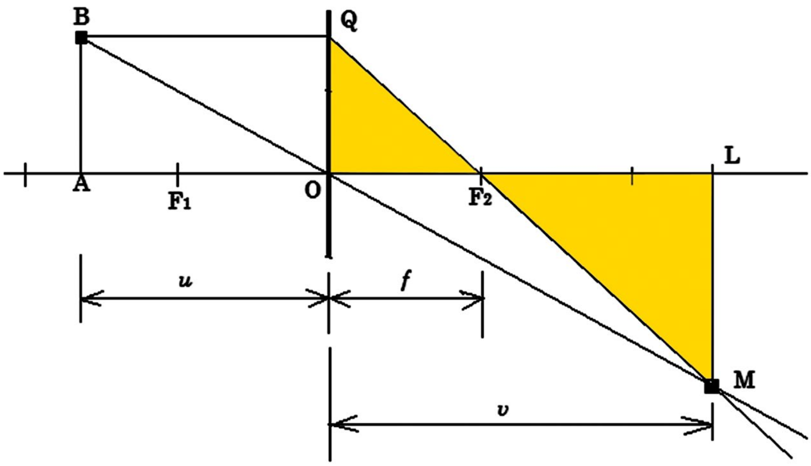


Figure 12.20

Substituting letters u, v and f into the equation

$$\frac{OL}{OA} = \frac{OL - OF_2}{F_2O}$$

where OL is v, OA is u and OF_2 is f

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

Removing denominators gives $vf = u(v-f)$

Removing the brackets gives $vf = uv - uf$

Dividing by uvf throughout the equation $\frac{vf}{uvf} = \frac{uv}{uvf} - \frac{uf}{uvf}$

The equation becomes $\frac{1}{u} = \frac{1}{f} - \frac{1}{v}$

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

The equation $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ is called lens equation.

Formula for magnification

Using the diagram above $magnification = \frac{image\ size}{object\ size} = \frac{LM}{AB}$

Consider equation 1, $\frac{LM}{AB} = \frac{OL}{OA}$

where LM is h_2, AB is h_1, OL is v, and OA is u

$$\frac{h_2}{h_1} = \frac{v}{u}$$

But $\frac{h_2}{h_1} = magnification, m$

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

Example

1. An object 3cm tall is placed at distance of 20cm from a convex lens of focal length 15cm.
   a. work out the following about the image;
      i. Position
      ii. Magnification
      iii. Image height
      iv. Nature.
   b. Repeat (a) when the object is placed 10cm from the lens.

a. Solution

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

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

$\frac{1}{v} = \frac{1}{15} - \frac{1}{20}$

$\frac{1}{v} = \frac{4-3}{60}$

$\frac{1}{v} = \frac{1}{60}$

$\therefore image\ position\ v = 60cm$

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

$m = \frac{60cm}{20cm} = 3$

iii. $m = \frac{h_2}{h_1}$

$\therefore h_2 = m \times h_1 = 3 \times 3cm = 9cm$

iv. $m > 1\ \therefore image\ is\ magnified\,.$

v is positive therefore image forms behind lens and image is real and all real images are inverted. Image is magnified, real and inverted.

b. Solution

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

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

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

$$\frac{1}{v} = \frac{2-3}{30}$$

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

$$\therefore image\ position\ v = -30cm$$

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

$$m = \frac{30cm}{10cm} = 3$$

iii. $m = \frac{h_2}{h_1}$

$$\therefore h_2 = m \times h_1 = 3 \times 3cm = 9cm$$

iv. $m > 1 \therefore image\ is\ magnified\,.$

v is negative therefore image and object are on the same side of lens and image is virtual and all virtual images are erect. Image is magnified, virtual and erect.

Exercise 12.3

1. The nature of image may depend on where object is placed from the lens. Where should the object be placed in terms of focal lengths in order to form an image which is
   a. Erect
   b. Inverted and magnified
   c. Erect and magnified
   d. Same size as object
   e. At infinity
2. A circular object with diameter 2cm is placed 30cm in front of a convex lens of focal length 20cm.
   a. Use appropriate formula to work out, image position, magnification and size of image. Describe the nature of image.

   b. What will be the image position, size and nature if the object is moved 20cm towards the lens.

3. A convex lens is used to magnify an object 2 times. If the object is standing at 10cm from the lens, calculate the following:
   a. Image distance
   b. Focal length of the lens.

Application of lenses in various optical devices

Lenses are very functional in many optical instruments. Their ability to refract light and bring them into focus is what makes them very important. Differences in optical instruments are mostly due to differences in their ray diagrams which shows the way light is manipulated by the lenses and other parts. In activity 12.6

Activity 12.6

Describing application of lenses in various optical devices

Materials

- Camera (a broken camera that can be dismantled can help)
- Film or slide projector
- Simple telescope
- Pencil
- Paper

Method

1. Study outside and inside parts of a camera and discuss their functions. Try to use the camera to appreciate how it works.
2. Draw diagram of a simple camera showing its parts especially relative positions of lens, diaphragm, shutter and film.
3. Draw light ray diagram to show how image is formed by a camera.
   a. Discuss the nature of images formed by camera?
   b. Discuss the object distance with respect to focal length to form such nature of image?
4. Repeat step 1 to 3 using a film or slide projector.

Feedback

The camera

A camera is used to take pictures, by forming real images of objects on the film inside it. The major parts in a camera are shown in figure 12.21

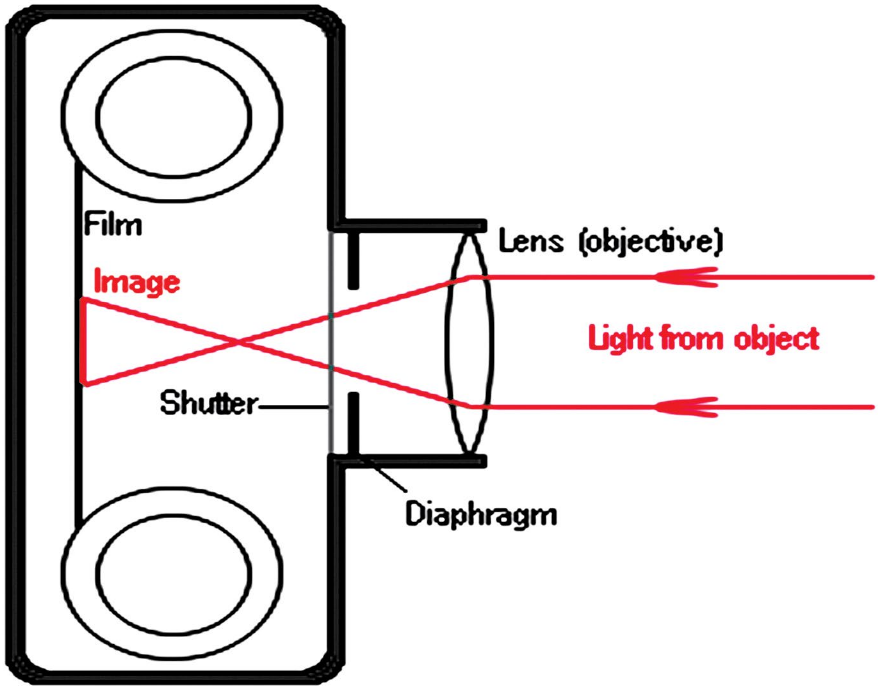


Figure 12.21: Parts of a simple camera

Figure 12.21 above has principal rays from two points on the object to show the light ray diagrams involved. The ray diagrams show that the object is at a distance greater than *2f* so that the image produced on the film is real, inverted and diminished.

A simple camera consists a biconvex lens, and film inside a box with a mechanism to adjust distance between the lens and the film. In addition, the camera has a shutter that can automatically close when opened during picture shooting. Camera diaphragm can be used to adjust size of aperture. Functions of some parts are as follows.

1. *Lens*. Forms a real, inverted and diminished image of object in front of it at the film placed at the back of the camera.
2. *Diaphragm (or stop)*. This is used to control the amount of light reaching the film by changing the size of aperture. The size of aperture is increased when taking pictures in dull light to allow more light to enter, which affects brightness of image formed.
3. *Shutter*. Allows light from object to reach the film only at the time of shooting by opening momentarily and then automatically close. The time it takes to close affects the amount of light reaching the film and this is called exposure time. Exposure time is increased when taking photographs in dull light to allow more light to pass through and reach the film. Shorter exposure time is used to take picture of fast moving object.

4. *Focus screw*. This is used to adjust image distance inside the camera to allow lens to focus sharp image for distant and far objects on the film. As discussed earlier when an object move closer to the lens, its image moves away. This means the film has to be moved away from the lens inside the camera to a position where sharp image forms. The image can also be focused by changing the distance between camera and the object.
5. *Photographic film*. This is a plastic sheet coated with light sensitive chemical. When shutter opens, light from object reaches the film. The chemicals on it are stimulated so that they get changed by different intensities of light from different shades on the object. The changes are fixed during film development and then photocopied to print a photograph.

The Film or slide projector

A film projector is used to produce a magnified, real, and inverted image on a large screen using a convex lens. The object is a picture on a film or slide. Figure 12.22 shows basic parts of a film or slide projector.

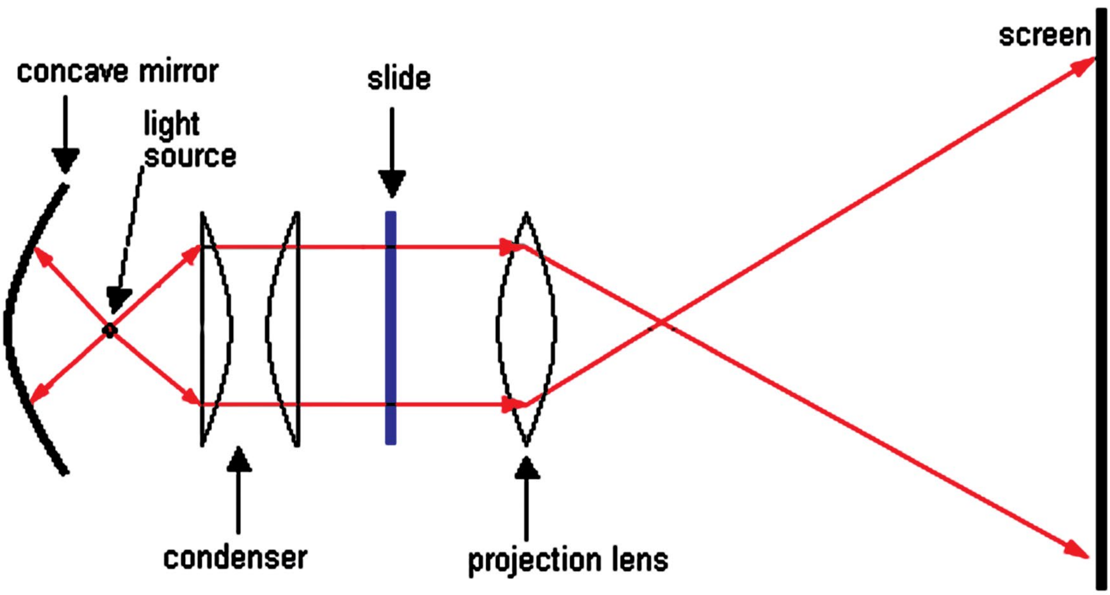


Figure 12.22 Parts of a film/slide projector.

Functions of parts of a film projector

1. *Light source (bulb).* Produce very strong light used to illuminate the film or slide.

2. *Curved mirror.* Used to reflect wasted light that goes to the left towards the right so that the film is strongly illuminated to produce bright image.
3. *Condenser lens.* Concentrates light rays by refraction towards the film for strong illumination. Condenser lens has a short focal length to allow strong refraction.
4. *Film or slide.* Used as object whose image is projected onto the screen. It is a transparent plastic with pictures on it. The pictures are objects whose image is shown on the screen. The film is placed between 2F and F to produce a real, magnified and inverted image. The pictures on the film are placed upside so that their inverted images look upright on the screen.
5. *Objective lens.* Used to focus images of pictures on the film onto the careen by refraction. Focusing is done by changing object distance between film and objective lens in the projector using adjusting screws. It may also be done by changing image distance between projector and film. The screen is put far away from the lens to make image large.

The Telescope

Telescopes are used to view objects that are very far like stars planets and the moon. You can use telescope to have a closer view of a very far mountain or tower. How does it work? Activity 12.7 will introduce you to how the telescope works.

Activity 12.7

Investigating how telescope works

Materials
- Retort stand and bosses
- Convex or plano-convex lens with long focal length (30cm or more)
- Convex or plano-convex lens with short focal length (5cm)
- Grease proof paper (or frosted screen or tissue paper)
- Lamp (100W or more)
- Lamp holder
- Metre ruler
- Plasticine or blue tack.

Method
1. Put the long focal length lens in a holder and mount and fix it on far end of metre ruler using plasticine or blue tack.
2. Mount the ruler to a retort stand and raise it to shoulder high.
3. Point the ruler towards the lens to get a real image of the lamp on a grease proof paper. As shown in figure 12.23.

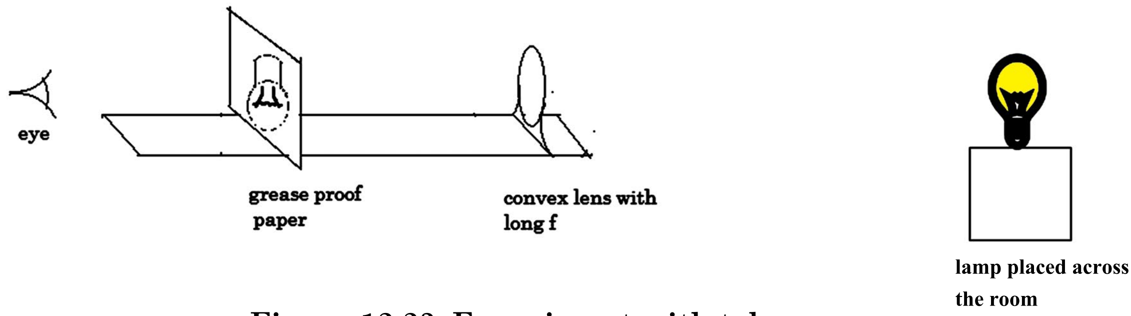


Figure 12.23: Experiment with telescope

4. Place the short focal length lens at the near end of the ruler as shown in figure 12.24 (do not stick it to the ruler.). Use this second lens to view the image at the grease proof paper as object (like in a magnifying glass situation). Slide the lens near and further until you can see what is on the grease proof paper magnified and focused.

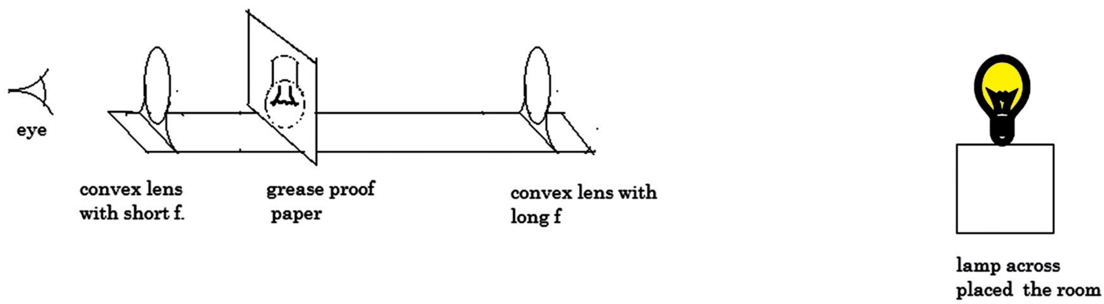


Figure 12.24: Telescope

What do you notice about the new image formed in terms of;
   a. Size
   b. Orientation (erect or inverted)
5. Use the arrangement to view other objects outside through the window.
6. Discuss and write a light ray diagram for your telescope.

Feedback

A telescope uses two lenses to produce a magnified virtual image of very far objects, like hills, and the moon. First lens produce an image which is used as object of second lens. The second lens produces its own image of the first image. Figure 12.25 shows parts of telescope and its ray diagram.

Functions of parts of a telescope

1. *Objective lens.* Used to produce a real, inverted and diminished image of a distant object at the position of focal point, F_o, inside the barrel of the

telescope.

2. *Eyepiece lens.* Used to produce second image using first image I_o, from objective lens as its object. The object produced by the eye piece lensis virtual, magnified and erect with respect to its object I_o, but inverted with respect to original object.

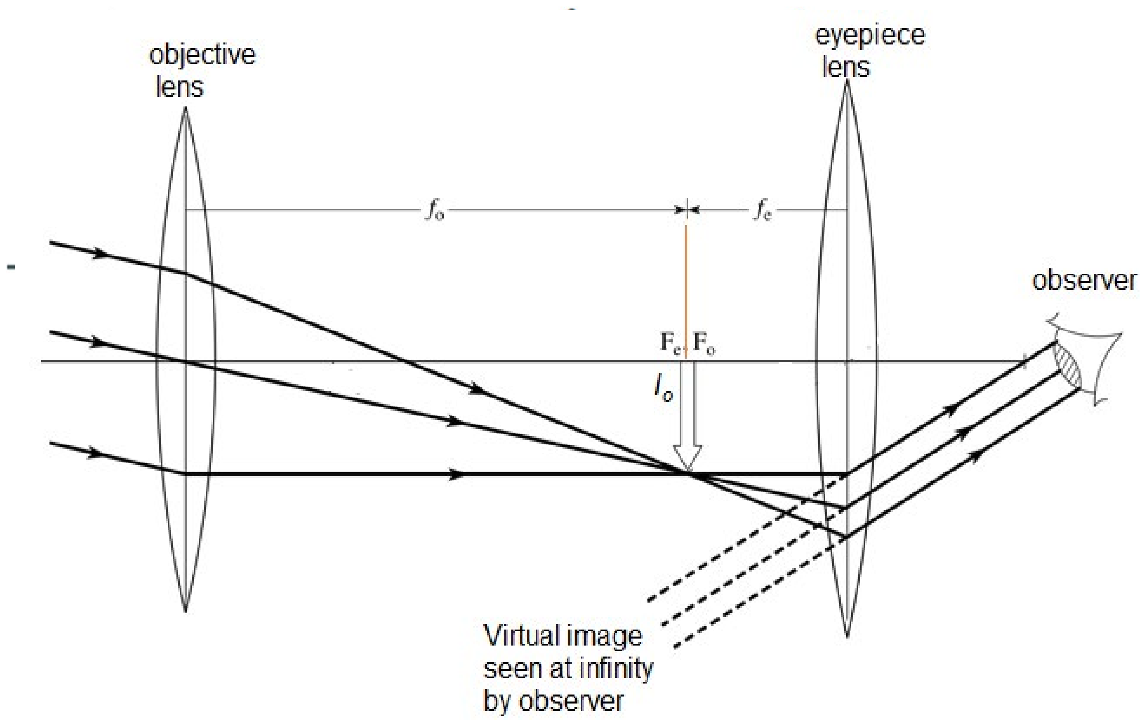


Figure 18.23 Parts of a telescope

To get maximum magnification, the distance between the two lenses are adjusted in such a way that the focal point of objective lens, F_o coincide with the focal point of eye piece lens F_e, as shown in figure 12.23. The telescope is said to be in its normal adjustment, and the distance from the objective to eye piece lens makes the total length of the telescope. When the telescope is in the normal adjustment, the image forms at infinity. The magnification of such telescope is given by the formula

$$m = \frac{\text{focal length of objective lens}, f_o}{\text{focal length of eye piece lens}, f_e}$$

.

Magnification is larger when objective focal length f_o ,is large and eye piece focal length f_e is smaller.

The image can be made smaller and closer by reducing distance between the two lenses.

Project: Making a telescope

In this project you will make your own telescope that you can use to view distant objects in and out doors.

Materials

- A lens with long focal length (30 to 50cm)
- A lens with short focal length (5cm)
- Two cardboard tubes (one can slide in and out of the other)
- Thick cardboard paper
- Scissors, p
- Pencil
- Razor knife
- Glue or cello tape.

Procedure

1. Get or make two cardboard tubes that can slide in and out of the other.
2. Mount one lens on the end of one tube and the other on the end of the other tube. Use the following steps:
   a. Put the lens down on a square of thick or corrugated cardboard and use the pencil to draw a line around the lens. Make one for each lens.
   b. Using the razor blade or knife cut a circle made with pencil. Make the whole slightly smaller than the lens.
   c. Place the lens into the cardboard hole so that it fits. If it does not, use the glue or cello tape. Wait for glue to dry.
   d. Use the pair of scissors to strip the cardboard ring so that it is same diameter as the tube so that it can be inserted and fit the tube.

3. Insert one tube into the other and slide them in and out to find the focus as shown in figure 12.24 below.

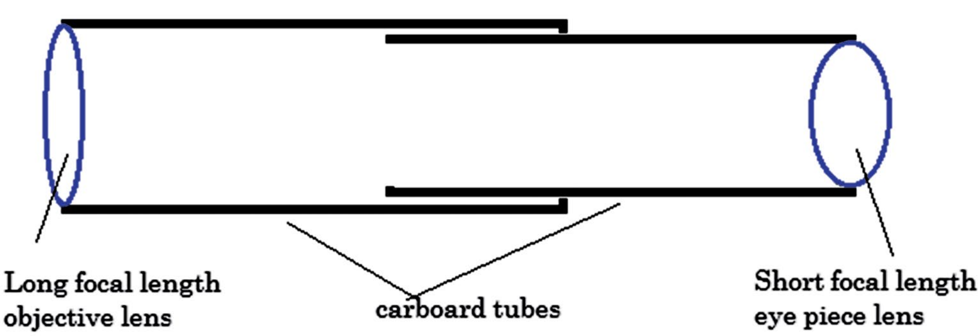


Figure 12.26: Making simple telescope

4. Use your telescope to view distant objects. Do not use it to view the sun, for you can damage your eyes. Store it properly after use.

Image formation in the human eye

The eye is an organ in the body that uses light to achieve vision. The eye forms images of objects that are both far and near. How does the eye work to achieve vision? What are the similarities and differences between the eye and the camera? A closer look at the camera and the eye model can help you to answer such questions. In activity 12.8 you will learn about how the eye works.

Activity 12.8

Explaining image formation in the human eye

Materials.

- pencils
- erasers
- charts
- models of the eye

Method

1. Look in the eyes of your classmate and discuss the parts that you can see from the front. Discuss functions of the parts.
2. Look at the eye model in and out and discuss the parts you can see and their functions. (Dismantle the model carefully to see parts inside).
3. On a piece of paper draw the major parts of the eye.
4. Discuss how the eye works to form images compared to a camera.

Feedback

Just like a camera, the eye uses a convex lens to focus images of objects in front of it on the retina. Figure 12.28 shows the major parts of the human eye and how it brings about vision.

1. Light from object enters the eye through the transparent cornea and the pupil. The cornea helps to refract light (due to its convex shape) towards the eye lens.
2. The eye lens is a convex lens that refracts light from object and focuses it on the retina forming a real, diminished inverted image. The aqueous and vitreous humor also takes part in refracting light towards the retina.
3. The retina is a surface with light sensitive cells that send image information inform of electric signals to the brain through optic nerve.
4. Optic nerve sends image information inform of electric impulses to the

brain which interprets the information from the image.

Iris is a circular muscle that controls amount of light entering the eye

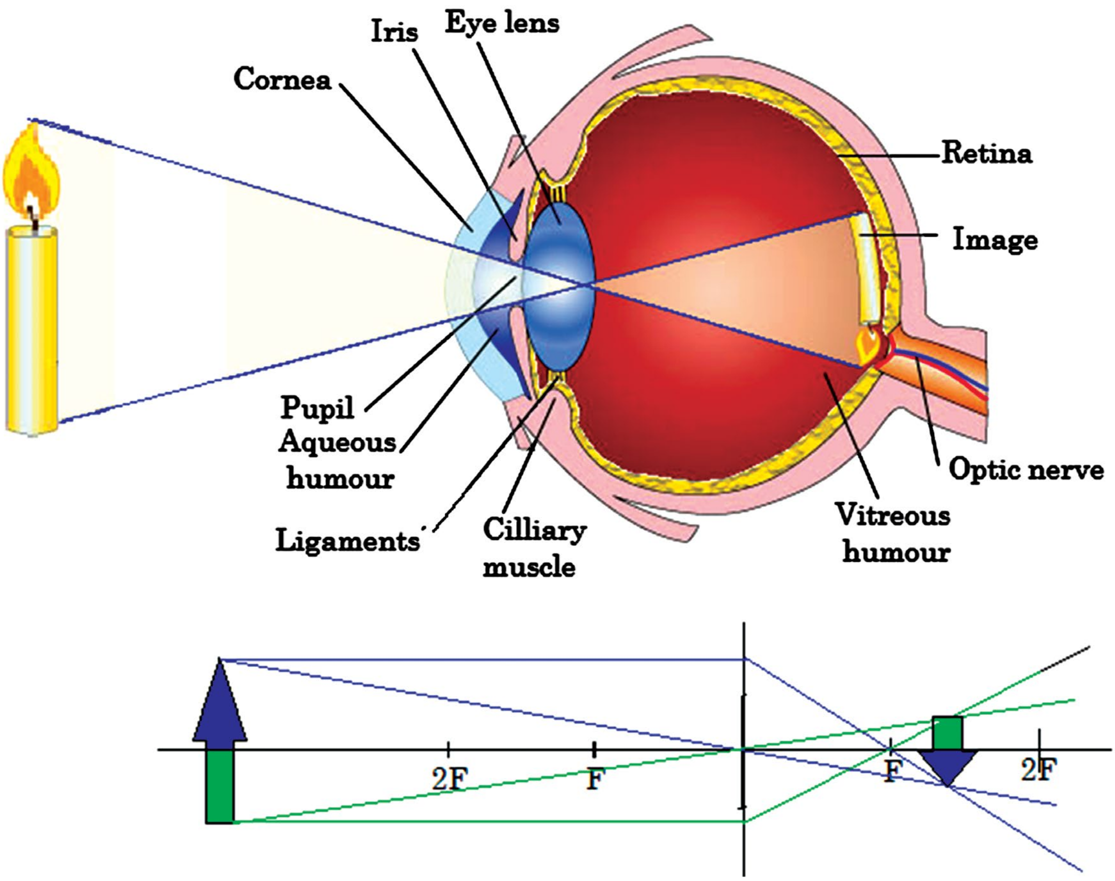
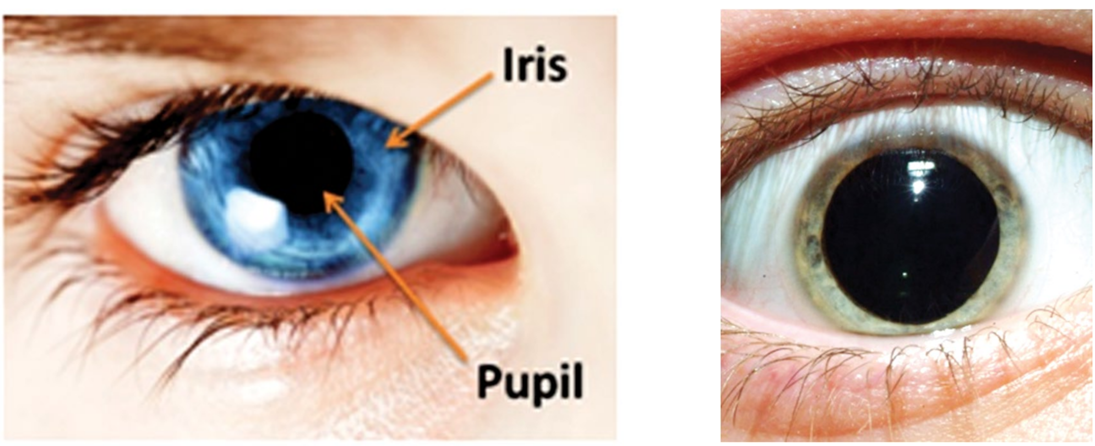


Figure 12.28: Parts of a human eye



a) Pupil size in normal light (b) Pupil size in dim light

Figure 12.29: Action of iris

by changing size of the retina. On a bright day, the iris reduces size (See figure 12.26) of aperture to avoid too much light to reach and damage light sensitive cells on the retina. In dull light the size of pupil is increased to allow enough light to pass through.

The image distance between the eye lens and the retina stays the same inside the eye. Focusing of image is done by changingthe focal length of the eye lens using ciliary muscles that change the shape of the lens. A distant object is focused by making the lens thin (long focal length) when ciliary muscles relax. A near object is focused by making the eye lens thick (short focal length), as shown in figure12. 27. The process of adjusting the shape of the eye lens to focus images of objects at different distances is called accommodation of the eye. When an object become too close (less than 25cm), the ciliary muscles fail to squeeze the lens any further and object looks blurred.

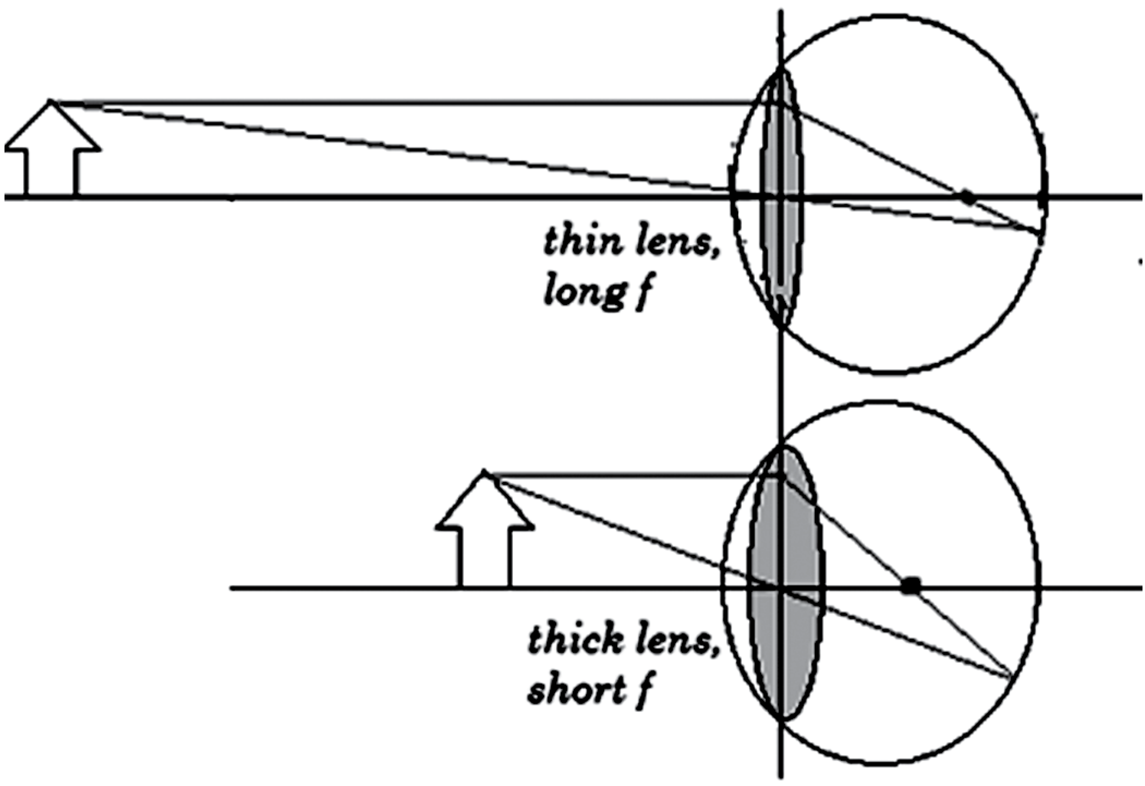


Figure 12.30: Accommodation of the eye

Similarities and differences between the eye and the camera

Similarities	Differences
1. Both use convex lenses to refract and focus a real, diminished and inverted image on a surface (retina/film).	1. Eye lens can change shape while camera lens cannot.
2. Both uses an opening (pupil/aperture) as a passage of light into the inside.	2. Eye lens is located in front of iris while camera lens is located behind the lens.
3. Both control amount of light entering by changing size of the hole (pupil/aperture) using iris in the eye and iris diaphragm in the camera.	3. Eye does not change image distance while camera can change image distance using adjusting screws
4. Both have a light sensitive surface (retina/film) where image forms.	4. Eye exposure to light from outside is continuous as long as the eye is open while in the camera light is allowed to reach the retina only when the shutter opens

Visual defects in the human eye

A normal eye can clearly focus images of objects at infinity and as close as 25cm using accommodation process; changing shape of the eye. The longest distance is called far point while the smallest distance is called near point of the eye. Some people have eyes that have problems to change shape of the eye lens and so they have eye defects. The common eye defects are short sight and long sight.

Short sight (myopia)

A person with short sight can focus and see near objects clearly but has problems to focus distant objects so that they look blurred. This is a result of either an eye ball that is too long or the lens is too strong (focal length is mostly too short). In this case the image of a distant object forms a distance before the retina as shown in figure 12.31(a).

The defect is corrected by wearing spectacles with concave (diverging) lens.

The lens diverge the light rays outwards, before the eye refracts it towards the retina as shown in figure 12.31 (a)

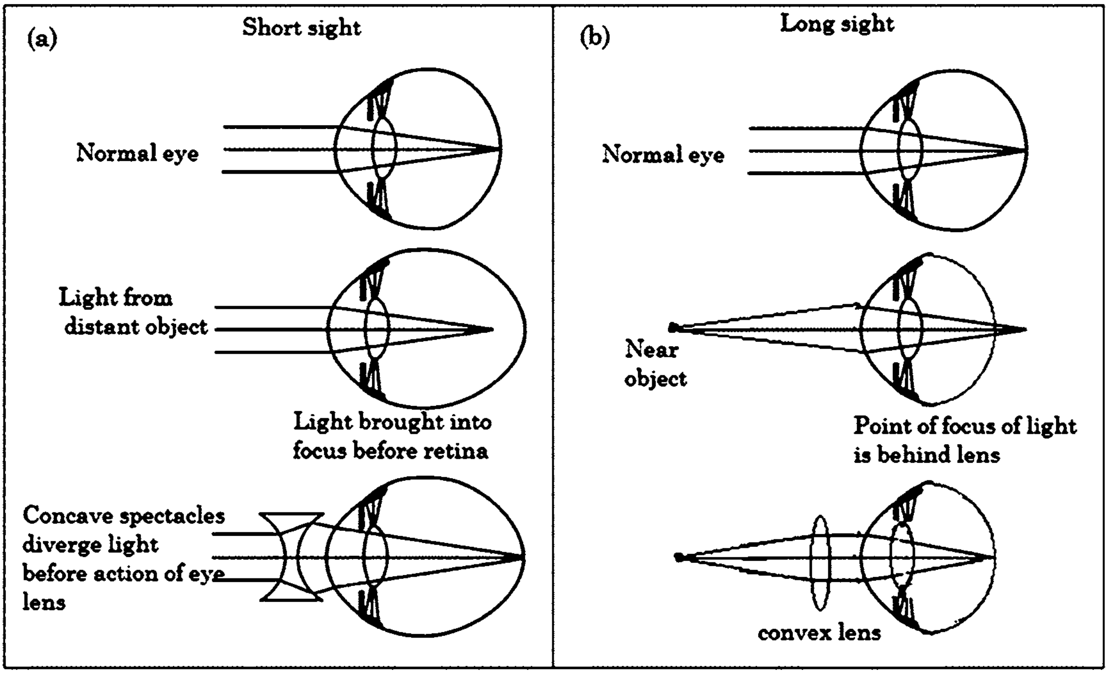


Figure 12.31: Eye defects.

Long sight (hypermetropia)

A long sighted person can focus and see distant objects clearly, but has problems to focus near objects. This can either be because of eye ball being too short or a weak lens (fails to make the eyes lens thick). In this case the focus point of image of a near object is behind the retina as shown in figure 12.31 (b).

To correct long sight, convex lenses are used as shown in figure 12.31(b) The convex lens converge the light rays before eye lens and cornea converge them. These two combined actions bring the light rays into focus on the retina.

Exercise 12.4

1. Name optical instruments that are used for the following:
    a. Taking pictures to make photographs.
    b. To see very objects.
    c. To show pictures on a wide screen.
2. Name three parts of the eye that take part in refracting light towards the retina.

3. Which parts of the eye perform the following functions:
   a. Change focal length of the lens.
   b. Controls amount of light entering the eye.
   c. Send electric impulses to the brain.
4. In a film or slide projector
   a. What is the function of the following in a slide projector?
      i. Curved mirror
      ii. Objective lens.
   b. Why are pictures put in an upside down position?

Unit Summary

- A converging lens is a convex lens that refracts light rays closer together while a diverging lens is a concave lens that refracts light rays away from each other.
- Focal length of a lens is the distance from the lens to the image of a distant object. On the ray diagram it is the distance from the lens to the focal point. The focal length of convex lens is positive while focal length of negative lens is negative.
- Position of image can be found using light ray diagrams. The magnification

  $$m = \frac{h_2}{h_1}$$

  where h_1 is object height and h_2 is image height.
- The lens formula is

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

  where f is focal length, u is object distance and v is image distance. The magnification

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

.

- Action of lenses to light is used in many optical instruments like camera, telescope and film projector. The eye also uses lens to achieve vision
- The eye works as a camera where the image of an object placed in front is made by refracting light and bring it into focus using convex lens.
- Short sight and long sight are common eye defects which are corrected using diverging and converging lens spectacles, respectively.

End of unit review exercise

1. State whether the following statements are true or false
   a. Distance from lens to object affects position of image.

b. There is only one position where a sharp and clear image is formed by a lens.
c. Only virtual images are erect.
d. Virtual images are never diminished.
e. A diminished image forms when object is placed at any distance less than focal length, f from the lens.

2. What changes occur in both the eye and camera under the following situations:
   a. Object changes position from near to far distance.
   b. Changing from dull to bright light.
   c. Object changes size from bigger to smaller.

3. A bank teller has problems to read what a client has written on a cheque deposit slip even at near point of the eye.
   a. What eye defect is the bank teller having?
   b. Sketch a ray diagram of the eye to illustrate how light is moving in the eyes of the bank teller.
   c. Suggest two likely causes of the problem.
   d. With aid of diagram explain how the situation could be corrected.

4. Parallel rays from a distant object are incident on a convex lens as shown in figure12.29. Which position represents
   a. Focal point of the lens.
   b. Image position.
   c. Focal length of the lens.

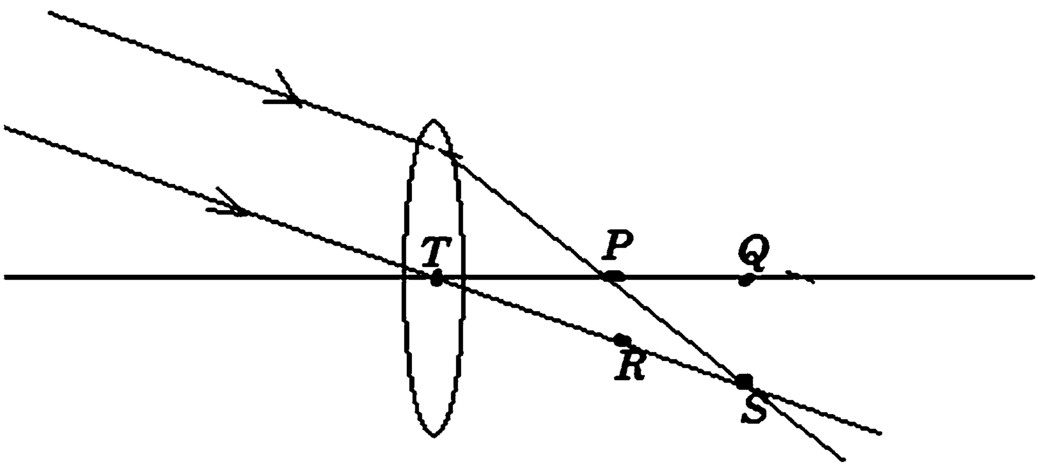


Figure 12.29

5. Find the image position, magnification and nature of image using lens formula in the following situation
   a. Object distance is 16cm while focal length is 12cm.
   b. Object distance is 8cm while focal length is 12cm.
   c. Object distance is 2m while focal length is -50cm.

6. Copy and draw light ray diagrams shown in figure12.28 to illustrate formation of image for object 1 and 2 standing at different positions to the lens

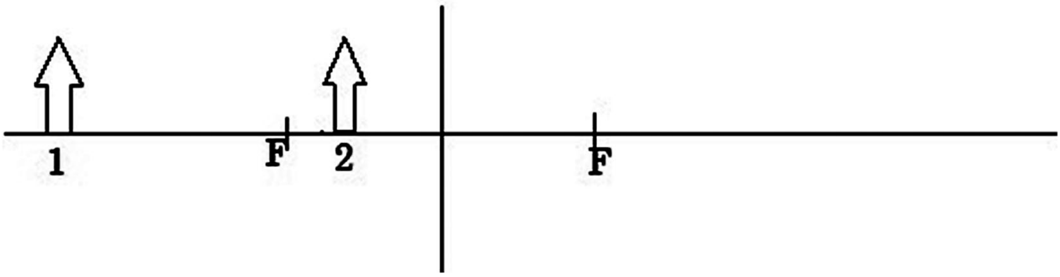


Figure 12.28

7. A slide projector had an objective lens of focal length20cm. A slide is placed 25cm from the lens in the projector. Use scale drawing to find;
   a. Position and size of image is object is 2cm tall.
   b. Magnification of image.
8. A camera lens focuses image of an object 3cm tall on the screen that is 12cm from the lens. If the object distance is 24cm, work out;
   a. Focal length of the lens
   b. Magnification of image
   c. Height of image

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UNIT 13

J.J. Thomson discovered that neon ions were not deflected with the same angle when passed through magnetic field. From then on, it has been known that not all atoms of the same element are identical. Such atoms are called isotopes. In this unit you will learn to describe isotopes using nuclear structure of atoms.

Isotopes

Nuclear structure of an atom

All atoms consist of protons and neutrons in the nucleus (together called nucleons) and electrons in the shells. Their numbers relative to each other can create effects that can be both useful and hazardous. In the activity 13.1 you will focus on learning the structure of the atom.

Activity 13.1

Describing the nuclear structure of an atom

Materials
- Periodic tables
- Charts
- Pental markers

Method
1. Discuss and name three types of particles found in an atom and where they are found.
2. Look at Hydrogen in the periodic table and discuss what the following stand for;
   a. Atomic number
   b. Atomic mass
3. Fill the table below by showing numbers of protons, neutrons and electrons, for the atoms with following atomic numbers and atomic masses.

Element	Atomic number	Atomic mass	Number of protons	Number of neutrons	Number of electrons
Helium	2	4			
Carbon	6	12			
Sodium	11	23			

5. Draw on a chart the atomic structures for the atoms in the table above using circles to represent the subatomic particles.

Feedback

Atoms are constituent particles of all matter. Atoms themselves consist of smaller particles namely protons, neutrons and electrons.

Protons and neutrons are found at the centre of the atom called nucleus and together they are called *nucleons*. The mass of each proton is nearly the same as that of neutron. In kilograms the mass of each proton and neutron is 1.66×10^{-27} *kg*. This is a very small number and difficult to deal with. The mass of such very small particles is measured in their own units called *atomic mass units, amu* where 1*amu* = 1.66×10^{-27} *kg*. In these units each proton and neutron has a mass of 1*amu*.

The mass of an electron is about 2000 times smaller than of a proton or neutron. Their contribution to mass of atoms is therefore negligible. In a neutral atom the number of electrons is always equal to the number of protons.

Atomic number, Z is the number of protons inside the nucleus of an atom. This number is very important because it is the identity of an atom. Atoms with $Z=6$ are carbon atoms. All atoms with $Z= 17$ are chlorine atoms. Each proton has a charge of 1.60×10^{-19}*Coulombs* (*C*). Again this is also a number that is difficult to deal with. To simplify, $1.60 \times 10^{-19}C$ of charge is taken as 1. In this case the charge on one proton is 1. The charge found in the nucleus comes from protons only so that in a way the atomic number Z shows the amount of charge in the nucleus. An electron has the same amount of charge which is opposite to that of a proton. The charge on an electron is therefore -1.

The mass, type of charge and amount of charge are as shown in table below:

Type of subatomic particle	**Mass on one particle (amu)**	**Charge on one particle**
Proton	1	+1
Neutron	1	0
Electron	1/2000	-1

The number of neutrons in the nucleus of atom is presented using letter, *N* called neutron number. The neutron number of one type of atom may vary, unlike Z which is always the same. Neutrons have zero charge hence the major influence of neutrons is the atomic mass.

Atomic mass (*A)* is the sum of neutrons and protons inside the nucleus of an atom, measured in *amu*. $A = Z + N$.

Atoms in the periodic table are usually represented using atomic number and atomic mass. For example the atoms of helium, carbon and sodium could be presented as

$$^{4}_{2}He\ ,\ ^{12}_{6}C \text{ and } ^{23}_{11}Na$$

The superscript shows atomic mass while the subscript shows atomic number and indeed the nuclear charge. Similarly individual particles can be presented using the similar notation,

$$^{1}_{0}n \text{ for neutron, } ^{1}_{1}p \text{ for proton and } ^{0}_{-1}e \text{ for electrons.}$$

The atomic structure for helium and sodium are as shown in figure 13.1 below.

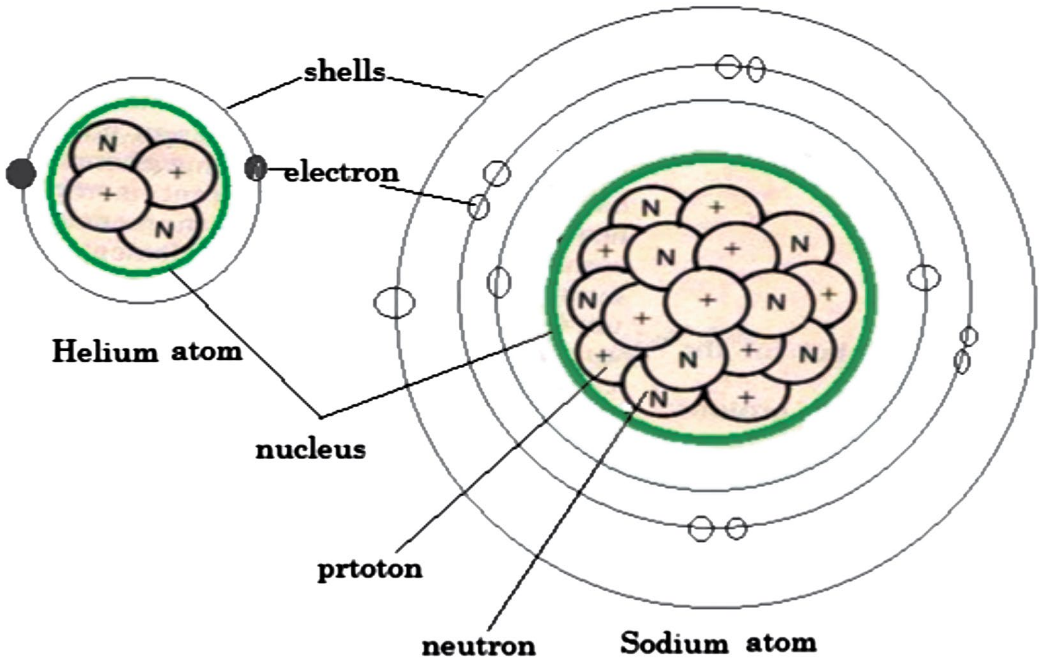

Figure 13.1 Atomic structures of helium and sodium

Key point
Particles inside the nucleus of an atom are referred to as nucleons namely
- Neutrons whose number is N
- Protons whose number is Z

Atomic mass A = N + Z

Isotopes

Not all atoms of the same element are identical. In this section you will be introduced to the concept of isotopes. Do activity 13.2 to learn how to describe isotopes.

Activity 13.2

Describing isotopes

Materials

- Periodic table

Method

1. Study the diagrams in figure 13.2 below which represent nucleons.

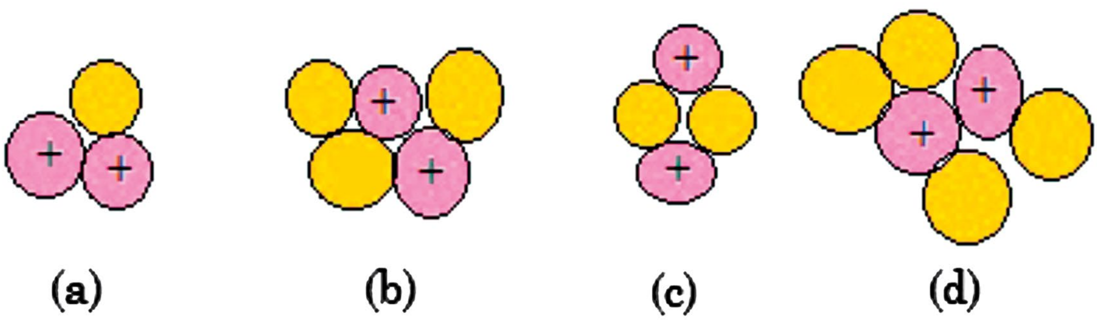

Figure 13.2

a. Write the atomic number Z and atomic mass A for each nucleus.
b. What number is used to identify the type of atom.
c. Identify each of these atoms from the periodic table.
d. These are isotopes. Describe isotopes from you observation.

Feedback

Isotopes are atoms of the same element (because they have the same number of protons), with different mass numbers due to different number of neutrons in the nucleus. In the activity above, all the atoms have 2 protons but their nucleon (mass) number varies due to different numbers of neutrons.

The following are examples of isotopes;

Element	Nuclide notation of isotope	Name of isotope
Chlorine	${}^{35}_{17}Cl$	Chlorine- 35 (Cl-35)
	${}^{37}_{17}Cl$	Chlorine-37 (Cl-37)
Oxygen	${}^{16}_{8}O$	Oxygen -16 (O-16)
	${}^{17}_{8}O$	Oxygen-17 (O-17)
	${}^{18}_{8}O$	Oxygen-18 (O-18)
Hydrogen	${}^{1}_{1}H$	Hydrogen-1 (H-1)
	${}^{2}_{1}H$	Hydrogen-2 or deuterium (H-2)
	${}^{3}_{1}H$	Hydrogen-3 or tritium (H-3)
Carbon	${}^{12}_{6}C$	Carbon-12 (C-12)
	${}^{13}_{6}C$	Carbon-13 (C-13)
	${}^{14}_{6}C$	Carbon-14 (C-14)

Most elements exist as isotopes. So far 117 elements are well known but out of these there are over 3, 100 well known different isotopes that have been identified. Most of them are artificially produced and very few exist naturally. Isotopes are identified by their mass number as shown in the table above.

The atomic mass of an element is the average atomic mass of its isotopes which is calculated taking care of their proportions in a sample. For example, the average atomic mass of isotopes of chlorine-35 and chlorine-37 which in any sample exist in the proportion of 4:1 is 35.5.

Isotopes have the same chemical properties because they have the same number and configuration of electrons. Since they have different nucleon numbers, their nuclear properties are also different. For example as it will be discussed in the next section uranium-235 are used in nuclear plants but uranium-238 are not.

Key point

Isotopes are atoms with same atomic number but different mass numbers due to difference in their number of neutrons in nucleus.

Unit Summary

- Atoms consist of protons and neutrons in the nucleus and electrons in the shells.
- Protons and neutrons together are called nucleons.
- Atomic number is number of protons in the nucleus designated as Z.
- Atomic mass is the sum of nucleons designated as A.
- Each form of element is called a nuclide.
- Isotopes are nuclides with same atomic number Z but different mass numbers A due to difference in number of neutrons.
- Isotopes are identified by their nucleon or mass number.
- Isotopes have same chemical properties but different nuclear properties.

End of unit review exercise

1. Which particle or particles inside an atom ;
   a. Is too light to be considered as part of atomic mass
   b. Is neutral
   c. Has a charge of -1
   d. Are nucleons
   e. Is $^{1}_{0}n$
   f. Is found in shells
2. How many neutrons, protons and electrons are in each of the following.
   a. $^{222}_{86}Rn$.
   b. $^{59}_{27}Co$
   c. $^{208}_{82}Pb$
   d. $^{19}_{9}F$
   e. $^{221}_{88}Ra$
3. Draw a diagram to represent atomic structure of the following
   a. $^{12}_{6}C$
   b. $^{7}_{3}Li$
   c. $^{6}_{3}Li$
4. The three naturally occurring isotopes of oxygen are $^{16}_{8}O, ^{17}_{8}O, and\ ^{18}_{8}O$. The atomic mass of oxygen is 12.01amu which of the isotopes is the most common in oxygen samples.

References

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UNIT 14

Protons and neutrons are found inside the nucleus. Amazing effects happen from the nucleus. Some of the effects happen naturally while some can be initiated. Most of the effects involve energy and particles that are emitted when nucleus disintegrate. This is called radioactivity. In this unit you will learn to explain radioactivity and describe radioactive emissions. You will also discuss dangers and applications of radioactivity.

Radioactivity

Stable and unstable nuclei

What keeps protons together inside the nucleus despite the fact that they have like charges. This is the immediate question that can explain the concept of radioactivity.

Activity 14.1

Discussing stability of nuclei

Materials

- Pen
- Paper

Method.

1. Discuss types of forces that you know.
2. Discuss which of the forces are attractive.
3. Discuss the law of forces between charges.
4. Discuss why protons do not move away from nucleus due to repulsions between them.

Feedback

There are four basic forces in nature namely *gravity*, *electromagnetic* (electrostatic and magnetic) strong nuclear and the *weak nuclear force*. All these forces are attractive. For the sake of electrostatic force the law of charges state that like charges repel, unlike charges attract.

Protons actually repel each other so

strongly in the nucleus, but still hold together because of two reasons.

1. **Strong nuclear force**

   Strong nuclear force is a fourth basic attractive force that holds nucleons together. It is the strongest of all the four basic forces **but** act when particles are extremely close.

   The required distance for strong nuclear force to hold is equal to the diameter of a proton or neutron (in the order x $10^{-15}m$) beyond which the force becomes too weak to make them stick together. Isotopes whose atomic number is larger than 83 have nuclei that are unstable, because protons on one side are outside the effective range and in that case electromagnetic forces can influence particles to move apart.

2. **Relative number of neutrons and protons**
   Neutrons moderate repulsions among the protons by staying in between the protons. Neutrons also hold nucleons by taking part in strong meson exchange force as explained above.
   Too many or too few number of neutrons compared to protons creates unequal distribution of protons and tend make nucleus unstable. Figure 14.1 shows a graph showing stable and unstable nuclei dependent on the neutron to proton ratio.

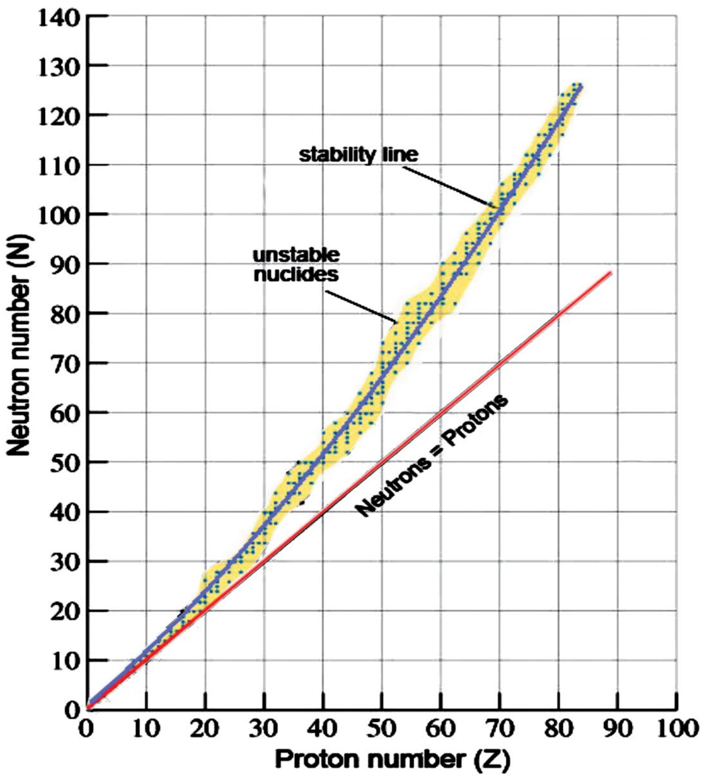


Figure 14.1: Stable and unstable nuclei

Notice that elements whose N = Z are mostly smaller atoms.

The strong nuclear force and the proper relative proportion of neutrons to protons create a strong force to overcome any mutual repulsion and make the nucleons to stay together. Above or below the stability line isotopes are unstable due to poor neutron to protons ratio.

Radioactivity

What happens to nuclei that are unstable? This is the concept of radioactivity. Activity 14.2 will help you to explore the term radioactivity.

Key point

The strong nuclear force and the proper relative proportion of neutrons to protons create a strong force to overcome any mutual repulsion and hence make nucleons stay together.

When the neutron: proton ratio, (N:Z) is too high or too low, isotopes become unstable and can disintegrate to become stable.

The proper stability ratio is 1:1 for light isotopes (Z up to 20) and 1.5:1 for heavier isotopes.

Activity 14.2

Explaining radioactivity

Materials.

- Periodic table
- Pen
- Paper

Method.

1. Discuss what will happen to a nucleus that is unstable.
2. Study large periodic table and site elements that have been labelled as radioactive.
3. Find out from the library artificial ways of making stable nuclei to be unstable.

Feedback

Many isotopes have unstable nuclei which means they can naturally disintegrate spontaneously. Such nuclear disintegration ejects particles and waves called nuclear radiation. The disintegration of a nucleus to emit nuclear radiation is called radioactivity or nuclear decay. Isotopes with unstable nuclei are called radioisotopes.

Induced radioactivity is when a stable nucleus is made radioactive by exposing the nucleus to specific radiation artificially. One example is a neutron bombarded into a nucleus of stable isotope in nuclear reactors. The neutron faces no repulsion so that it is captured into the nucleus. Once in the nucleus, the nucleon number changes and this disturbs both the neutron-proton proportion and the strong nuclear force which sometimes makes the nucleus unstable. For example, the stable Cobalt-59 becomes radioactive Cobalt-60 under neutron bombardment.

Radioactive emissions

Nuclear disintegration of unstable nuclei ejects particles and energy. Activity 4.3will help you to describe particles and energy emitted from disintegrated nuclei.

Activity 14.3

Describing radioactive emissions

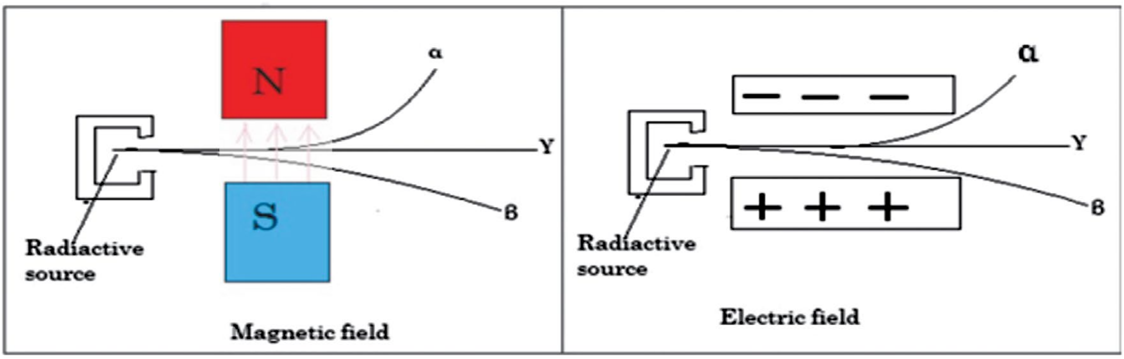
Materials
- Charts
- Radioactive sources (standardised)
- Geiger-Muller tubes
- Ratemeters (counters)

Method
1. Find out the type of particles or energy that are ejected when a nucleus disintegrates.
   a. Discuss the differences in properties between these ejected particles.
2. Find out and discuss ways used to detect radioactive emissions.
3. Use the Geiger-Muller tube to measure radiations from a radioactive source.
   a. In what units are the measurements?
   b. What do the units tell you about nuclear emissions?
   c. Will radiations from the source be constant forever?
4. Find out and discuss the difference between Fission and fusion

Feedback
There are three major types of nuclear radiations namely alpha (α), beta (ß) particles and gamma (γ) rays. These differ in terms or their form, penetrating power, ionising effects, and effect of electric and magnetic field on them. The table below shows some of these differences. Figure 14.2 shows differences in penetration and deflection in magnetic and electric field.

	Alpha (α)	**beta (β)**	**gamma (γ) rays**
Form	• Massive. • Has 2 protons and 2 neutrons like a helium ion, He+2 • Positively charged	• Light • Like an electron, e-1 • Negatively charged	• Electromagnetic wave. • Has no charge

Range	• Few centimetres in air	• Some metres in air	• Long distance even Km
Ionising effect	• Very strong	• Weak	• Very weak
Penetration	• Weak. Stopped by skin and thick sheet of paper	• Considerable. Stopped by few mm of metal	• Very strong. Can be weakened by lead metal and thick concrete
In magnetic field	• Deflected	• Deflected	• Not deflected
In electric field	• Deflected towards negative	• Deflected towards positive	• Not deflected



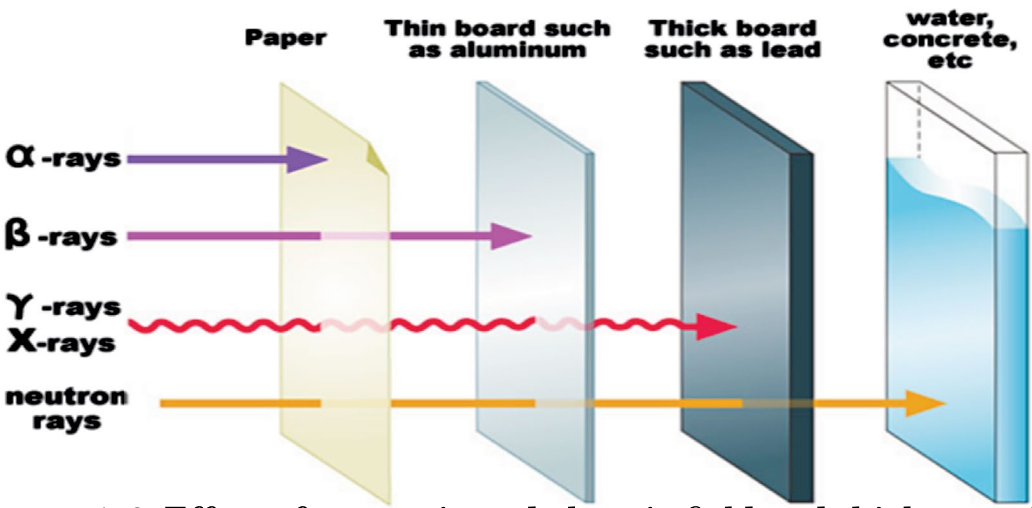


Figure14. 2: Effect of magnetic and electric field and thickness of material on nuclear radiations.

Ionising effect

When nuclear radiations pass through matter they may knock off electrons or break molecules apart making them become charged. As shown in the table, the alpha particles are most ionising. This effect is important especially in Geiger-Muller tube and spark counter which are devices used to detect and measure the amount of radiation.

(a) Geiger Muller tube

When radiation enters the tube as shown in figure 14.3, the argon gas inside it is ionised into positive and negative charges. The negative electrons go to anode while the positive charges go to cathode and in the process a small electric current passes through the circuit. The meter detects the electric signal each time a nucleus disintegrates.

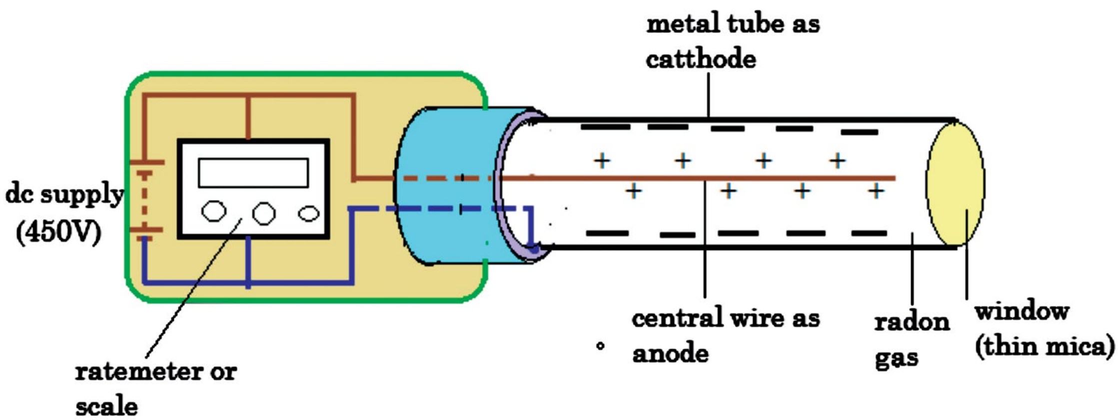


Figure 14.3: Geiger Muller tube

If a rate meter is used it will register the average number of nuclear disintegrations in 1 second, called *activity* measured in Becquerel (Bq). 1 Bq equals 1 disintegration per second.

If a scaler is used, the total number of electric signals representing the number of particles passing into the tube is registered from start to the end of recording.

The other devices that can detect radiations include photographic films, electroscopes, and cloud chambers.

(b) Electroscope

When a source of nuclear radiation is put close to a charged gold leaf electroscope, it discharges because the radiations ionise the air molecules above the cap of the electroscope. Figure 14.4 shows a gold leaf electroscope that can be discharged by radiations.

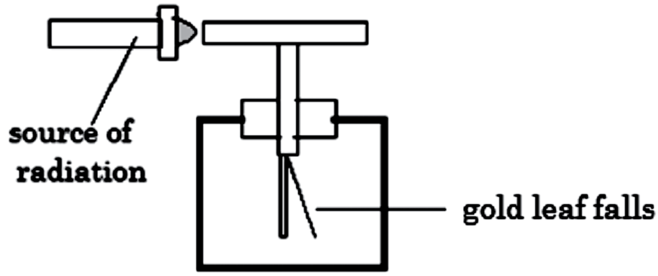


Figure 14.4: Gold leaf electroscope.

A flame put near top of the cap has same effect. These charged air molecules discharge the electroscope.

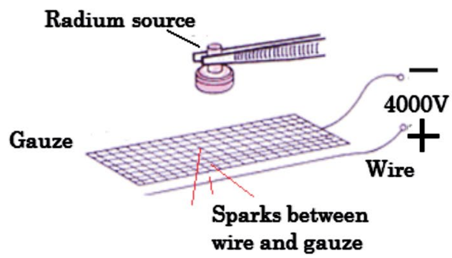


Figure 14.5: Spark counter

(c)Spark counter

Figure 14.5 shows a spark counter. It is made of wire gauze placed above a single wire, connected to high voltage. When switched on, no current passes across the gap between the gauze and the wire due to open circuit. When a source of radiation is put close to the wire gauze, while the switch is on, sparks are seen. This is so because, air in between is ionised and give sparks as they cross the gap. The spark counter can also be connected to meters to show rate of nuclear disintegration.

(d) Photographic film badge

A nurse working in a radiotherapy room puts on a film badge to monitor nuclear radiations as illustrated in figure 14.6.. When the film is exposed to nuclear radiation the colour of the film in the badge becomes darker. In some badges the actual amount of exposure to radiation is registered.

Figure 14.6: Film badge to monitor occupational nuclear radiation

Types of radioactive decay

The nuclei of unstable radioactive isotopes become stable by emitting nuclear radiations. These change the nucleon number. In the process the atomic number changes, which changes name of atom. There are so many ways of nuclear decay but the following three are explained.

Alpha decay

In this type of decay an alpha particle is lost from nucleus. This means the nucleus loses 2 protons and 2 neutrons. The atomic number reduces by 2 while the atomic mass reduces by four. For example radon-226 is radioactive and decay by alpha. The process is

$$\frac{226}{88}Ra - \frac{4}{2}a \longrightarrow \frac{226}{86}Rn$$

An atom with atomic number of 86 is radon, Rn.

Rearranging the equation gives

$$\frac{226}{88}Ra \longrightarrow \frac{226}{86}Rn + \frac{4}{2}$$

In this equation $\frac{226}{88}Ra$ is parent nucleus, $\frac{226}{86}Rn$ is daughter nucleus, $\frac{4}{2}a$ is nuclear radiation.The daughter nucleus and the nuclear radiation together are called decay products.

Notice that the equation shows conservation of both mass and charge. The total number of charge (subscript) and mass (superscript) are equal before and after the process.

Beta decay

During alpha decay, a neutron changes into an electron (a beta particle) and a proton. This can be presented as

$$^{1}_{0}n \longrightarrow \ ^{1}_{1}p + \ ^{0}_{-1}e$$

Notice that mass and charge are both conserved in the equation.

The beta particle (the electron) is emitted but the new proton remains in the nucleus so that the atomic number increases by 1. The atomic mass remains the same. For example carbon-14 decays by beta. The nuclear equation for the process is

$$^{14}_{6}C \longrightarrow \ ^{14}_{7}N + \ ^{0}_{-1}\beta$$

The mass and charge are also conserved in the equation.

Note

- This process is reversible. A proton can combine with an electron to produce a neutron in a process called electron capture.
- In most cases the daughter nucleus from the alpha and beta decay is also radioactive so that it can decay into other isotopes, forming a decay chain, or series like one seen in the table below:

Table14: The radium series.

Element	Isotope	Half-Life	Type of decay
Radium	^{226}Ra	1622yrs	alpha
Radon	^{222}Rn	3.83days	alpha
Polonium	^{218}Po	3.05min	alpha
Lead	^{214}Pb	26.8min	beta
Bismuth	^{214}Bi	19.7min	beta
Polonium	^{214}Po	164µsec	alpha
Lead	^{210}Pb	19.4yr	beta
Bismuth	^{210}Bi	5.0days	beta
Polonium	^{210}Po	138.4days	alpha
Lead	^{206}Pb	stable	

Notice how the atomic mass changes from one isotope to the other to find type of decay.

Gamma Decay

Excited particles in the nucleus release gamma rays when they return to lower state. Gamma rays may also be emitted during alpha or beta decay as rearrangement of protons and neutrons occurs to form a daughter nucleus.

Since gamma rays have no mass and charge, gamma decay does not change atomic number and atomic mass.

Exercise 14. 1

1. Define the following terms
   a. Isotope
   b. Radioisotope
   c. Nuclear radiation
   d. Radioactivity
   e. activity
2. What type of nuclear radiation is the following;
   a. The most penetrating
   b. The least ionising
   c. Is an electromagnetic wave
   d. Is positive
   e. Is not deflected by magnetic field
3. Name any two devices that are used to detect the presence of nuclear radiations.
4. Give a difference between natural and induced radioactivity.
5. Use the periodic table to find the daughter nucleus of the following elements which decay by alpha.

   a. $^{224}_{92}U$

   b. $^{197}_{83}Bi$

6. Write the nuclear equation for beta decay of the following;

   a. $^{18}_{7}N$

   b. $^{131}_{53}I$

7. What type of decay is involved in the following and complete the equation by replacing the question mark with proper particle

   a. $^{254}_{100}Fm \longrightarrow ^{250}_{98}Cf + ?$

b. $^{233}_{90}Th \longrightarrow ^{233}_{91}Pa + ?$

c. $^{24}_{11}Na \longrightarrow$ _____ $+ ^{0}_{-1}\beta$

Half life of isotopes

The rate of radioactive decay of an isotope is difficult to establish because disintegrations happen spontaneously. The decay process cannot be influenced by changes in pressure or temperature or chemical changes making any prediction about rate difficult. Despite all this difficulty, it is a well- known fact that some isotopes are more unstable therefore, decay faster than others. The measure used to define the rate of decay of isotope is called its half life.

Half life is the time it takes for half nuclei present in a radioisotope sample to decay. The half lives of radioisotopes range from a small fraction of a second to billions of years as shown in table below.

Element	Isotope	Half life
Hydrogen	$^{3}_{1}H$	12.3yr
Helium	$^{5}_{2}He$	2×10^{-21s}
	$^{6}_{2}He$	0.805s
Carbon	$^{8}_{2}He$	0.119s
	$^{14}_{6}C$	5 730yr
	$^{15}_{6}C$	24s
Radon	$^{220}_{86}Rn$	52s
	$^{222}_{86}Rn$	3.8dy
Uranium	$^{232}_{92}U$	70yr
	$^{233}_{92}U$	159 000yr
	$^{234}_{92}U$	245 000yr
	$^{235}_{92}U$	704 000 000yr
	$^{236}_{92}U$	23 400 000yr
	$^{237}_{92}U$	6.75d
	$^{238}_{92}U$	4 470 000 000yr
	$^{238}_{92}U$	23.5min

The half life can also be defined in terms of activity. Activity is the average number of nuclear disintegrations per second, in Becquerel (Bq). Any radioactive sample will reduce its activity as more and more nuclei disintegrate. Half life is therefore the time taken for the activity of any given sample to reduce by half from its original value. Half lives can be presented on a decay curve as shown in figure 14.7. In this graph it takes 50minutes for activity to reduce by half so the half life is 50minutes

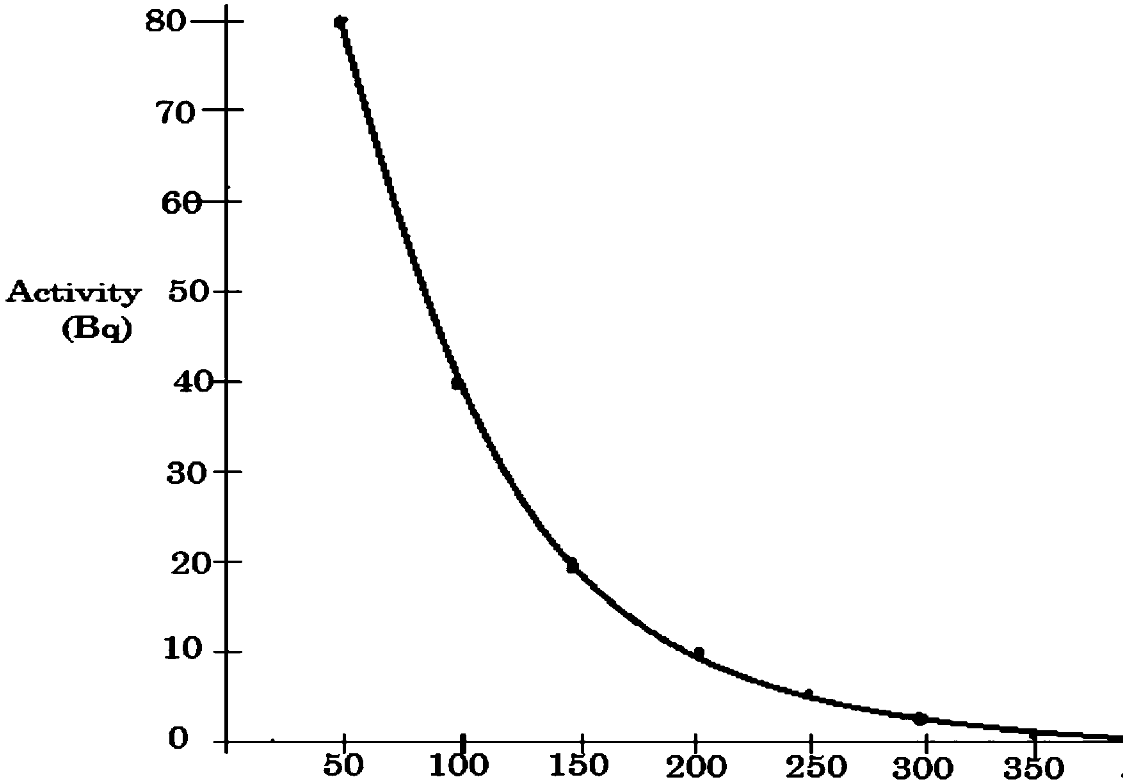


Figure 14.7: Radioactive decay curve.

Knowing about half of radioisotope is important. People can estimate to what time a sample will still be active or dead in terms of emitting radiations. This is important in medicine, agriculture and industry.

Example

An iodine isotope was found to have an activity of 200Bq. 75 minutes later the activity had reduced to 25 Bq. What is the half life of iodine?

Solution

The number of halves of activity from 200 to 25 are 200→100→50→25. There are 3 halves.

The half life is therefore

$$\frac{\textit{total times}}{\textit{number of halves}} = \frac{75min}{3} \quad 25min$$

Exercise 14.2
1. If a radioactive sample has a mass of 4g and its half life is 10days. How much mass of the sample will remain after 50 minutes?
2. A radioactive sample has a mass of 8kg and its half life is 5 years. For how long will it take the sample to reduce to 125g?
3. Radio activity of a radioisotope is found to be 32Bq.what will be the activity after 5 half lives?

Nuclear Fission and fusion

Nuclear Fission
Fission is the splitting of a large nucleus into smaller nuclei. This is commonly done by bombarding nuclei with neutrons, but other particles like alpha, protons, and gamma rays can also be used.

Example
Some isotopes of uranium-235 decay naturally, emitting neutrons with high speed. The emitted neutron hits other neighbouring nuclei and breaks them into two fission fragments. Three of the many possible fission reactions of U-235 are shown below.

$$\frac{235}{92}U + \frac{1}{0}\,n \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}\mathrm{n}$$

$$\frac{235}{92}U + \frac{1}{0}\,n \longrightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2\,{}^{1}_{0}\mathrm{n}$$

$$\frac{235}{92}U + \frac{1}{0}\,n \longrightarrow {}^{140}_{54}Ba + {}^{94}_{38}Kr + 2\,{}^{1}_{0}\mathrm{n}$$

Energy is released because the total mass of fission fragments and the neutrons is less than the mass of the original uranium-325 and stray neutron. The missing mass is converted mostly into kinetic energy of fission fragments. These high speed fragments collide with surrounding atoms raising their kinetic energy, hence increase the temperature.

Note
- Most fission fragments are also radioactive therefore they are dangerous nuclear waste as they emit more radiations.
- The neutron that is released as part of fission fragments can strike and split other U-235 nuclei and split them again, creating a chain

reaction as illustrated in figure 14.7.

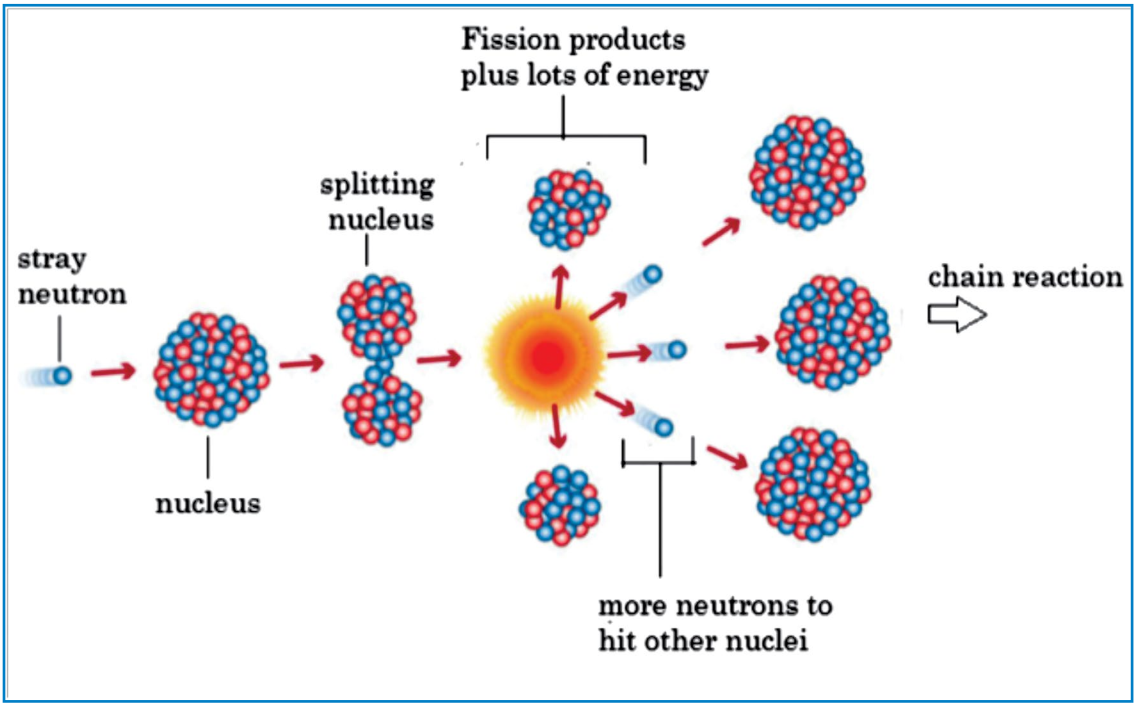


Figure 14.8: Chain reaction

If the number of neutrons from each fission is controlled, a stable chain reaction that releases energy at stable rate is achieved like what is done in nuclear power plants. If the number of stray neutrons are not controlled, unstable chain reaction occurs resulting into explosion, like what happens in atomic bombs.

Nuclear power plant

It is used to generate electricity. The nuclear reactor releases energy from nuclear fission. The rate is controlled by controlling stray neutrons that induce fission using water or carbon graphite core as moderators and control rods made of boron or cadmium. The rate of fission therefore becomes the rate of energy released. Figure 14.9 shows basic construction of a nuclear reactor.

- Moderator slows down fission neutrons.
- The boron rods absorb some of high speed neutrons. Inserting and withdrawing them can reduce or increase neutrons that go under fission.
- Carbon dioxide pumped into the core carries heat energy which is used to boil water to produce steam in the heat exchanger. The steam is used to drive turbines of dynamos hence generate electricity.

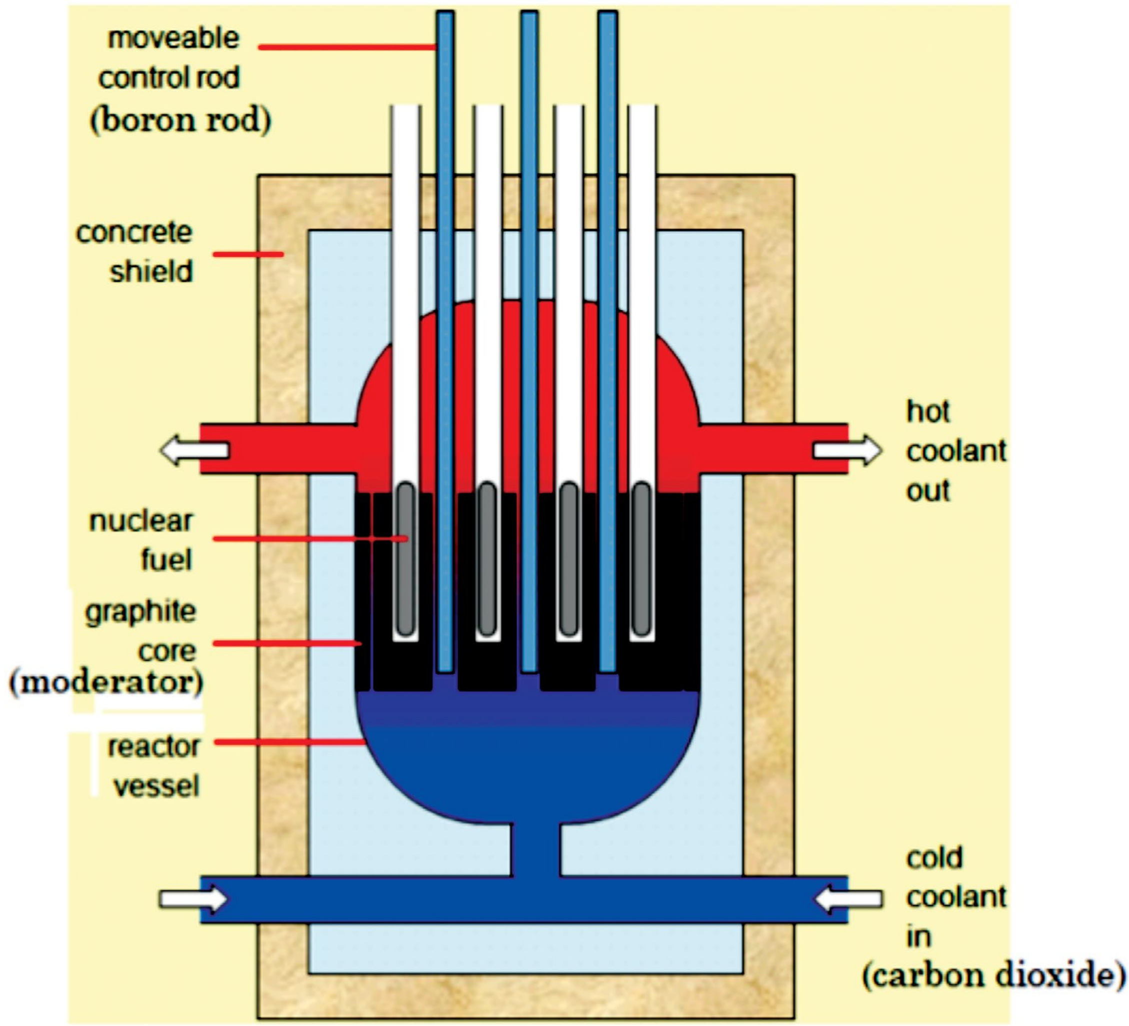


Figure 14.9: Basic parts of nuclear reactor

- The concrete shield protects from gamma as well as stray neutrons.
- The nuclear wastes include spent fuel rods which are highly radioactive. These are taken to reprocessing plants to remove unused fuels and plutonium fragments. The rest is sealed and stored in thick shielding and sent to long term storage sites, usually old underground mines.

Fusion

Fusion is the combining of two light nuclei to form a larger nucleus. This process releases energy and is an example of what happens to energy from the sun, stars and hydrogen bomb.

The equation below shows some fusion nuclear reactions:

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n + \gamma$$

$$^{1}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + \gamma$$

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n + \gamma$$

$$^{2}_{1}H + ^{3}_{2}H \longrightarrow ^{4}_{2}He + ^{1}_{1}p + \gamma$$

In each case, energy is released because the total mass of the nucleons after fission is less than the total mass before. The missing mass is converted into kinetic energy of new nucleus, proton or gamma ray.

Fusion is difficult because the repulsion between protons of two fusing atoms can only be overcome at very high temperatures of about 50 million degrees. At such high temperatures matter tends to be in plasma form which is difficult to contain under laboratory conditions. Fusion reaction produces the light that we get from the sun and stars.

Dangers and applications of radioactivity

Radioactivity has so many uses today owing to their high energies and ability to penetrate and ionise matter. Nuclear radiations have dangers too. In activity 14.4 you will learn about some of the applications and dangers of radioactivity.

Activity 14.4

Discussing dangers and applications of radioactivity

Materials
- Internet.
- Pens paper
- library

Method
1. Find out from internet and library the dangers of radioactivity and ways of minimising hazardous exposure.
2. Find out and discuss applications of radioactivity.

Feedback
Energies from nuclear radiations are too large therefore they cause ionisation (eject electrons from molecules or even break the molecule) as they pass through material

Most directly observable effects of radiation are:

1. **Cells fail to reproduce**
   - Damage is at molecular level therefore cells may continue to function in apparently normal fashion, without being noticed until the time the cell would fail to reproduce normally; 'cellular reproductive death'.
   - The exposure to ionising radiation produces no pain or other sensory response, but produces damage which shows up at a later date.
2. **Illness or death**
   - Organism dies when enough cells are prevented from reproduction.
3. **Cancer**
   - Radiation damage may disrupt the cell reproductive system so that an altered or 'mutated' cell results.
   - Most mutated cells would be destroyed by the body's defense mechanism but in some cases mutation is close enough to normality, therefore escape the body's defense mechanism, take in all nourishment, and reproduce rapidly without recognising bounds to its growth as do normal cells. This is called cancer.

Methods of safely handling and storing radioactive materials

Since radiation effects are hidden and lack sensation to exposure, extreme caution in the use of sources of ionising radiation is very important. Some of the measures onhow to minimise exposure to radiation are;
1. Increase your distance from the source.
2. Decrease time of exposure near the source.
3. Place shielding between you and the source.
4. Safely expose the nuclear waste. In industry the waste is sealed in concrete and steel containers which are buried in concrete bunkers. Under school laboratory conditions the collected radioactive waste is disposed as per the following guide lines depending on state of the waste.
   i. *Dilute and Disperse*. Liquid waste may be diluted first before disposal to weaken the radiations.
   ii. *Delay and Decay*. This involves weakening the radiations first

in a safe area by allowing it to naturally decay to safe levels of radiations, before it is disposed.

iii. *Concentrate and Contain*. In some cases all radioactive sources are collected together and sealed properly in safety well shielded containers before final disposal.

iv. *Incineration*.Small items like papers that have been used in nuclear experiments may just need to be burned.

Applications of radioactivity

Radioactive substances have so many uses today. Some of the uses are discussed below.

1. **Nuclear power generation**
As explained above, heat obtained from nuclear fission in a nuclear reactor is used to boil water. The steam produced run turbines of dynamo which generate electricity as seen in figure 14.10.

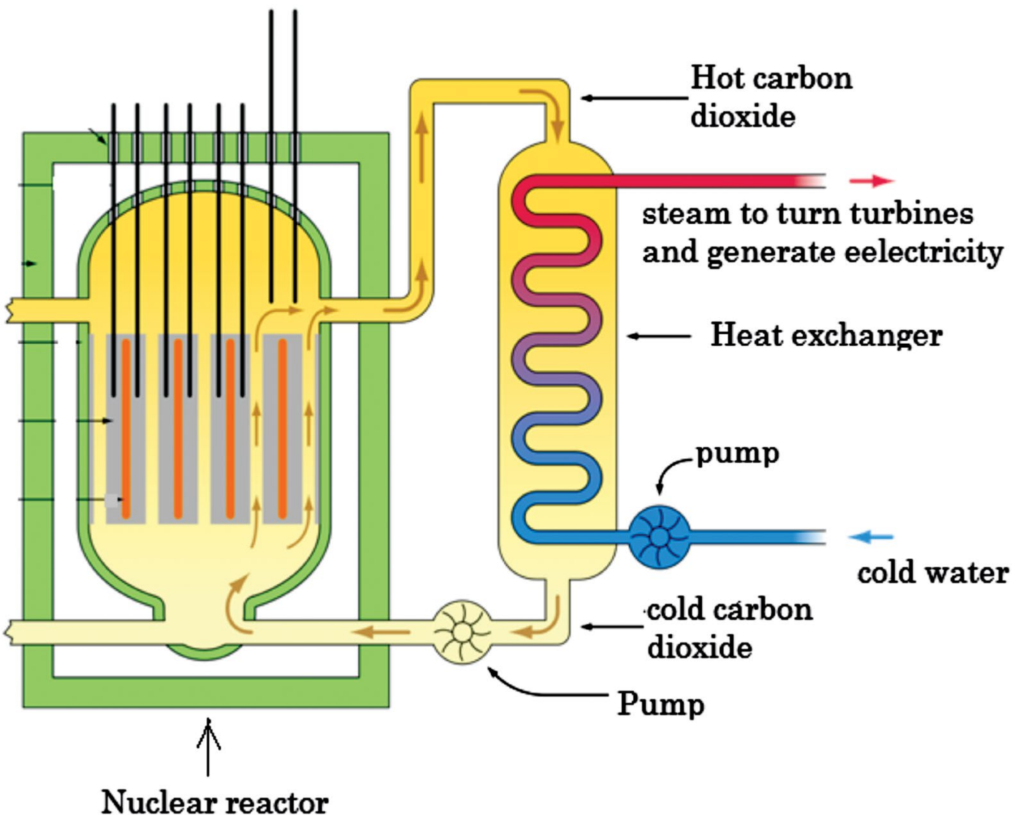


Figure 14.10: Nuclear power plant

2. **Agricultural**
The movement of a weak radioisotope can be monitored using radiation detector. This is called tracing. In agriculture uptake of fertiliser by plant from roots to leaves can be traced by introducing a radioisotope into the fertiliser or water in the soil.

3. **Industrial**
There are so many applications of nuclear radiations in industry.
   a. **Tracing**. Fluid flow in pipes can be measured by monitoring radiations from radioisotope injected into the fluid. Cracks in manufactured pipes can be traced in similar matter since a crack will show large amount of radiation escaping from it.
   b. **Thickness gauge**. When sheets like rubber, plastic and metal, thickness of the sheet is maintained by monitoring the changes in nuclear radiation that passes through it. Figure 14.11 Shows a thickness gauge being used

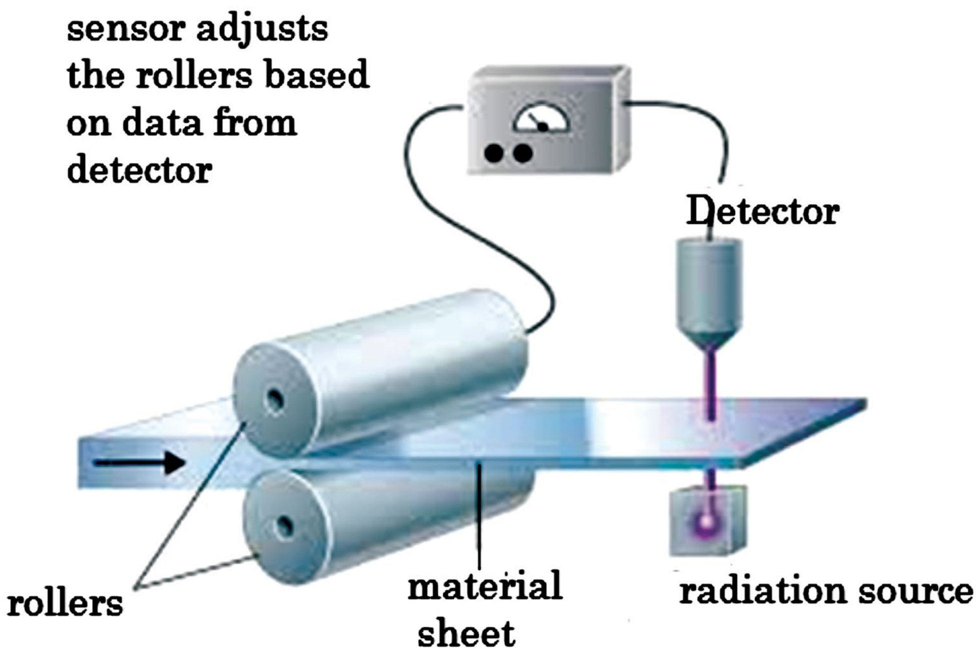


Figure 14.11: Thickness gauge

` The gamma or beta radiations pass through the sheet whose amount is detected on the other side. When thickness increases, the passing radiations reduce and the control unit adjusts making rollers come closer to get a required thickness.

c. **Packed food items.** These are irradiated with gamma rays to kill bacteria and micro organisms like salmonella. This increases shelf life and reduces spoilage.

d. **Smoke detectors.** These use alpha particles to ionise air molecules between two electrodes and so create an electric current of certain value. When there is smoke, the ionised air is attracted to the smoke particles which reduce the electric current passing. The decrease in electric current switches on an alarm.

4. **Medical**

In medicine nuclear radiations have so many uses. Some of them include sterilising products like syringes and gloves. Gamma rays can also be used to kill cancerous cells in a treatment of radiotherapy as illustrated in figure14.12.

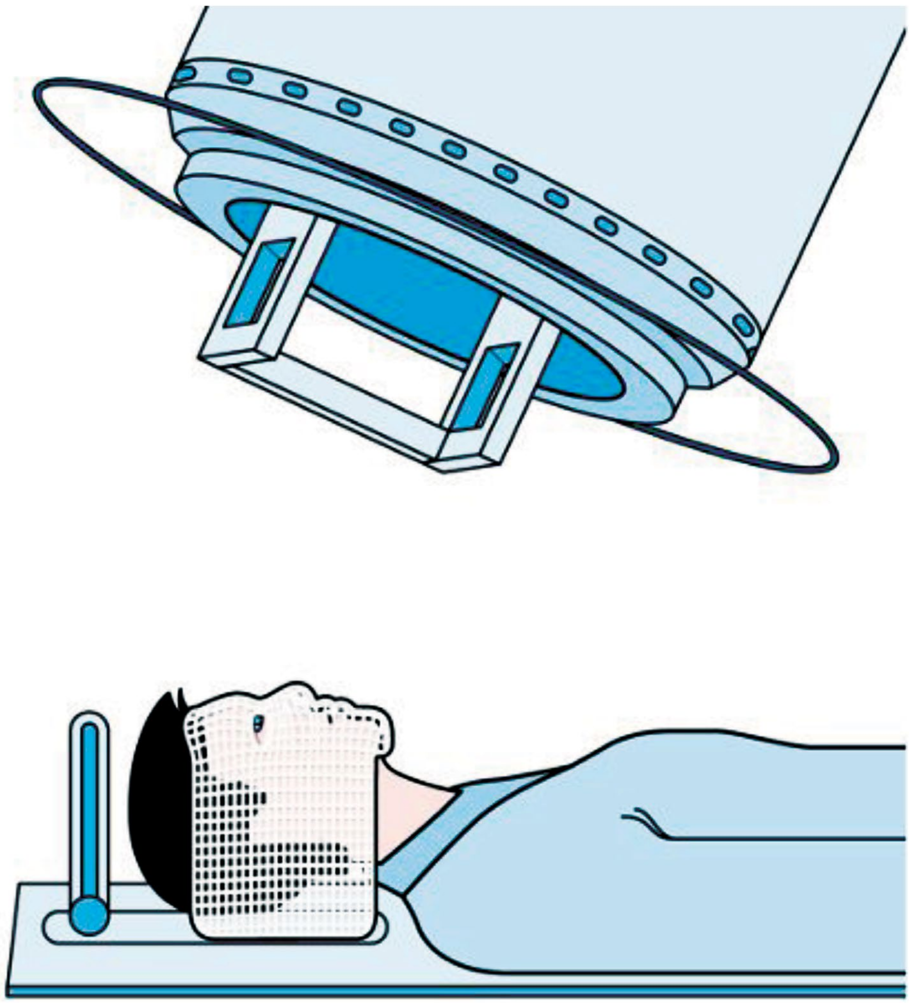


Figure 14.12: Radiotherapy.

Brain Scan by tracer. The Technetium-99m emits gamma rays that can be imaged by the scintillation camera. The radioisotope is injected into blood and allowed to distribute itself throughout the circulatory system. The camera is used to image the gamma radiation from the blood that reaches the brain.

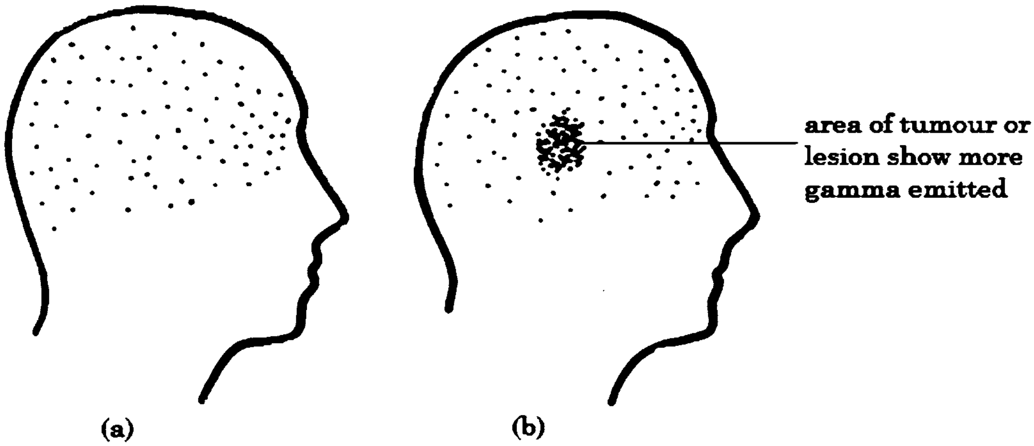


Figure 14.13: Brain scan using gamma rays.

When normal, gamma events are distributed uniformly across the brain tissue and the image looks as in figure 14.13(a). If any pooling of blood occurs as a result of some lesion or tumour, it shows up an area of higher gamma activity in that area as shown in figure 14.13(b).

Technetium has a short half life of 6 hours so that it is quickly cleared from the body.

5. **Radiocarbon dating**
This uses the idea that activity of a radioactive sample decreases with time. The amount of decreases is dependent on the half life of the radioisotopes found in the sample. Living bodies are made of lots of carbon atoms some of which are carbon-14 atoms which are radioactive. When alive the radiations emitted are almost constant because the amount of carbon remains almost constant. This is due to natural intake and disposal process that balance each other. In humans for example carbon is taken is by food consumption and some of this is lost from carbon dioxide breathed out. When dead, the amount of carbon-14 decreases due to natural nuclear decay. It is possible to calculate the age of the dead by measuring the activity of the sample of the dead, if half life and activity in live body are known.

Unit Summary

- The nuclei of isotopes can be stable or unstable depending on strength of strong nuclear forces and proportion of neutrons to protons. Atoms with atomic mass that is greater than 83, tend to be unstable.
- Unstable nuclei disintegrate spontaneously and in the process eject particles like alpha, beta and gamma rays.
- Induced radioactivity is when a stable nucleus is made unstable by exposing it to radiation artificially.
- The three types of nuclear radiations differ in terms of penetrating power, form, ionising effect and their deflection in magnetic and electric field
- There are many types of devices used to detect nuclear radiations and some of them are Geiger Muller tube, spark counter, and photographic film.
- In alpha decay, a nucleus loses an alpha particle so that the atomic number of daughter nucleus is less by 2 and atomic mass is less by 4
- In beta decay, a neutron changes into a proton and an electron. The electron is lost as a beta particle while the proton remains in the nucleus raising the atomic number by 1 while the atomic mass remains the same.
- Gamma emission, are electromagnetic waves produced when nucleons in excited state move to lower states. Atomic number and atomic mass are not changed.
- Half life is the time for activity of radioactive sample to reduce to half
- Fission is an induced nuclear reaction where a nucleus is split by bombarding it with neutrons as done in nuclear power plants and atomic bomb.
- Fusion is when light nuclei are combined to make a heavier atom as done in hydrogen bomb and the stars
- Nuclear radiations are dangerous because they may cause cancer, illness and death
- Radioactivity is used in p\ nuclear power generation. Agriculture, medicine and industry

End of unit review exercise

1. Define the following terms:
   a. Radioactivity
   b. Half-life
   c. Fission
2. What is the difference between natural and induced radioactivity.
3. What happens to the charge of the nucleus when it decays by beta?
4. Explain any two applications of radioactivity in the following areas:
   a. Medicine
   b. Industry

5. What isotopes of lead with atomic number 82 could be decay products of $^{234}_{90}Th$ if the decay is;

   a. By alpha
   b. By beta

6. Helium-6 goes under beta decay.
   a. Write the nuclear reaction equation
   b. Name the decay products.
7. The activity of a certain radioisotope is 60Bq and its half life is 100 years. Work out its activity after 1000 years.
8. A sample of iodine-131 has 40 million atoms with unstable nuclei.
   a. If the half life of I-131 is 8days, how many nuclei will be left after 40days?
   b. Write a nuclear equation if the process is beta decay
   c. Draw a graph of number of atoms against time for the process
9. What is the age of a piece of old cutting found in cave if the amount of carbon-14 in it was found to be ¼ that found in fresh wood?
10. The following equation shows fission processes.

    a. $^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{95}_{39}Y + ? + 2\,{}^{1}_{0}n$

    b. $^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{143}_{57}La + ? + 3\,{}^{1}_{0}n$

       i. Work out and find the missing isotopes in each equation.
       ii. Explain one application of such type reactions above

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Periodic Table of the Elements

1 IA 11A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 **H** Hydrogen 1.008																	2 **He** Helium 4.003
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012											5 **B** Boron 10.811	6 **C** Carbon 12.011	7 **N** Nitrogen 14.007	8 **O** Oxygen 15.999	9 **F** Fluorine 18.998	10 **Ne** Neon 20.180
11 **Na** Sodium 22.990	12 **Mg** Magnesium 24.305											13 **Al** Aluminum 26.982	14 **Si** Silicon 28.086	15 **P** Phosphorus 30.974	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.453	18 **Ar** Argon 39.948
19 **K** Potassium 39.098	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.956	22 **Ti** Titanium 47.88	23 **V** Vanadium 50.942	24 **Cr** Chromium 51.996	25 **Mn** Manganese 54.938	26 **Fe** Iron 55.933	27 **Co** Cobalt 58.933	28 **Ni** Nickel 58.693	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.732	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.922	34 **Se** Selenium 78.09	35 **Br** Bromine 79.904	36 **Kr** Krypton 84.80
37 **Rb** Rubidium 84.468	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.906	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.906	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium 98.907	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.906	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.868	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.71	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.6	53 **I** Iodine 126.904	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.905	56 **Ba** Barium 137.327	57-71	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.948	74 **W** Tungsten 183.85	75 **Re** Rhenium 168.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.22	78 **Pt** Platinum 195.08	79 **Au** Gold 196.967	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.383	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.980	84 **Po** Polonium [208.982]	85 **At** Astatine 209.987	86 **Rn** Radon 222.018
87 **Fr** Francium 223.020	88 **Ra** Radium 226.025	89-103	104 **Rf** Rutherfordium [261]	105 **Db** Dubnium [262]	106 **Sg** Seaborgium [266]	107 **Bh** Bohrium [264]	108 **Hs** Hassium [269]	109 **Mt** Meitnerium [268]	110 **Ds** Darmstadtium [269]	111 **Rg** Roentgenium [272]	112 **Cn** Copernicium [277]	113 **Uut** Ununtrium unknown	114 **Fl** Flerovium [289]	115 **Uup** Ununpentium unknown	116 **Lv** Livermorium [298]	117 **Uus** Ununseptium unknown	118 **Uuo** Ununoctium unknown

Lanthanide Series	57 **La** Lanthanum 138.906	58 **Ce** Cerium 140.115	59 **Pr** Praseodymium 140.908	60 **Nd** Neodymium 144.24	61 **Pm** Promethium 144.913	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.966	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.925	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.930	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.934	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
Actinide Series	89 **Ac** Actinium 227.028	90 **Th** Thorium 232.038	91 **Pa** Protactinium 231.036	92 **U** Uranium 238.029	93 **Np** Neptunium 237.048	94 **Pu** Plutonium 244.064	95 **Am** Americium 243.061	96 **Cm** Curium 247.070	97 **Bk** Berkelium 247.070	98 **Cf** Californium 251.080	99 **Es** Einsteinium [254]	100 **Fm** Fermium 257.095	101 **Md** Mendelevium 258.1	102 **No** Nobelium 259.101	103 **Lr** Lawrencium [262]

Alkali Metal	Alkaline Earth	Transition Metal	Semimetal	Nonmetal	Basic Metal	Halogen	Noble Gas	Lanthanide	Actinide