CHAPTER 1

Thermal expansion

Objectives

At the end of chapter 1, you must be able to:

- ***Define temperature***
- ***Describe thermal expansion in solids, liquids and gases***
- ***Explain expansion in terms of particle behaviour***
- ***Describe the unusual expansion of water and its effects***
- ***Explain the effects and applications of thermal expansion***

1.1 What is temperature?

Temperature is the measure of the hotness and coldness of a substance or an object. Temperature determines the amount of heat energy which each molecule of an object or substance possesses. Different objects have different temperature readings because they absorb different amount of heat energy. An object that absorbs greater amount of heat energy has higher temperature and vice versa. The higher the temperature of an object, the more the kinetic energy its molecules have and these molecules move faster. This situation occurs because high temperature increases the internal energy of the body by increasing the kinetic energy.

Difference between temperature and heat

Heat energy and temperature always work hand in hand but these two terms have a difference. Let us explain the difference between temperature and heat because these terms confuse us a lot. **Heat** is the measure of the total internal energy contained in a body while **temperature** is the measure of the level of heat energy (measure of how hot or cold a body is). Heat energy always flows from a higher temperature to a lower temperature.

Example:

When a hot metal ball at a temperature of 100^0C is dropped into water at a temperature of 25^0C, heat energy flows from the metal ball to the water. The flow of heat energy continues until the two temperatures are equal.

The heat lost by the hot object is equal to the heat gained by the cold object. This is called **principle of conservation of heat.**

Heat lost by a hot object = heat gained by a cold object

Heat lost by a hot metal ball = heat gained by water

This can also be described in terms of temperature changes. The decrease in temperature of a hot object is equal to an increase in temperature of a cold object.

Decrease in temperature of a hot object = Increase in temperature of a cold object

Decrease in temperature of a hot metal ball = Increase in temperature of water

Experiment 1.1

AIM: To measure temperature of substances.

MATERIALS: Beakers, sources of heat, water and thermometers.

PROCEDURE:

1. Pour 100 ml in separate beakers A and B.
2. Measure the initial temperature of the water in beaker A. Record its initial temperature.
3. Heat the water in beaker B until it reaches 100^0C.
4. Pour the hot water in beaker A of cold water and stir. Record the temperature of the mixture.

DISCUSSIONS

1. Complete the following statements:

   The initial temperature of water in beaker A = ^0C

   The temperature of hot water in beaker B = ^0C

   The temperature of the mixture = ^0C

   Rise in temperature of cold water in beaker A= ^0C

   Fall of temperature of hot water in beaker B = ^0C
2. How would you improve the accuracy of your results?

1.2 Thermal expansion

When matter is heated, it expands and when cooled it contracts.

The amount of expansion or contraction depends upon the following factors:

a. The size of the object.
b. The type of substance it is made of.
c. The temperature change of the substance.

Expansion of solids

When a solid is heated, the molecules vibrate more violently and the solid expands in all directions. We will just look at the increase in length for simplicity. The hotter it gets and the longer it was to start with the more the solid expands. The expansion is not very large and it has to be magnified in some way to be appreciated.

Experiment 1.2

AIM: To demonstrate expansion of a solid.
MATERIALS: knitting needle, straw, needle, source of heat, wooden block, mirror, paper scale.
PROCEDURE:

1. Arrange the apparatus as shown in **Figure 1.1.**

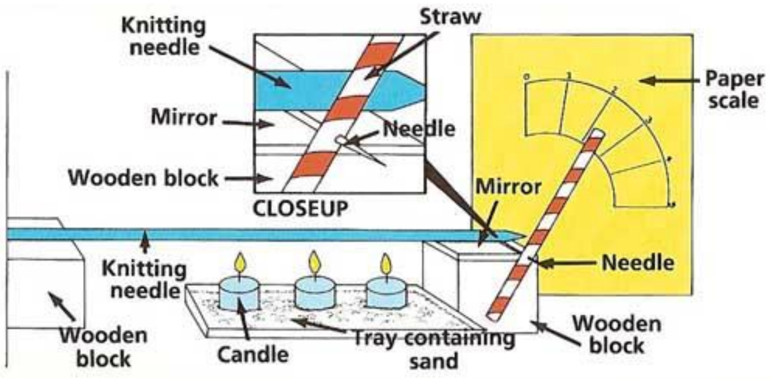

Figure 1.1

2. Heat the knitting needle.
3. Observe what happens to the straw.

RESULT
When a knitting needle is heated, the straw gets deflected.

EXPLANATION
The straw gets deflected because the knitting needle gets longer and pushes the roller.

CONCLUSION
Therefore a solid expands when it is heated.
Expansion in solids can also be demonstrated in the following:

1. **Using a slide projector**

You can do this in the laboratory with a bar of iron or steel and a slide projector, the bar need only be about 50 cm long. The bar is fixed in a retort stand and the end of the bar is placed so that it sticks into the beam of the projector where the slide carrier would have been.

The shadow of the bar is focused onto a wall on the other side of the laboratory.
The bar is now heated strongly in a Bunsen flame and you will see the shadow grow.

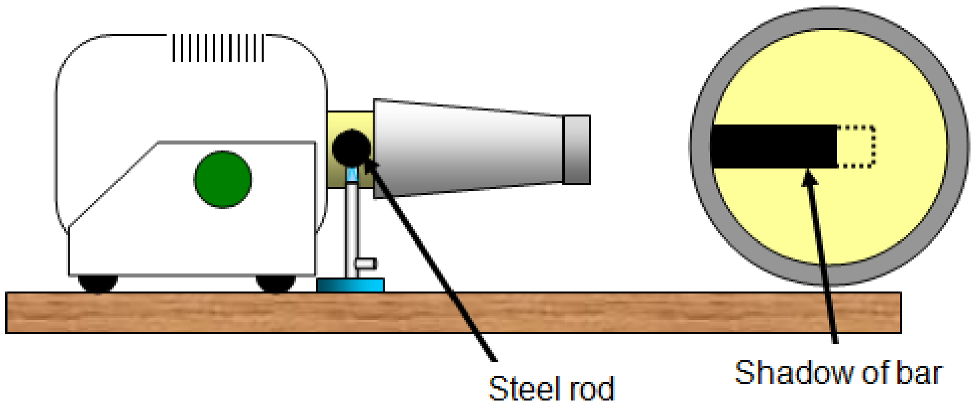

Figure 1.2 Slide projector

2. **Bar breaker**

This piece of apparatus shows that it is very difficult to stop metals from expanding when you heat them and shrinking when you cool them. A strong steel bar is fixed in the frame of the apparatus by a large nut at one end a cast iron peg at the other.
When the bar is heated the peg breaks because of the huge force in the bar. It is also possible to make the peg break when the bar contracts on cooling by tightening the nut when the bar expands.

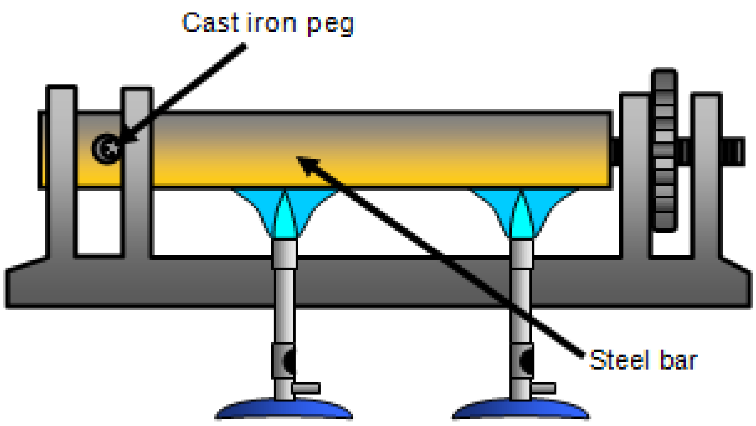

Figure 1.3 Bar breaker

Comparing expansion of various solids

Different materials expand by different amounts for the same rise in temperature.

Experiment 1.3

AIM: To demonstrate expansion of different solids.
MATERIALS: Iron metal and copper metal welded side by side to form a bimetallic strip and a Bunsen burner.
PROCEDURE:

1. Heat up the bimetallic strip.

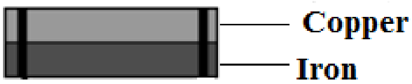

Figure 1.4 bimetallic strip before heating.

2. Notice what happens to the strip.

RESULT
When the bimetallic strip is heated, it bends with copper forming on the outside part.

EXPLANATION
Copper metal is forming the outside part because it is longer than iron.

CONCLUSION
Experiment 1.3 shows that when both copper and iron of the same size are heated with the same amount of heat energy, copper expands more than iron.

The bimetallic strip will look as shown in **Figure 1.5** shown:

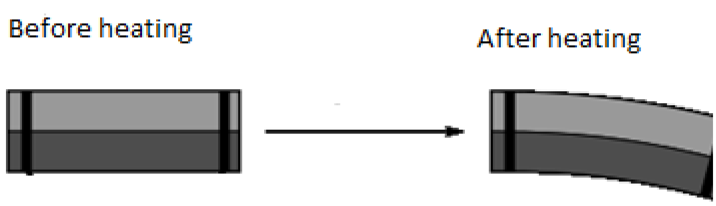

Figure 1.5 bimetallic strip before and after heating

Therefore, different solids expand with different amounts.

Table 1.1 shows how much 1 metre lengths of different solids expand when their temperature goes up by 100^0C.

Table 1.1 Increase in length of a 1m bar for a 100^0C rise in temperature

Solids	**Increase in length (mm)**
Invar	0.1
Pyrex glass	0.3
Platinum alloy	0.9
Glass	0.9
Concrete	1
Steel	1
Brass	2
Aluminium	3

Expansion of liquids

When the liquid is heated, the motion of molecules increases and they spread farther apart so the liquid occupies a greater volume. Therefore, the liquid expands when it is heated. Liquids expand much more than solids.

Experiment 1.4

AIM: To demonstrate expansion in liquids
MATERIALS: Bunsen burner, glass flask, glass tube and water.
PROCEDURE:

1. Set up an experiment as shown in **Figure 1.6.**

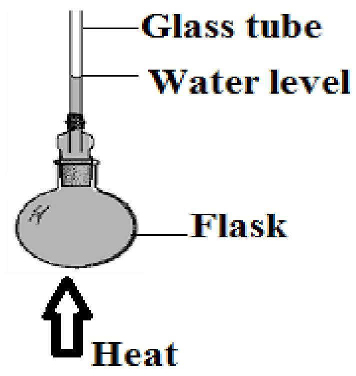

Figure 1.6

2. Heat the flask and notice the level of water in the tube.
3. This can also be done by placing the tube in the water.

RESULT
When a glass flask is heated the level of water first falls and then rises.

EXPLANATION/CONCLUSION
The level of water in a glass tube falls first because the glass flask expands first before the heat gets through the water in the glass flask. As the glass is a bad conductor of heat, it takes some time for heat to reach the liquid inside the flask. When the water in the glass flask warms up, it expands. This makes the level of water in the glass tube to rise.

Comparing expansion of various liquids

When different liquids are heated equally, they have different thermal expansions. This can be demonstrated in **Experiment 1.5.**

Experiment 1.5

AIM: To demonstrate the expansion of various liquids.
MATERIALS: Flasks, rubber stoppers, glass tubes, water, paraffin, cooking oil, basin and hot water.
PROCEDURE:

1. Set up the experiment as shown in **Figure 1.7**.

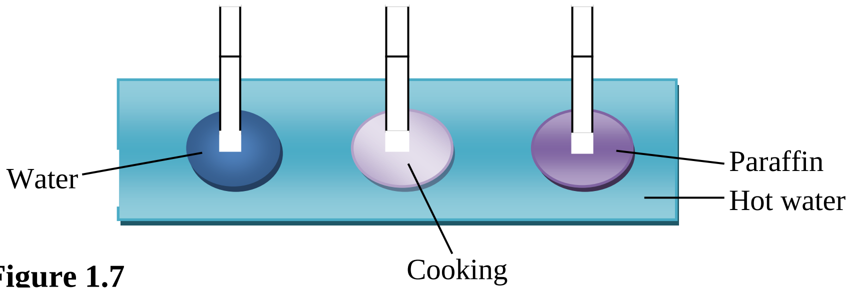

Figure 1.7

2. When the flasks are placed in hot water, compare the levels of the liquids in the glass tubes.

RESULT
The liquid levels will rise by different amounts.

EXPLANATION
The liquid levels have risen by different amounts because the liquids have different rate of expansivity.

CONCLUSION
Therefore, various liquids expand at various rates when they are at the same temperature or equally heated.

Expansion of gases

When a gas is heated in a container, molecules move faster, collide with each other and move farther apart. Consequently, the volume increases and the gas expands. Gases expand much more than solids for a given temperature rise because gas particle move more freely.

Experiment 1.6

AIM: To demonstrate expansion of gases.
MATERIALS: Liquid nitrogen or dry-ice or acetone, balloon, and container.
PROCEDURE:

1. Pour liquid nitrogen or dry ice or acetone on the inflated balloon as shown in **Figure 1.8.**

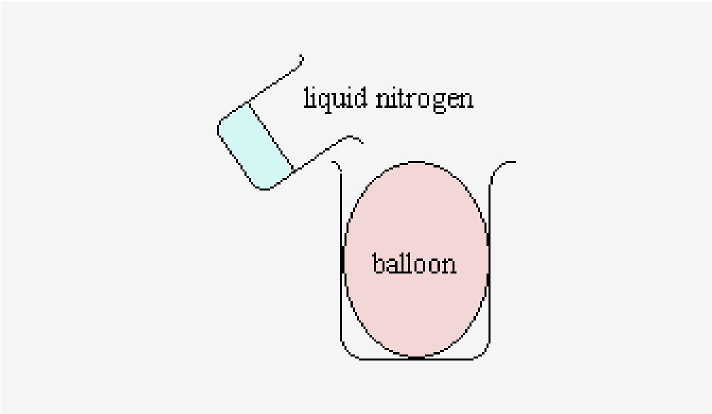

Figure 1.8

2. Observe what happens to the shape of the balloon. Explain your observation.
3. Remove the balloon from the liquid nitrogen or dry ice or acetone.
4. Observe what happens to the shape of the balloon. Explain your observation.

Comparing expansion of various gases

When equal volumes of various gases are heated equally, they expand or contract at the same rate.

Experiment 1.7

AIM: To demonstrate expansion of different gases of the same volume.
MATERIALS: Four identical tubes with different gases (oxygen, hydrogen, nitrogen and carbon dioxide), hot water, container, tubes, drops of water in each tube and rubber bangs.
PROCEDURE:

1. Set up the experiment as shown in **Figure 1.9**:

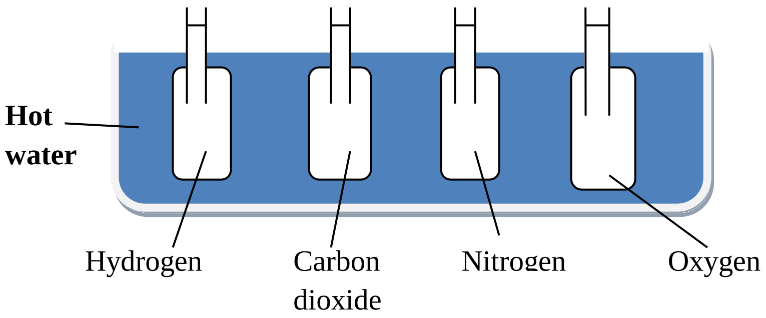

Figure 1.9

2. When four tubes of four different gases are placed in hot water, notice the rise in the level of water in the tubes.

RESULT
When the tubes of four different gases are placed in hot water, the water in the tubes will rise to the same level.

EXPLANATION
This means that the gases have increased their volumes with the same amount.

CONCLUSION
Therefore, different gases of the same volume expand equally when heated by the same amount of heat energy.

Exercise 1.1

In your groups, answer the following questions:

1. Describe the difference between temperature and heat.
2. Explain thermal expansion.
3. Which one generally expands more, for the same increase in temperature – solid or liquid? Give a reason for your answer.
4. Explain why a bimetallic strip bends when heated.
5. When equal volumes of alcohol and ether are equally heated, ether expands more than alcohol. Describe in detail how you would check this experimentally. Draw a diagram of an apparatus you would use.

1.3 Particle behaviour and expansion

When a substance is heated, its temperature rises. The rise in temperature increases the kinetic energy of its particles. The particles move further apart and increase the volume. When a substance increases its volume without gaining any matter, we say that the substance **expands**.

When a substance is cooled, its temperature decreases. The decrease in temperature decreases the kinetic energy of its particles. The particles move closer to each other and decrease the volume. When a substance decreases its volume without losing any matter, we say that the substance **contracts**.

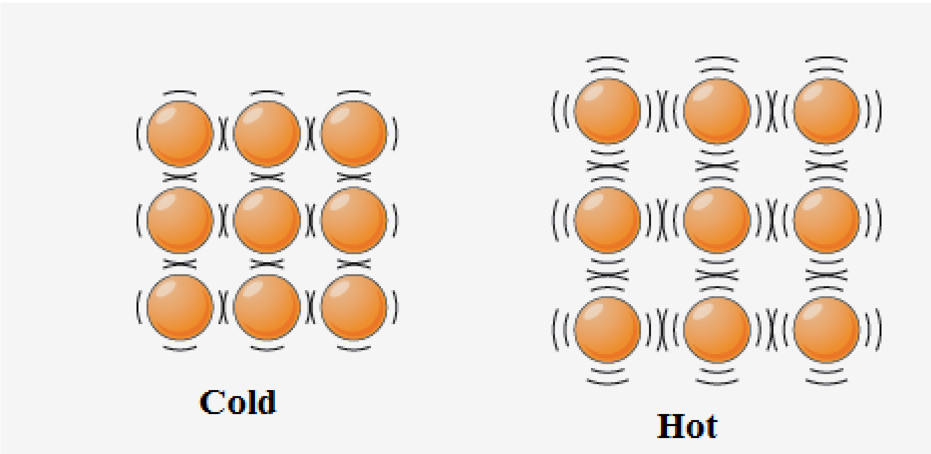

Figure 1.10 Particle behaviour during expansion

1.4 Unusual expansion of water

Unlike most other liquids, water does not always expand when it is heated and contract when it is cooled. When water is cooled to 4^0C it contracts, as we would expect. However, between 4^0C and 0^0C it expands surprisingly.

As water freezes at 0^0C, it expands because particles in an ice link up in a very pen structure. Every 100 cm^3 of water becomes 109 cm^3 of ice. This causes the bursting of bottles and pipes in very cold weather. This is common in the Northern hemisphere or in freezers.
The density of water changes as its volume changes. Water has its least volume at 4^0C. Therefore, the maximum density of water is at 4^0C.

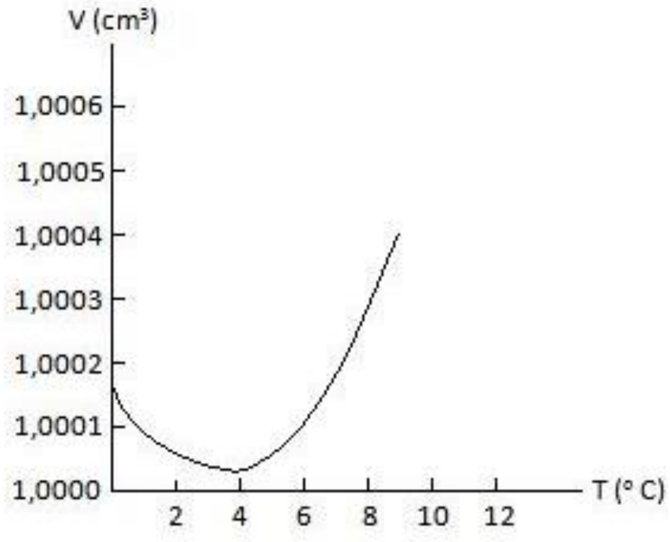

Figure 1.11 graph showing unusual expansion of water

Effects of unusual expansion of water

The unusual expansion of water has the following effects:

- **a.** It causes the bursting of pipes in very cold weather.
- **b.** It causes breaking of a bottle.

Precautions: When water is in a pipe or bottle, make sure that there is room for expansion during the time of freezing.

- **c.** It causes breaking of the rocks. When a rock is filled with water, the water on the surface freezes first. If the temperature falls low enough to freeze the whole of the water, the force of the expansion may cause a large chunk of rock to split.
- **d.** It causes weathering of soil. In winter the ground is saturated with water and water freezes. There is a large expansion which forces the soil apart.
- **e.** Freezing ponds

When water freezes at 0^0C, it becomes less dense and floats on top. This forms a layer of ice at 0^0C. Temperatures in the pond will be as shown in **Figure 1.12.**

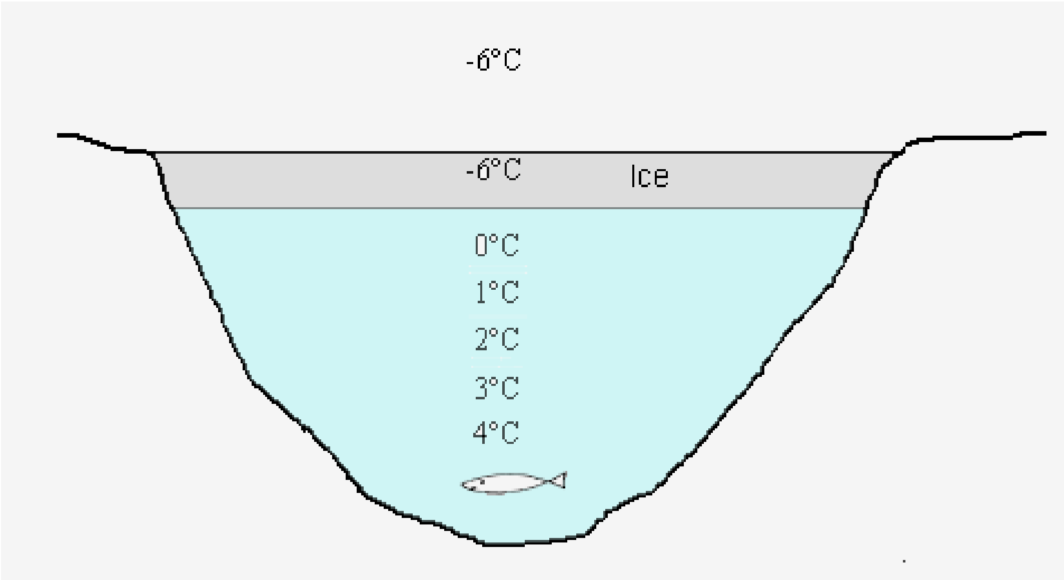

Figure 1.12 temperatures in a pond

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1.5 Effects and applications of thermal expansion

Thermal expansion has the following effects and practical applications:

a. Separating stuck glass tumblers: When glass tumblers are stuck, fill the top glass with a little ice and put the bottom into a bowl of warm water. After some minutes the top glass will contract a little while the bottom glass will expand a little. In this way, it is easy to separate them.

Figure 1.14 Separating stuck glass tumblers

b. Removing tightly screwed bottle covers: We can open a bottle's screw-on metal cap by holding it under hot water. The hot water makes the bottle top to expand more than glass bottle neck.

c. Provide tight fitting: The axle is shrunk in liquid nitrogen at -1960C until the gear wheel can be slipped on to it. When the axle gains normal temperature, it expands to give a very tight fit.

d. Riveting metal plates: A white-hot rivet is placed in rivet hole and its end hammered flat.

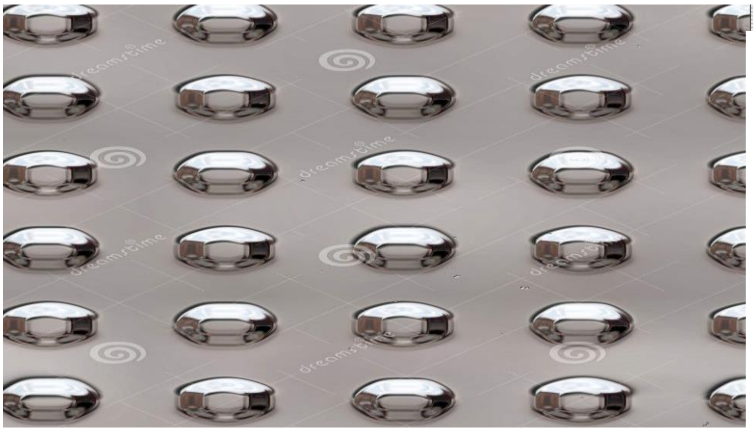


Figure 1.15 Riveting

e. Telephone wires are hung up slack in the hot summer weather so that they do not pull the telegraph poles over when they contract in the winter.

f. Concrete roads are laid in sections with soft pitch between the sections.

g. Girders in buildings and bridges are made with gaps at the ends.

h. The glass to be used in cooking is a low expansion type such as Pyrex otherwise it would shatter as it got hot.

i. The high-speed planes are heated by air friction.

j. The old buildings can be fixed and held together by a metal rod fixed through them and joined to plates on the walls.

k. Rocks in deserts crack, bits fall off them and turn into sand in the end.

l. Steam pipes, hot water pipes and fuel pipes often have large bends. The bends allow the pipes to expand without cracking.

m. Tooth filling: People with fillings experience toothache because their fillings expand at a different rate to the original tooth. This happens mainly when drinking a hot drink.

n. Any kind of pressurised gas canister will explode if heated over a fire and so can be very dangerous.

o. The gas/air mixture in the cylinder internal combustion engine "explodes" and expands when heated by a spark from the spark plug.

p. The air in a hot air balloon expands when it is heated so lowering its density and helping the balloon to rise.

q. An inflated sun bed or rubber dinghy may explode if left in the sun for a long time.

r. A dent can be removed from a table tennis ball by putting it in hot water.
s. Cakes "rise" because of the gas in them expanding.
t. Galileo's air thermometer works by the expansion of air.
u. Racing car tyres are kept warm to make them expand and become firm. This raises the cars slightly off the road.
v. When a bullet is fired the air behind it is heated rapidly by the explosion of the cartridge and the bullet is forced up the barrel of the gun.
w. Expansion of liquid is used in a liquid-in-glass thermometer.

Bimetallic strip

It is made of two equal lengths of different metals, e.g. copper and iron, riveted together so that they cannot move separately. When copper and iron are heated, copper expands more than iron. This causes the strip to bend, with copper on the outside.

Figure 1.5 bimetallic strip before and after heating

Bimetallic strip has the following uses:

a. The bimetallic thermostat

A thermostat is a switch which uses the expansion and contraction of the bimetallic strip. It is used to control the temperature in immersion heaters, electric irons, ovens, and refrigerators. **Figure 1.17** shows a thermostat used to control an electric heater to keep the room temperature constant.

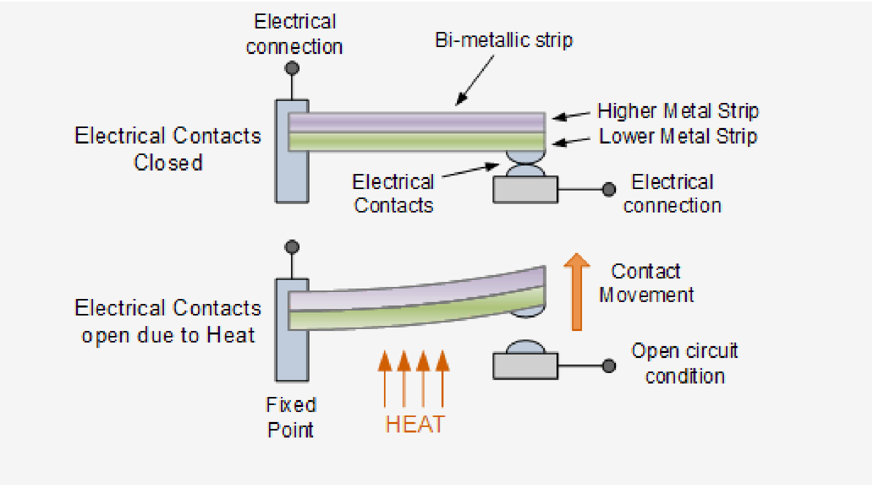


Figure 1.17 Thermostat

How the bimetallic thermostat works

When the room warms up, the bimetallic strip bends. The bending of the bimetallic strip breaks the circuit at the contacts and switches off the heater.

When the room cools down, the bimetallic strip straightens. Straightening of the bimetallic strip closes the contacts and switches on the heater.

b. Fire alarm

Figure 1.18 shows a bimetallic strip used to control the fire alarm.

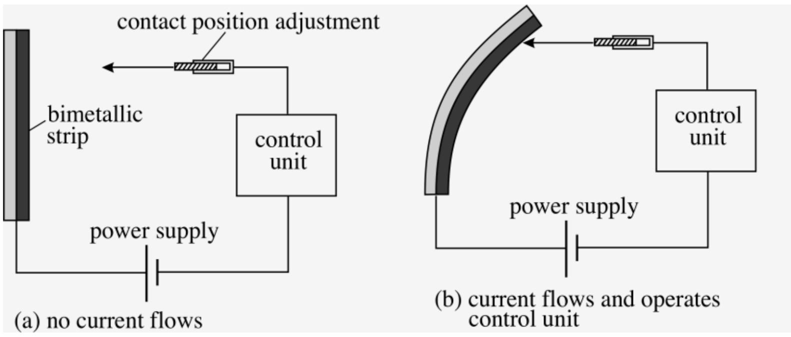


Figure 1.18 Bimetallic strip controlling the fire alarm

When there is fire, the heat from the fire makes the bimetallic strip bend. The bending of the bimetallic strip completes the circuit, ringing the alarm bell.

c. Bimetallic thermometer

A bimetallic thermometer contains a bimetallic strip in form of a long spiral as shown in **Figure 1.19.**

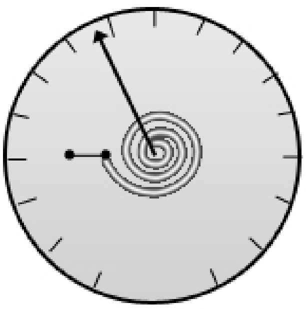


Figure 1.19 Bimetallic thermometer

When the temperature rises, the bimetallic strip coils itself into an even tighter spiral. This makes the pointer to move across the scale, recording the temperature.

Field trip

Your teacher will arrange a field trip to see the practical applications of thermal expansion. Prepare your presentation.

Exercise 1.2

In your groups, answer the following questions:

1. Explain the following in terms of particle behaviour:

- **a.** a substance expands when heated
- **b.** a substance contracts when cooled.

2. Explain why water expands when it is cooled below 4^0C.

3. State **one** danger and **one** use of expansion of water when it is cooled below 4^0C.

4. State **one** practical use of

- **a.** expansion of liquids
- **b.** expansion of gases.

5. Discuss how the following practical applications of thermal expansion take place:

- **a.** shrink fitting
- **b.** riveting.

Summary

Heat is the measure of the total internal energy contained in a body while **temperature** is the measure of the level of heat energy (measure of how hot or cold a body is).

When a substance is heated, its particles gain kinetic energy and move farther apart, increasing its volume. Hence the substance expands.

In solids: Expansion is not very large.
Various solids have various rates of expansion when equally heated.

In liquids: Expansion is larger than in solids.
Various liquids have various rates of expansion when equally heated.
Water expands when it is cooled below 4^0C.

In gases: Expansion is larger than in solids and liquids.
Various liquids have the same rate of expansion when equally heated.

Some of the effects and practical applications of thermal expansion are:

- Separating stuck tumblers
- Railway line gaps
- Tooth filling
- Removing tightly screwed bottle covers
- Gaps or rollers in bridges
- Gaps in fences
- Shrink fitting
- Riveting

Student assessment

1. Define temperature.

2. Explain the difference between temperature and heat.

3. A form four class carried out a heating experiment. The students take the temperature of water at room temperature in beaker B. **Figure 1.20** shows the thermometer used.

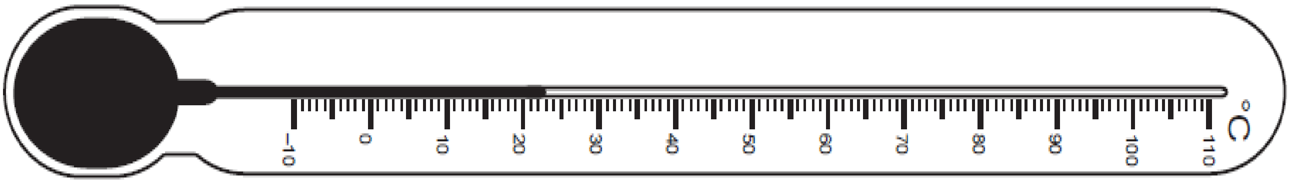


Figure 1.20

   a. What is the reading shown on the thermometer?
   b. The students heated water in beaker A, then transferred hot water from beaker A to beaker B. The temperature of water in beaker B rises to 40^0C.
   Calculate
      i. The temperature rise of the water in beaker B.
      ii. The temperature fall of hot water.
   c. Explain **one** improvement to be done to the experiment in order to obtain accurate results.

4. **Table 1.2** shows the linear expansivities of some common substances.

Substance	Linear expansivity (mm/^{0}C)
Concrete	1
Aluminium	3
Brass	2
Platinum	9
Steel	1

Table 1.2

   a. When identical rods of aluminium and platinum are heated at 50^0C, which one will be longer?
   b. Give a reason for your answer in **4(a).**
   c. Which of the substances listed in the table above would be most suitable for reinforcing concrete?
   d. Give a reason for your answer in **4(c).**
   e. A bimetallic strip is made from steel and platinum. Label the bimetallic strip as it bends when heated.

5. Explain why

a. Telephone wires are hung up slack in the hot summer weather.
b. A bimetallic strip bends when heated.
c. Concrete roads are laid in sections with soft pitch between them.
d. Guirders in buildings and bridges are made with gaps at the ends.

6. When a substance X is heated at temperature A, it expands. When the same substance is cooled at the same temperature it expands.
a. Name the substance X.
b. State the temperature A.
c. Sketch a graph of volume against temperature of substance X when it is cooled.
d. At what temperature, does substance X have maximum density?
e. Give a reason for your answer in **6(d).**

7. Discuss how a bimetallic strip can be used in flashing indicators.

8. Describe a simple experiment to demonstrate that for the same temperature change
a. Paraffin and benzene expand or contract by different amounts.
b. Aluminium and copper expand and contract by different amounts.
c. Oxygen and nitrogen gases expand and contract by the same amount.

9. A copper rod, water and nitrogen gas were heated equally.
a. Which one expands most?
b. Give a reason for your answer in **9(a).**
c. Which one expands least?
d. Give a reason for your answer in **9(c).**

10. Describe an experiment that you would carry out to show that solids expand when they are heated.

11. Explain why it is easier to unscrew a bottle top after placing it in hot water.

12. Discuss how the expansion of water is different from that of most other liquids.

13. The temperature of the water in an electric geyser can be controlled by a thermostat which switches an electric heater on and off.
a. Draw a well labeled diagram of a circuit used.
b. Explain how the circuit diagram works to control the temperature of the water in the geyser.

CHAPTER 2

Newton’s laws of motion

Objectives

At the end of chapter 2, you must be able to:

- ***Describe Newton’s laws of motion***
- ***Describe simple experimentations to illustrate inertia***
- ***Describe the law of conservation of linear momentum***
- ***Describe applications of frictional force***
- ***Explain terminal velocity***

2.1 Newton’s laws of motion

Isaac Newton (1642-1727) studied mathematics and got into considering planetary orbits and the related physics of motion. Newton developed his famous three laws of motion. He took and built upon Galileo's thinking about forces and motion and investigated the concept of force much further developing his three laws of motion called **Newton’s laws of motion.**

Newton’s first law of motion

Newton’s first law of motion states that:

- An object at rest continues to do so provided it is not acted upon by an external force.

This is common in our everyday life. **For example:** If you leave a pen on a table it will stay in the same position until someone applies a force on it to change its position or moves it.

- An object moving in a straight line continues to move at a constant speed in a straight line, unless acted upon by an external force.

This statement is not quite as obvious as the first one because on earth this is not possible due to frictional force between the moving object and air (or the sliding surface). For example: If you push a book on a bench to move in a straight line, it does not continue to move at the same speed. The book will slow down and eventually stop because friction heats up objects so that kinetic energy is changed into heat energy.

Unbalanced forces

When two unequal forces are acting on an object in opposite directions, the forces are called **unbalanced forces.**

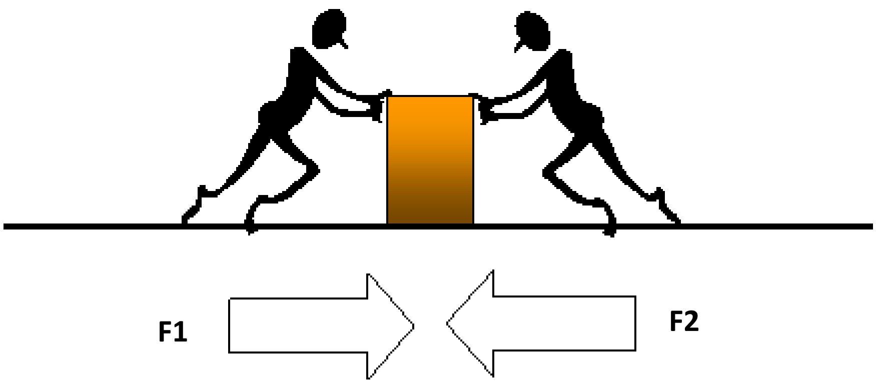


Figure 2.1 Unbalanced forces acting on an object

Resultant force, FR = F2 – F1

When F2 is greater than F1 (F2 > F1), the object moves on the direction of F2.
Unbalanced forces cause acceleration in an object.

Figure 2.2 shows a car which is traveling in a tarmac road.

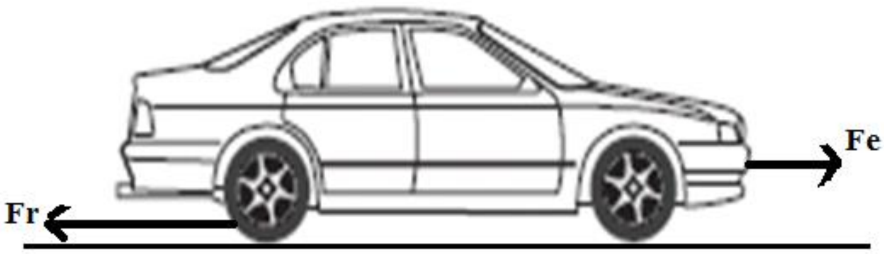


Figure 2.2 a car traveling on a tarmac road

When Fe > Fr, the car accelerates.
When Fe = Fr, the car travels with constant velocity or zero acceleration.
When Fe < Fr, the car decelerates until it stops (brakes).

Newton's second law of motion

When force is applied on an object, it causes acceleration
When force **F** is applied on an object it causes acceleration **a**. Doubling the force **F** applied on the same object will double the acceleration **a**.
Therefore, force **F** is directly proportional to acceleration **a** when mass is kept constant.

$$\mathbf{F} \propto \mathbf{a} \quad \text{......} \quad (1)$$

When force **F** is applied on an object of mass **m**, it causes acceleration **a**.

Doubling the mass **m** of an object will require double force **F** to cause the same acceleration **a.**
Therefore, force **F** is directly proportional to mass **m** when acceleration is kept constant.

$$F \propto m \quad \text{……………………………………………………………………..(2)}$$

Connecting force **F**, acceleration **a** and mass **m:**

Combination of equations (1) and (2) can be written as:

$$F \propto m \times a$$

In words, we say: Force **F** is directly proportional to both mass **m** and acceleration **a.**
We can also say that: Force **F** is directly proportional to the product of mass **m** and acceleration **a.**
In mathematics, this is written as:

$$F = k \times m \times a$$

But k = 1

Therefore, $F = m \times a$

Whereby: **F** is force in Newtons (N)
m is mass in Kilograms (Kg)
a is acceleration in metres per second squared (m/s^2)

This relationship is called **Newton's second law of motion.**

Newtown's second law of motion states that force **F** acting on an object of mass **m** to cause acceleration **a** is directly proportional to the product of mass and acceleration.

Worked examples

1. Elizo express bus has a mass of 500 kg. Calculate the engine force which is required to cause an acceleration of 5 m/s^2.

Solution

m = 500 kg a = 5 m/s^2

F = m x a
F = 500 kg x 5 m/s^2
F = **2500 N**

2. An object of mass 800 g is pushed and accelerates from rest to 40 m/s in 10 seconds. Calculate:
   a. Its acceleration
   b. The size of the pushing force

Solution

a. $u = 0$ m/s $\quad v = 40$ m/s $\quad t = 10$ s

$$a = \frac{v - u}{t}$$

$$a = \frac{40\text{ m/s} - 0\text{ m/s}}{10\text{ s}}$$

$a =$ **4 m/s²** → $a = \mathbf{4\ m/s^2}$

b. $$m = \frac{800}{1000}\text{ kg}$$

$m = 0.8$ kg

$F = m \times a$

$F = 0.8\text{ kg} \times 4\text{ m/s}^2$

$F =$ **3.2 N**

Newton's third law of motion

Newton's third law of motion states that for every force acting on an object there is an equal and opposite force of reaction acting on the other object.

This law means that if object X exerts a force on object Y, then object Y will exert an equal but opposite force on object X.

"For every force of action there is an equal and opposite force of reaction".

Figure 2.3 is a diagram showing how Newton's third law of motion is applied.

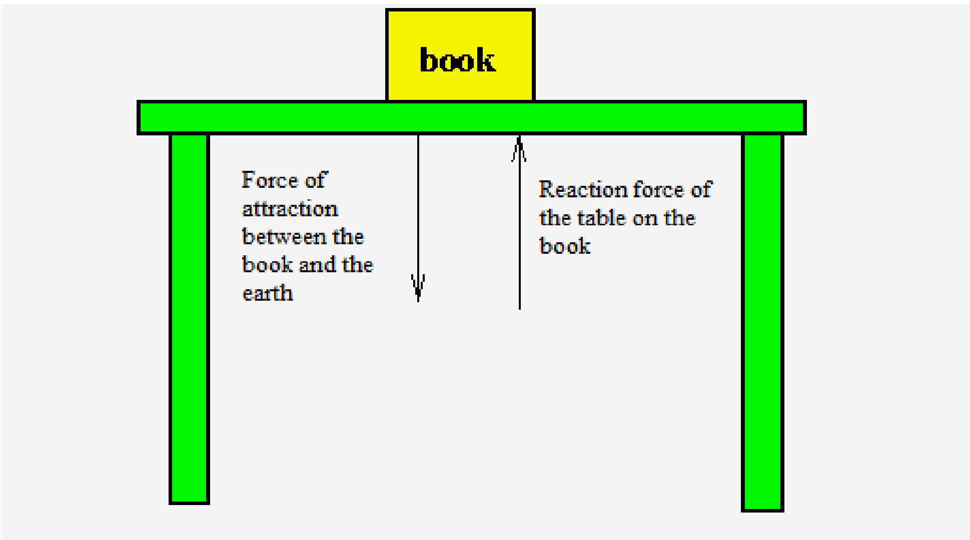


Figure 2.3 applying Newton's third law of motion

In **Figure 2.3**, a book exerts a force of action to a desk while a desk exerts a force of reaction to a book. Therefore, the book remains stationary since the force of action and force of reaction are balanced.

Resultant force: FR = force of action – force of reaction

FR = 0 N

Applications of the Newton's laws of motion

Applications of Newton's first law of motion

Newton's first law of motion is applied in the following situations:

1. When you are in a car and the driver starts the car without you noticing, you pull backwards because you want to remain stationary.
2. During collision of two vehicles, passengers hit the windscreen. An external force stops the vehicle, but the passengers continue their straight-line motion.
3. A person riding a bicycle on a level ground does not come to rest immediately he stops pedaling. The bicycle continues to move forward, but eventually comes to rest due to an external force called frictional force.
4. Blood rushes from your head to your feet while quickly stopping when riding on a descending elevator.
5. The head of a hammer can be tightened onto the wooden handle by banging the bottom of the handle against a hard surface.

Applications of Newton's second law of motion

Newton's second law of motion has the following applications:

1. Finding the weight of a body.
   W = m x g
2. Used in analysing physical situations as follows:
   The magnitude of any individual force can be determined if the mass of the object and the acceleration of the object are known.
   When a force acts on an object, the object accelerates in the direction of the force.
   If the mass of an object is held constant, increasing force will increase acceleration.
   If the force on an object remains constant, increasing mass will decrease acceleration.

Applications of Newton's third law of motion

Newton's third law of motion has the following application:

1. When you walk, the Earth pushes on you in response to your push on the Earth. Therefore, a frictional force between your feet and the ground is essential for forward motion.
2. Vehicles move along a road because the reaction of the road pushes the car along in response to the action of the wheels pushing on the road.
3. Propulsion of a fish through the water. A fish uses its fins to push water backwards. But a push on the water will only serve to accelerate the water. Since forces result from mutual interactions, the water must also be pushing the fish forwards, propelling

the fish through the water. The size of the force on the water equals the size of the force on the fish.

4. The bird flies by using its wings. The wings of a bird push air downwards. Since forces result from mutual interactions, the air must also be pushing the bird upwards. The size of the force on the air equals the size of the force on the bird. The direction of the force on the air (downwards) is opposite to the direction of the force on the bird (upwards). For every action, there is an equal (in size) and opposite (in direction) reaction. Action-reaction force pairs make it possible for a bird fly.
5. A rifle recoils when fired. The coiling is the result of action-reaction force pairs. A gunpowder explosion creates hot gases that expand outward allowing the rifle to push forward on the bullet. Consistent with Newton's third law of motion, the bullet pushes backwards upon the rifle. The acceleration of the recoiling rifle is the same size as the acceleration of the bullet.
6. In a car crash. The action force(s) are the cars colliding with each other. The reaction force is the force sent back due to the collision, which is what causes damage to the car.

Exercise 2.1

In your groups, answer the following questions:

1. Discuss the relationship between force, mass and acceleration of an object.

2. A 800 kg vehicle increases its velocity from 30 m/s to 60 m/s in 10 s.
Calculate

a. the acceleration of the vehicle
b. the size of engine force.

3. A box of mass 20 kg was pushed. If the acceleration of the box is 2.5 m/s^2, calculate the magnitude of the push.

4. A resultant force of 50 N acts on a mass of 0.60 kg starting from rest.
Find:

a. the acceleration in m/s^2
b. the final velocity after 10 s
c. the distance moved in m.

2.2 Inertia

Newton's first law of motion can be summarised as **"an object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an external force."**
The tendency of an object to remain at rest or, if moving, to continue its motion in a straight line is described as **inertia**. Therefore, Newton's first law of motion is sometimes called **the law of inertia.**

Inertia is the resistance an object has to a change in its state of motion.

Simple experimentations to illustrate inertia

Below are simple experimentations to illustrate inertia:

1. Stand a pile of books on a table. Then remove the lower book without touching the others.
   When it is pulled horizontally, the bottom book will move so that any horizontal force between it and the one above will not move the rest of the pile in a horizontal direction. Once the lower book has been removed the weight of the other books makes them fall vertically onto the table.

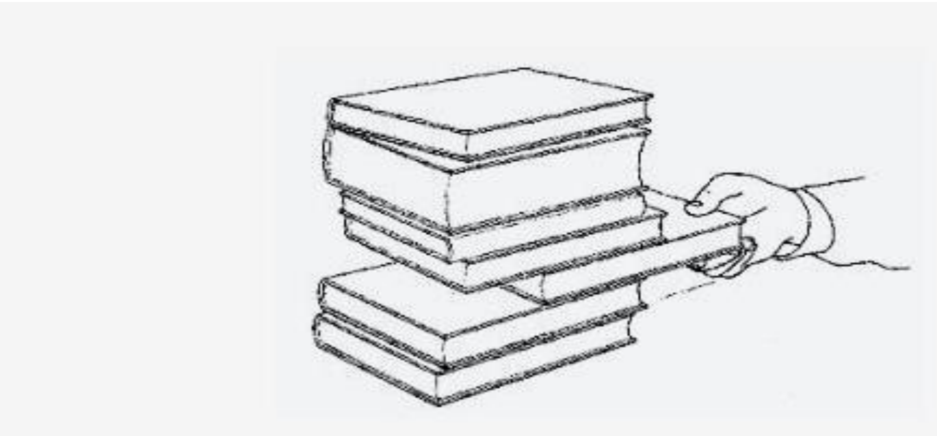


Figure 2.4

2. Place a tumbler partly filled with water on a seamless cloth on a table. Then remove the cloth without touching the glass or spilling the water.
   If the cloth is given a quick sharp downward pull, the horizontal force between the cloth and the base of the tumbler is not strong enough and not act long enough to move the tumbler horizontally. You will notice that the cloth is removed and the tumbler drops vertically onto the table due to its weight.
3. Place a coin on a piece of paper over a box.
   If the piece of paper is given a sharp push, the piece of paper moves horizontally while the coin will continue to stay as it is.

4. Place a coin on a stiff piece of card resting on a tumbler that is standing on a table.

If the card is given a sharp horizontal flick with a finger, the card shoots away allowing the coin to drop vertically into the tumbler due to its weight.

Figure 2.5

5. Rest a rectangular Perspex sheet with its corners resting on four tumblers. Place a ball supported on a narrow ring directly above each tumbler. If the Perspex sheet is given a short, sharp, horizontal force to the edge, the Perspex sheet will be pushed out from between the rings and tumblers. Each ball will fall into the tumbler beneath.

In the above simple experiments, we have noticed that each object is reluctant to change what it is doing. If it is at rest it tends to remain at rest and if it is moving it tends to continue moving. Each object behaves like this because of its inertia. The bigger the mass of the object the more difficult it is either to move it when it is at rest or to stop it when it is moving. Therefore, the greater is its inertia. From this we can refer inertia to the mass of an object. Hence the mass of an object is a measure of its inertia.

2.3 Linear momentum

What is linear momentum?

In Newton's second law of motion, it was noticed that an object with greater mass requires a larger force to set in motion than an object with a smaller mass to move with the same velocity or acceleration. Likewise, an object with a greater mass requires a larger force to stop when it is in motion than an object with a smaller mass with the same velocity. The heavier vehicle possesses a greater quantity of motion or momentum than the lighter one.

If a tennis ball hits you, it does not hurt you even if it hits very hard but you can get killed when hit by a motor car even if it is traveling quite slowly.
A small mass such as a bullet can kill when fired from a gun.
From these examples, the objects can produce a lesser or greater damaging effect depending on their mass and motion. This is called **linear momentum.**

Linear momentum of an object is defined as the product of its mass and its velocity.
Linear momentum = mass x velocity

$$\boldsymbol{\rho = mv}$$

Whereby **m** is mass in kg
v is velocity in m/s
ρ is momentum in kg m/s

Momentum has both magnitude and direction. Therefore, momentum is a vector quantity.

Worked example
An object of mass 120 kg falls from a height of 5 m above the ground to rest in 2 seconds. Calculate the linear momentum of an object.

Solution
m = 120 kg d = 5 m t = 2 s

Momentum = mass x velocity

$$\rho = mv$$

$$v = \frac{d}{t}$$

$$v = \frac{5\ \text{m}}{2\ \text{s}}$$

$$v = 2.5\ \text{m/s}$$

$$\rho = 120\ \text{kg} \times 2.5\ \text{m/s}$$

$$\rho = \mathbf{300\ kg\ m/s}$$

Momentum and Newton's second law of motion

Newton`s second law of motion can be stated as the rate of change of momentum of an object. The unbalanced force applied to an object causes the change in momentum to take place in the direction of the force.

Considering a mass **m** moving with an initial velocity **u** accelerated to a final velocity **v** in a time **t**.

Momentum = mv
Change in momentum = mv – mu

$$\text{Rate of change of momentum} = \frac{mv - mu}{t}$$

Factorising:

$$\text{Rate of change of momentum} = \frac{m(v - u)}{t}$$

but $\frac{v-u}{t} = a$

Therefore, rate of change of momentum = m x a

But **F = m x a**

Therefore, rate of change of momentum = Force

Therefore, f = change of momentum

$$\mathbf{m \times a = \frac{m\,(v-u)}{t}}$$

$$\mathbf{F = \frac{m\,(v-u)}{t}}$$

Worked example

The space craft has a mass of 2000 kg. Its velocity increases from 10m/s to 25m/s in 10 s. What force is acting on the space craft?

Solution

m = 2000 kg u = 10 m/s v = 25 m/s t = 10 s

Force = Rate of change of momentum

$$F = \frac{m\,(v-u)}{t}$$

$$F = \frac{2000\text{ kg }(25\text{ m/s} - 10\text{ m/s})}{10\text{ s}}$$

F = **3000N**

2.4 Law of conservation of linear momentum

Newton's third law states that for every force of action there is an equal and opposite force of reaction. The force of action and force of reaction are pairs of forces and they act together.

Figure 2.6 shows two toy cars before separation

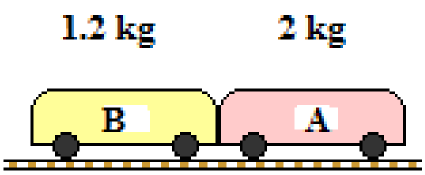


Figure 2.6 toy cars before separation

Mass of

Initial momentum of toy car A = m x v

Initial momentum of toy car A = 2 kg x 0 m/s = 0 kg m/s

Mass of toy car B = 1.2 kg and its velocity is 0 m/s
Initial momentum of toy car B = m x v
Initial momentum of toy car B = 1.2 kg x 0 m/s = 0 kg m/s

Figure 2.7 shows the toy cars after separation

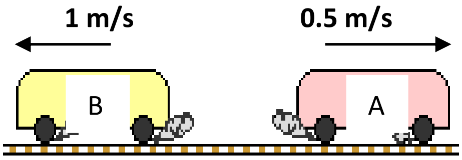


Figure 2.7 toy cars after separation

After the toy cars have sprung apart, the toy car with less mass will have more velocity.

Final momentum of toy car A = m x v
= 2 kg x 0.5 m/s
Final momentum of toy car A = 1.5 kg m/s

Final momentum of toy car B = m x v
= 1.5 x 1 m/s
Final momentum of toy car B = 1.5 kg m/s

From the results:
Initial momentum of toy car A = Initial momentum of toy car B
Final momentum of toy car A = Final momentum of toy car B
(momentum to the left) = (moment to the right)

If initial velocity is **u** and final velocity is **v**,
Change in momentum of toy car A = $m_A v_A$ - $m_A u_A$
Change in momentum of toy car A = 1.5 kg m/s – 0 kg m/s = 1.5 kg m/s

Change in momentum of toy car B = $m_B v_B$ - $m_B u_B$
Change in momentum of toy car B = 1.5 kg m/s – 0 kg m/s = 1.5 kg m/s

Change in momentum of toy car A = change in momentum of toy car B
(change in momentum to the left) = (change in momentum to the right)

$$\mathbf{m_A v_A - m_A u_A = m_B v_B - m_B u_B}$$

Each toy car gains the same amount of momentum because of the application of the equation:
Force x time = change in momentum

The change of momentum is equal because in Newton's third law of motion, equal forces act on both trolleys. The forces act at the same time, so the change in momentum must be the same in each case.

Momentum is a vector quantity, so its direction must be considered.
From **Figure 2.7**:
Momentum of toy car A = -1.5 kg m/s (since it is to the left)
Momentum of toy car B = 1.5 kg m/s (since it is to the right)

Total momentum before separation = $m_A u_A + m_B u_B$
= 0 kg m/s + 0 kg m/s
= **0 kg m/s**

Total momentum after separation = $m_A v_A + m_B v_B$
= -1.5 kg m/s + 1.5 kg m/s
= **0 kg m/s**

Total momentum before separation = total momentum after separation

$$\mathbf{m_A u_A + m_B u_B = m_A v_A + m_B v_B}$$

Total momentum of both trolleys is zero.

This shows that momentum has been **conserved.**

The Law of Conservation of Momentum states that when two or more objects act on each other, their total momentum remains constant, provided no external forces are acting.

Collisions

The law of conservation of momentum applies to explosions and collisions.
Two trolleys X and Yare made to move towards each other as shown in **Figure 2.8.**

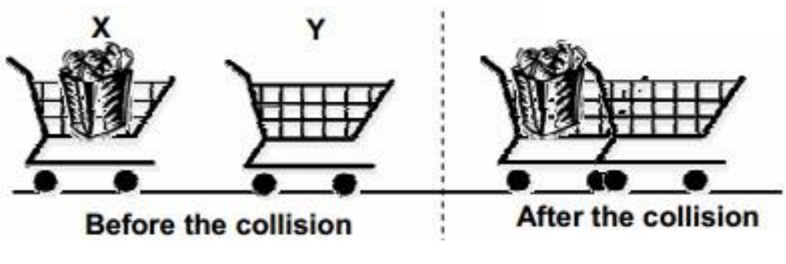


Figure 2.8 conservation of momentum during a collision

Mass of trolley X is 1.5 kg and its velocity is 5 m/s. Mass of trolley Y is 1.2 kg and its velocity is 2 m/s.

Before the collision

The momentum of trolley X = 2 kg x 5 m/s = 10 kg m/s
The momentum of trolley Y = 1.2 kg x (-2 m/s) = -2.4 kg m/s
The total momentum of trolley X and trolley Y = 7.6 kg m/s

After the collision

When trolley X collides with trolley Y, the trolleys attach to each other and they have a combined mass travelling at the same velocity.
Whenever the objects collide, their total momentum is conserved unless there are external forces acting on them.

Momentum before collision = momentum after collision

$$\mathbf{M_1 \times v_1 = m_2 \times v_2}$$

To calculate the velocity of a combined mass of trolleys X and Y.

$M_1 \times v_1 = 7.6$ kg m/s
M_2 = combined mass = 2 kg + 1.2 kg
$M_2 = 3.2$ kg
7.6 kg m/s = 3.2 kg x v_2

$$V_2 = \frac{7.6 \text{ kg m/s}}{3.5 \text{ kg}}$$
$$= \mathbf{2.38\ m/s}$$

The trolleys have a velocity of 2.38 m/s to the right.

NOTE: The negative velocity means the direction is to the left.

In the above example, the before and after collision is conserved but the total energy usually decreases because the impact converts some of it to heat energy, sound energy and work done is permanently distorting the objects leaving them with an increased amount of potential energy.

A collision in which some kinetic energy is lost is called **inelastic collision.** For example, a collision in which the objects stick together on impact.

A collision in which there is no loss of kinetic energy (kinetic energy is conserved) is called **perfect elastic collision.** For example, molecules colliding in a gas.

Worked examples

1. A girl of mass 60 kg jumps (to the right) with a horizontal velocity of 5 m/s on a stationary skateboard of mass 3 kg. What is her velocity as she moves on the skateboard?

Solution

Momentum before interaction = momentum of a girl + momentum of a skateboard
= 60 kg x 5 m/s + 3 kg x 0 m/s
Momentum before interaction = 300 kg m/s

Momentum after interaction = momentum before interaction
Momentum after interaction = 300 kg m/s
The combined mass (m_2) = 60 kg + 3 kg = 63 kg
To find v_2

$m_1 \times v_1 = m_2 \times v_2$
300 kg m/s = 63 kg x v_2
$V_2 = \frac{300 \text{ kg m/s}}{63 \text{ kg}}$
V_2 = **4.76 m/s**

2. A man fires a gun. His mass and the gun is 75 kg. The mass of the bullet is 15 g and its velocity is 300 m/s. Calculate the velocity of the recoil.

Solution
m_1 = 75 kg v_1 (v_R)=? m_2 = 15g (0.015 kg) v_2 = 300 m/s
$m_1 \times v_1 = m_2 \times v_2$
75 kg x v_R = 0.015 kg x 300 m/s
$v_R = \frac{0.015 \text{ kg} \times 300 \text{ m/s}}{75 \text{ kg}}$
v_R = **0.06 m/s**

Exercise 2.2

In your groups, answer the following questions:

1. Derive a formula to relate force and the rate of change in momentum.

2. An object of mass 25 kg travelling at a velocity of 8 m/s increases its velocity to 12 m/s in 4 seconds. Calculate
a. the initial momentum of an object
b. the final momentum of an object
c. the size of the force acting on an object.

3. A 12 kg mass travelling to the right at 4 m/s collides with a 4kg mass travelling to the left at 4 m/s. Calculate
a. the momentum of each mass
b. the combined momentum
c. the velocity of the two masses if they stick together when they collide.

2.5 Frictional force

An object which is moving over a horizontal surface does not continue with constant velocity when the accelerating force is removed. The object slows down and eventually stops. The object slows down and stops because of the force which is opposing the motion. This force is called **frictional force.**

Frictional force is the force which acts to oppose the motion. To move a body over another that is at rest requires a force. This force is supposed to overcome frictional force between two surfaces and to change momentum of the body you want to move.

Static or **limiting frictional force**

In **Figure 2.9** a box is placed on a flat surface with a string attached to it.

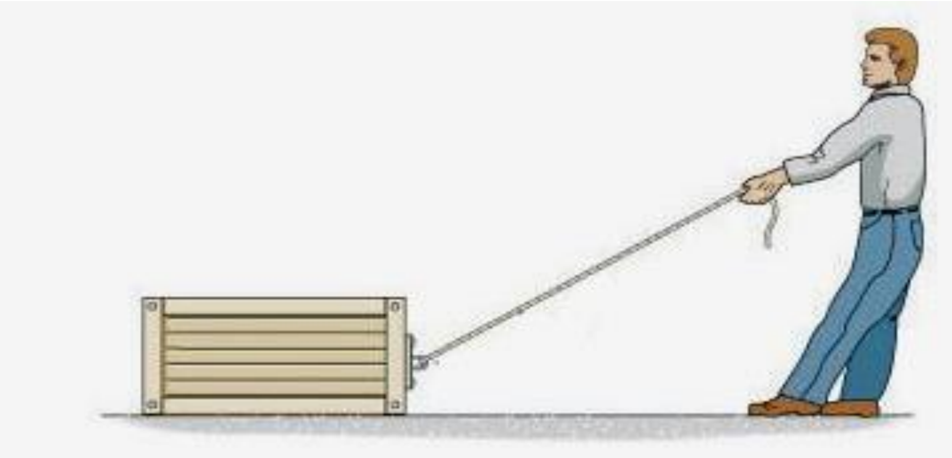


Figure 2.9 static and sliding frictional force

When the man pulls the box, at first, it will remain at rest because the pulling force P is smaller due to an equally increasing but oppositely directed force of friction F. If gradually increasing the pulling force P the point will be reached when the box just begins to slip. At this point, the value of pulling force P equals the friction force F but there is a maximum frictional force which can be brought into play. This frictional force is called **static or limiting frictional force.**

Static or **limiting frictional force** is the maximum value of the frictional force between two surfaces. It occurs when the two surfaces are on the point of sliding over each other.

Sliding or **dynamic frictional force**

This is the value of frictional force when one surface is sliding over another at a constant speed. It is slightly less than the limiting frictional force.

Coefficient of friction

If the demonstration in **Figure 2.10** is repeated with various weights on the box, you will notice that both static and sliding frictional force F are increased in simple proportion to the force, perpendicular to the surfaces, which is pressing them together N.

The ratio of static or sliding force F to the force pressing the surfaces together are called the **coefficients of static** and **sliding friction** respectively.

$$\mu = \frac{F}{N}$$

Whereby: **F** is the static frictional force or the sliding frictional force in Newtons (N)
N is the normal force pressing surfaces together in Newtons (N)
μ is coefficient of friction

To calculate frictional force

Using the formula for coefficient of friction,

Force = coefficient of friction x normal force

$$F = \mu N$$

Worked examples

1. A horizontal force of 15 N is necessary to just hold a block stationary against a wall. The coefficient of friction between the block and the wall is 0.5. Calculate the weight of the block.

Solution

F = 15 N μ = 0.5 N(weight) =?

$F = \mu N$

$N = \frac{F}{\mu}$

$= \frac{15}{0.5}$

N = **30 N**

2. If a brick weighing 20 N is placed on a floor having coefficient of friction between it and the floor of 0.3. What is the maximum force of friction available at the point of contact between the brick and the floor?

Solution

μ = 0.3 N = 20 N F = ?

$F = \mu N$

$= 0.3 \times 20$ N

F = **6 N**

3. A ladder weighing 200 N is placed against a smooth vertical wall. The maximum force of friction available at the point of contact between the ladder and the floor is 50 N. Calculate the coefficient of friction between the ladder and the floor.

Solution

N = 200 N F = 50 N μ =?

$F = \mu N$

$$\mu = \frac{F}{N}$$

$$= \frac{50}{200}$$

μ = **0.25**

Applications of frictional force

Low coefficient of friction is used in bearings, pistons in the cylinders and on ski runs.
High value of coefficient is used forces being transmitted by belt drives and braking systems.

Below are other applications of friction force in our everyday life:

1. Almost all fastening devices rely on frictional forces to keep them in place once secured, e.g. screws, nails, nuts, clips, and clamps.
2. Satisfactory operation of brakes and clutches rely on frictional forces being present.
3. In absence of frictional forces, most accelerations along a horizontal surface are impossible, for example when a person attempts to walk the shoes will just slip, when a car wants to have a forward motion its tyres will just rotate.

2.6 Terminal velocity

Terminal velocity is the maximum, constant velocity reached by an object falling through a vacuum and fluids (gas or liquid).

Falling of objects in a vacuum

When objects fall in a vacuum they do not experience frictional force or resistance. The objects are said to have a **free fall.**

When objects are falling in a vacuum, they have a free fall because there is no opposing force (frictional force) acting upon them.

All objects have the same motion and fall with the same acceleration. All objects fall at a constant speed or velocity called **terminal velocity.** Therefore, the objects fall with the same acceleration called **acceleration due to gravity, g.** Acceleration due to gravity is nearly 10 m/s/s or 10 m/s^2.

For example: When a feather and a coin are dropped from the same height in a vacuum as shown in **Figure 2.10**, both the feather and the coin will reach the bottom of the container at the same time because they fall at the same terminal velocity and with the same acceleration.

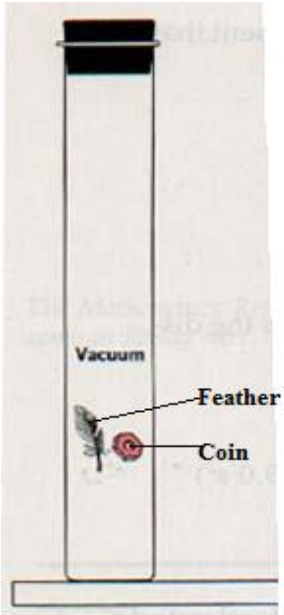


Figure 2.10 falling in a Vacuum

Falling of objects in fluids

A fluid is any substance that can flow (e.g. gas or liquid). Frictional force in fluids is experienced due to the air particles that act on a moving object in an opposite direction.
A frictional force caused by air is also called **Air Resistance.** Air resistance slows down cars and aeroplanes. Air resistance on cars and aeroplanes is reduced by streamlining the cars and aeroplanes.

When an object is falling in a fluid the resistance due to the air or liquid increases. Eventually the resistance becomes equal to the weight of the object. At this point an object falls with the maximum constant velocity called **terminal velocity.**

Falling in liquids

In **Figure 2.11** is a diagram used to describe the change in velocity of the metal ball when it is dropped in viscous motor oil.

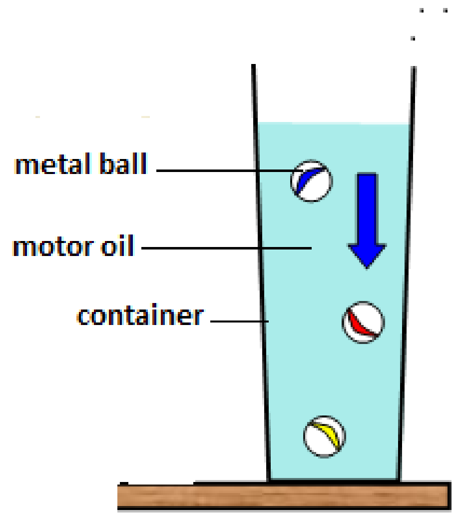


Figure 2.11 velocity of a ball in oil.

At first, the metal ball accelerates because there are unbalanced forces. The weight of an object is greater than the fluid resistance.

When the metal ball is dropped in the liquid, it experiences the following forces:

Weight, **W** acting downward

Frictional force, **Fr** in oil acting upwards

Upthrust, **U** acting upwards

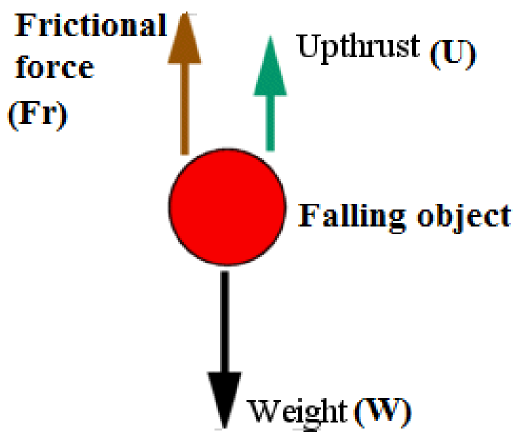


Figure 2.12 forces acting on a falling object

Final force acting on the ball or the resultant force on the ball is found as:

Resultant force = Downward forces – Upward forces

FR = Weight – (Upthrust + Frictional force)

FR = W – (U + Fr)

As the velocity of an object increases, the frictional force increases until the upward forces (upthrust + frictional force) equals the downward force (weight) of an object.

Weight = (Upthrust + Frictional force)

$$\mathbf{W = (U + Fr)}$$

The resultant force, **FR = 0 N**

When the downward forces equal the upward forces, the metal ball moves at a constant velocity called **Terminal Velocity.** When a metal ball reaches terminal velocity, the forces acting on it are said to be balanced forces. The metal ball continues falling at this terminal velocity until it reaches the bottom of a container.

Figure 2.13 is a velocity time graph of the motion of a metal ball in motor oil.

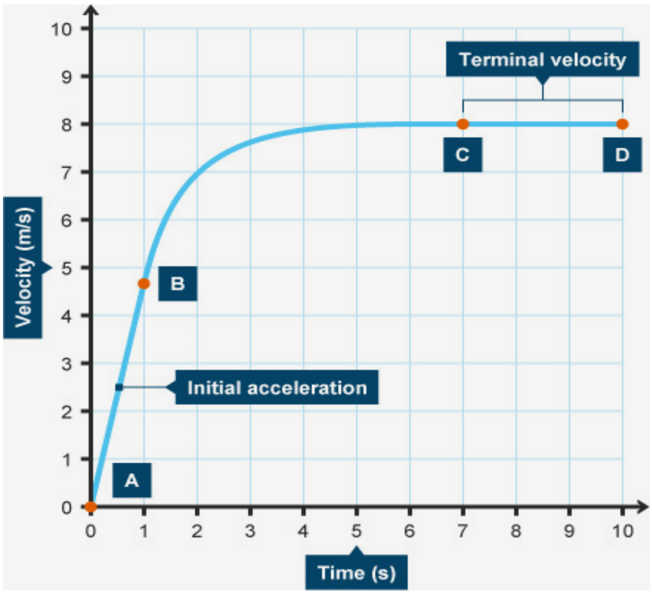


Figure 2.13 traveling graph for the motion of a metal ball in motor oil

NOTE:

Upthrust, U remains constant.

Frictional force, Fr changes and its size depends on the following factors:

- Size of the falling object.
- Speed of the falling object.
- Viscosity of the liquid.

Falling in different liquids

Drop three identical metal balls in three different liquids of different viscosity, e.g. ethanol, glycerine and water. In this experiment, its only viscosity of liquids that varies.

The factors that must remain constant are size or shape, mass or weight of the metal balls, volume of liquids or depth and temperature.

EXPLANATIONS

In ethanol
A metal ball dropped in ethanol took a very short time to reach the bottom of the container. Ethanol is less viscous compared to the other two liquids because it has very weak intermolecular forces. Therefore, frictional force in ethanol is very weak. The metal ball in ethanol travels at a high velocity (accelerates) because of reduced frictional force.
Resultant force, FR = W – (U + Fr). Therefore, W – (U +Fr) is very big (greater).
A metal ball reaches a constant terminal velocity after a longer time because the difference is greater.

In glycerine
A metal ball falling in glycerine takes longer to reach the bottom of the container compared to the other two liquids. Glycerine has greater viscosity because it has stronger intermolecular forces since it has two OH. Therefore, W – (U + Fr) is very small, hence a metal ball travels at a very slow velocity. A metal ball reaches a constant terminal velocity after a shorter time.

In water
It produces intermediate results.

Falling in the air

Figure 2.14 is a diagram used to demonstrate the velocity of objects (a feather and a coin) the in air. The shape of the feather and coin, the height where they are dropped and the time they are released must be the same. The size (mass or weight) of the feather and the coin must be different.

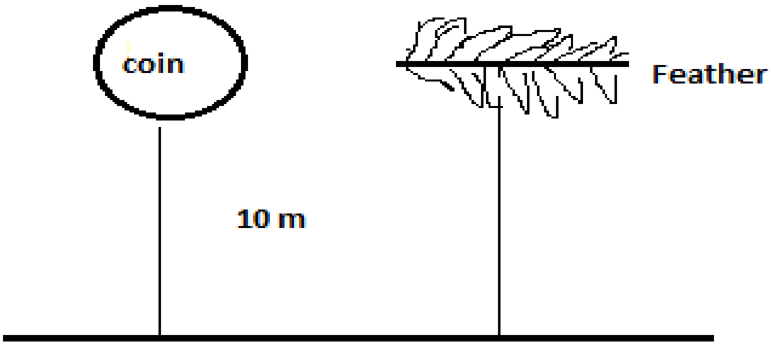


Figure 2.14 falling in the air (same shape, different sizes)

When a feather and a coin are dropped in the air at the same time from a height of 10 m:

- A coin reaches the bottom of the ground faster than a feather.
  A coin reaches the bottom first because it has greater weight, W.
  Therefore, W – (U + Fr) is greater. A coin reaches a constant terminal velocity after a longer time.

- A feather reaches the ground after a longer time because it has less weight. Therefore, W – (U + Fr) is very small. A feather reaches a constant terminal velocity after a shorter time.

Figure 2.15 is a diagram used to demonstrate the velocity of objects (card A and card B) in the air. The size (mass or weight) of the cards, the height where they are dropped and the time they are released must be the same.
The shapes of the cards must be different.

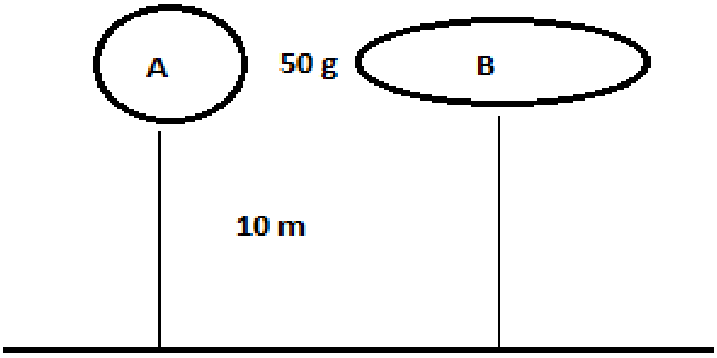


Figure 2.15 falling in air (same size, different shapes)

When cards A and B are dropped in air:

- Card A reaches the ground earlier than card B.
  Card A reaches the ground first because it has a smaller surface area. Card A experiences less air resistance or frictional force.
  Therefore, W – (U + Fr) is greater. Card A reaches a constant terminal velocity after a longer time.

- Card B reaches the ground after a longer time because it has a larger surface area. Card B experiences greater air resistance or frictional force. Therefore, W – (U + Fr) is very small. Card B reaches a constant terminal velocity after a shorter time.

NOTE:
The above demonstrations show that the factors that affect the motion of the falling objects in the air are size (mass or weight) and shape of the object.

Exercise 2.3

In your groups, answer the following questions:

1. A box weighing 100 N is placed on a floor. The maximum force of friction available at the point of contact between the box and the floor is 50 N. Calculate the coefficient of friction between the box and the floor.

2. If a brick weighing 40 N is placed on a floor having coefficient of friction between it and the floor of 0.2, what is the maximum force of friction available at

Summary

Newton's first law of motion states that an object at rest continues to do so provided it is not acted upon by an external force and an object moving in a straight line continues to move at a constant speed in a straight line, unless acted upon by an external force. **Newtown's second law of motion** states that the **F** acting on an object of mass **m** to cause acceleration **a** is directly proportional to the product of mass and acceleration.

$$\mathbf{F = m \times a}$$

Newton's third law of motion states that for every force acting on an object there is an equal and opposite force of reaction acting on the other object.

Newton's first law of motion is sometimes called **the law of inertia.**
Inertia is the resistance an object to a change in its state of motion.

Linear momentum of an object is defined as the product of its mass and its velocity.
Linear momentum = mass x velocity.

Newton`s second law of motion can be stated as the rate of change of momentum of an object.

$$\mathbf{F = \frac{m\,(v - u)}{t}}$$

The Law of Conservation of Momentum states that when two or more objects act on each other, their total momentum remains constant, provided no external forces are acting.

Frictional force is the force which acts to oppose the motion.
The ratio of static or sliding force F to the force pressing the surfaces together are called the **coefficients of static** and **sliding friction** respectively.

$$\boldsymbol{\mu} = \mathbf{\frac{F}{N}}$$

Terminal velocity is the maximum, constant velocity reached by an object falling through a vacuum and fluids (gas or liquid).

When objects fall in a vacuum they do not experience frictional force or resistance. The objects are said to have a **free fall.**

The factors that affect the motion of falling objects in a liquid are viscousity of a liquid, size, and speed of a falling object.

The factors that affect the motion of falling objects in air are size and shape of a falling object.

Student assessment

1. Define the following:
   - **a.** Inertia
   - **b.** Terminal velocity
   - **c.** Momentum

2. **a.** State Newton's first law of motion.
   b. State **three** applications of Newton's third law of motion in our everyday life.

3. **a.** State Newton's second law of motion.
   b. Calculate the force needed to give a mass of 2kg an acceleration of 4 m/s^2.
   c. Cynthia applies a force of 20 N on a 5kg box which is at rest. Calculate the final speed of the object.

4. A car of mass 300kg travelling at 50km/h changed its speed to 20 km/h in 6 seconds. Calculate
   - **a.** The deceleration of a car.
   - **b.** The size of the engine force.
   - **c.** The distance moved during the deceleration.

5. **Figure 2.16** is a diagram showing an object falling in air.

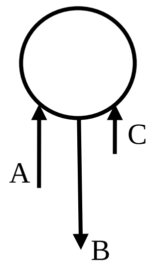


Figure 2.16

   - **a.** Name the forces A, B and C.
   - **b.** What would be the relationship between the magnitudes of A, B, and C at equilibrium.
   - **c.** Name **two** forces that are constant.

6. Explain the following:
   a. A gun recoils after it is fired.
   b. During a collision of two vehicles, passengers hit the windscreen.

7. **Figure 2.17** is a diagram of the cards of the same mass but different shapes dropped from the same height.

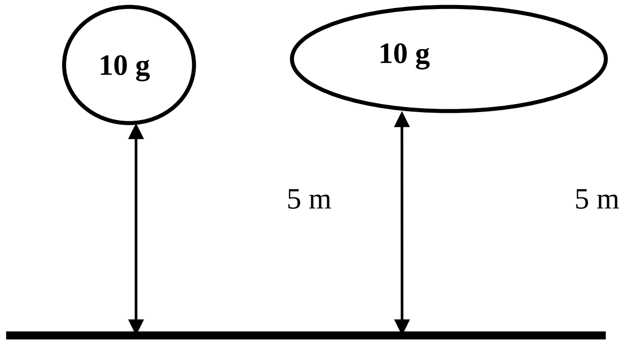


Figure 2.17

a. Which card will reach the ground first?
b. Give a reason for your answer in **7 (a).**
c. State three forces that are acting on the falling cards.
d. State two forces that are constant.

8. Describe an experiment that you would carry out to show that the motion of an object in the air is affected by its size.

9. Describe an experiment to investigate the relationship between the force applied to an object and the acceleration produced in an object.

10. A body of mass 10 kg moving with uniform acceleration has an initial momentum of 150 k gm/s and after 10 s the momentum is 200 kg m/s. What is the acceleration of the body?

11. Calculate the momentum of Paulosi, of mass 55 kg, running at a velocity of 7 m/s south.

12. Natasha fires a gun. Assuming the mass of Natasha and the gun is 65 kg and she fires a 20g bullet from the gun at a velocity of 200 m/s, calculate the velocity of the recoil.

13. A boy of mass 52 kg jumps with a horizontal velocity of 2.5 m/s onto a stationary skateboard of mass 1.5 kg. Calculate his velocity as he moves off on the skateboard?

14. Chipiliro and Madalitso are hockey players. Chipiliro has a mass of 70 kg and is travelling at 3 m/s while Madalitso has a mass of 60 kg and is travelling at 5 m/s towards Chipiliro.
They collide directly and immediately become entangled. At what speed and in which direction do they travel after they become entangled?

15. Describe an experiment that you would carry out to explain the changes in velocity of an object dropped in lubricating oil.

16. Explain **two** factors that affect the motion of an object falling in a liquid.

17. a. State and explain the law of conservation of momentum.
b. Describe an experiment you would perform to test this law.

18. A vehicle of mass 1100 kg travelling at 20 m/s crashes into a brick wall and comes to rest in 0.8 s. Calculate the average force exerted by the wall on the car.

19. A trolley of mass 0.9 kg moves horizontally with a velocity of 0.6 m/s. A 500 g mass of sugar is dropped vertically onto the trolley where it sticks to the trolley. Calculate the final velocity of the trolley.

20. A bullet of mass 5.8 g travelling at 110 m/s penetrates deeply into a fixed target, and is brought to rest in 0.1 s.
Calculate
a. The distance of penetration of the target.
b. The average retarding force exerted on the bullet.

CHAPTER 3

Hooke's law

Objectives

At the end of chapter 3, you must be able to:

- ***Explain the effects of force***
- ***Verify Hooke's law experimentally***
- ***Apply Hooke's law in solving related problems***
- ***Explain the significance of the term limit of proportionality for an elastic solid***

3.1 The effects of a force

A force is defined as a pull or push.
Below are some of the effects of forces on objects:

a. Forces can cause movement of a stationary object. For example, when an object is pushed, it moves away.
b. Forces can make moving objects stop. For example, when a goal keeper makes a moving ball stop he exerts a pushing force on an object.
c. Forces can turn things. For example, a natural force like wind can turn the blades of a wind turbine to generate electricity.
d. Forces can change the direction of an object. For example, when a force act on an object, the object can change direction if you have changed the direction of the force.
e. Forces can change the speed of the object. For example, when riding a bicycle, the speed of a bicycle can increase by applying a larger force. Increasing in speed with time or making it move faster is called **accelerating.** Therefore, acceleration is an increase in speed or velocity with time.
f. Forces can change the shape of an object. For example, when a wooden block is suspended at the end of the spring it causes the stretching of the spring.

3.2 Hooke's law

About 300 years ago, Robert Hooke, who was the Chief Surveyor to the City of London, investigated the springs and elasticity in general.

When force is applied on a material, it can deform or change its shape.

For example
The shape of a clay ball can be changed by simply applying a force with your hand. The shape of a balloon can be changed by simply squeezing it. The shape of a spring can be changed by simply pulling it.

In the given examples, when the force is removed, the shape of the clay ball remains the same while the balloon and the spring return to their original shapes. Therefore, the balloon and the spring are called **elastic materials.**

An **elastic material** is the material that, when it is deformed, it springs back to its original shape when the force has been removed. The ability of an object to return to its original shape when the force has been removed after it has been stretched, compressed, bent, or twisted is called **elasticity.** Examples of elastic materials are a rubber band and a spring.

When more force is applied to a material, it becomes permanently deformed (out of shape). At this point, the object stops being elastic. Therefore, there is a limit to the applied force from which the material will return to its original shape when the force is removed. This limit is called **elastic limit** and it is different for each material.

Robert Hooke investigated the relationship between the extension and applied force, for example, in a spring. Applied force to the spring is called the **load**. When the spring stretches, the difference between its stretched and unstretched lengths is called **extension**.

Experiment 3.1

AIM: To verify Hooke's law

MATERIALS: Bosses (50 g, 100 g, 150 g and 200 g), clamp, ruler, spring.

PROCEDURE:

1. Set up an experiment as shown in **Figure 3.1.**

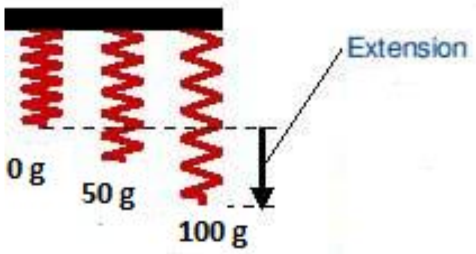


Figure 3.1

EXPLANATION

The results from **experiment 3.1** show a straight-line graph as shown in **Figure 3.2.**

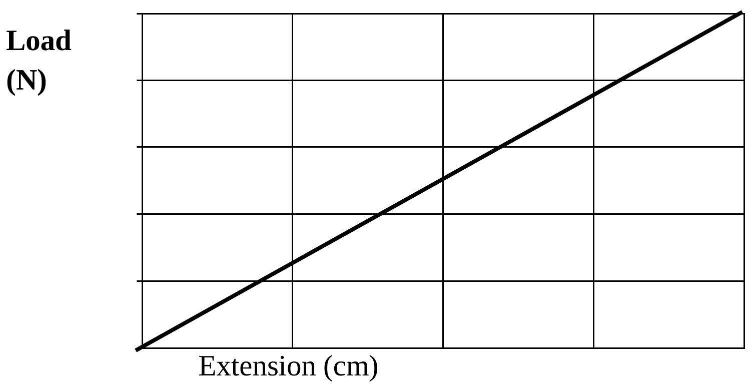


Figure 3.2

From the graph, it is indicated that the extension increases if the load (stretching force) increases. If the load is doubled, the extension is also doubled.
Therefore, the extension (e) is directly proportional to stretching force (F).

$$e \propto F$$

This is true only within the limits of elasticity.

The relationship between stretching a force and the extension is called **Hooke's law.**

Hooke's law states that **for a helical spring or other elastic material, the extension e is directly proportional to the applied force F, provided the limit of elasticity is not exceeded.**

Within the limit of elasticity:

$$\mathbf{F \propto e}$$
$$\mathbf{F = k \times e}$$
$$\mathbf{k = \frac{F}{e}}$$

Whereby:
F is force in Newtons (N)
e is extension in centimetres (cm).
k is the force constant of the spring in Newton per centimetre (N/cm)

For a spring, which obeys Hooke's law, the value of **k** must be the same for any amount of stretching force applied at its end.

From the Hooke's law, the values of spring proportionality constant **k** and extension **e** determine the stiffness of the spring or how difficult the spring is to stretch.

- A spring which is stiffer or difficult to stretch has a smaller extension **e** with a large spring proportionality constant **k.**
- A spring which is easy to stretch has a large extension e with a smaller spring proportionality constant **k.**

3.3 Apply Hooke's law in solving related problems

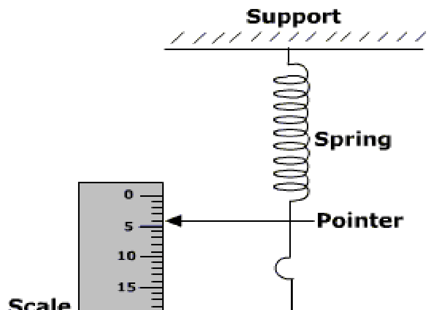
Constructing and calibrating a spring balance

A spring which does not have any scale must be calibrated first before it is used. **Calibrating a spring** simply means putting a scale on the spring so that it may be used to find the weight of some given masses. Therefore, a **calibrated spring** is the one which has a scale.

Experiment 3.2

AIM: To calibrate a spring to be used in a spring balance
MATERIALS: Spring in the Hooke's law apparatus.
PROCEDURE:

1. Set up the apparatus as shown in **Figure 3.4.**



Mass

DISCUSSION

The graph plotted from the results in **Table 3.2** can be as shown in the sketch in **Figure 3.5.**

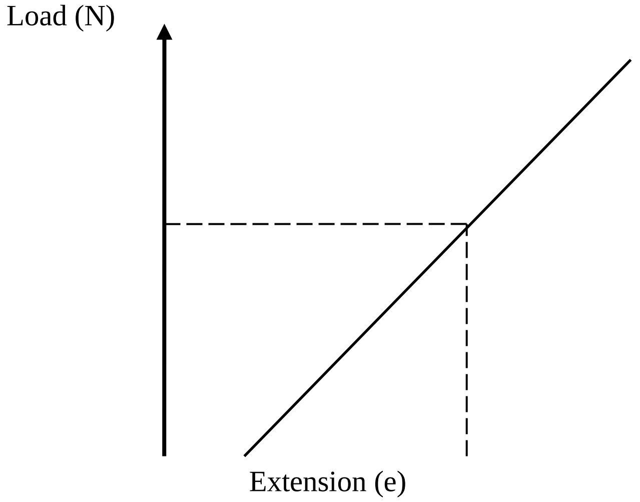


Figure 3.5 Calibration of the spring

The graph shows that the load is directly proportional to the extension.
You can use the graph to find the weight of an object. Hang the object whose weight you want to find on the end of the spring. Check the extension caused by the object. Then use the extension to check its weight on the graph as shown by dotted line.

To make a scale on the spring balance
On the strip of blank paper highlight the original mark (when there was no mass) and the mark made at the (1000g) 1 kg mass.
The reading at the original mark = 0 N
The reading at the (1000g) 1 kg mass = 10 N
Divide the starting point and the ending point (0 N – 10 N) in ten equal divisions. The scale now will have subdivisions of 1 N.
Therefore, we can use this spring balance to measure weights from 0 N to 10 N.

Extending springs in series

Figure 3.6 shows two springs in series. When the force is applied, the springs extend with the same amount and the total extension is double what it would have been with just one spring. Therefore, the spring constant is halved.

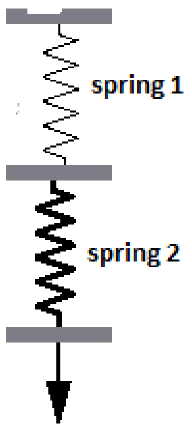


Figure 3.7 springs in series

Extending springs in parallel

Figure 3.8 shows two springs in parallel. When the force is applied, the springs extend half the amount compared to what happened with just one because the springs share the load. Therefore, the spring constant is doubled.

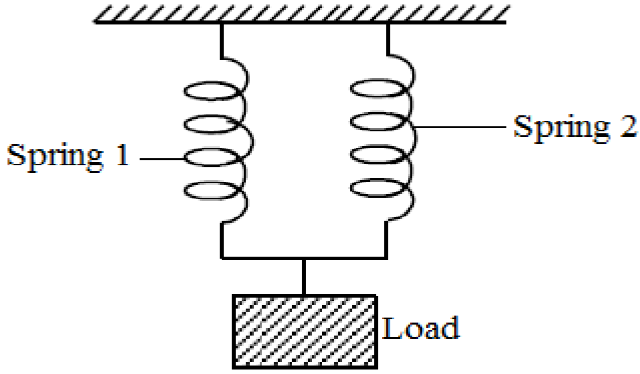


Figure 3.8 springs in parallel

Hooke's law calculations

The following are the important equations to use in Hooke's law calculations:

1. Force = spring proportionality constant x extension
   F = k x e

2. Extension = stretched length – unstretched length
   e = SL - UL

Worked examples

1. A spring of normal length 30 cm becomes 35 cm long when stretched by a stretching force of 20 N.

Work out

a. extension of the spring

b. the force that causes an extension of 3 cm

Solution

UL = 30 cm SL = 35 cm F = 20 N

a. Extension = SL – UL

$e = 35\ cm - 30\ cm$
e = **5 cm**

b. To find f,

$F = k \times e$

$k = \frac{F}{e}$

$k = \frac{20\ cm}{5\ cm}$

k = **4 N/cm**

k of the spring is the same

e = 3 cm

$F = 4\ N \times 3\ cm$

Force = **12 cm**

2. The spring proportionality constant k of a spring is 0.2 N/cm. Calculate the extension produced by a load of 3 N.

Solution

k = 0.2 N/cm   F = 3 N   e =?

$F = k \times e$

$e = \frac{F}{k}$

$e = \frac{3\ N}{0.2\ N/cm}$

e = **15 cm**

Exercise

In your groups, answer the following questions:

1. The original length of a spring is 20cm.
A mass of 200g is placed at the end and the spring becomes 30 cm long.
Calculate

a. the extension of a spring.

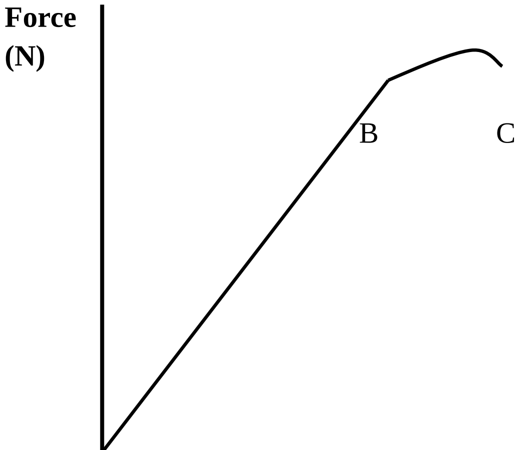
b. the force required to cause an extension of 20cm.

2. Describe how you would investigate experimentally the relationship between the extension of a spring and the load.

3.4 Significance of the term limit of proportionality for an elastic solid

If you repeat **Experiments 3.1 and 3.2** and more force is applied, the spring overstretches and does not obey Hooke’s law. The spring is said to be beyond the limit of proportionality as shown in **Figure 3.9.**

The straight-line graph in **Figure 3.5** shows that the force at the end of the spring was steadily increased until a point B was reached. At point B, the graph starts to bend because the spring loses its elasticity or starts being permanently stretched. Therefore, after point B be the spring breaks at point C because it is overstretched.



AB = Within the limit of elasticity or proportionality. Hooke's law is obeyed because extension is directly proportional to the stretching force.
B = Limit of elasticity
BC = Beyond the limit of elasticity or proportionality. Hooke's law is not obeyed because there is no straight line, showing that extension is not directly proportional to the stretching force.

Summary

The effects of force on an object are:

- **a.** Forces can cause movement of a stationary object.
- **b.** Forces can make moving objects stop.
- **c.** Forces can turn things.
- **d.** Forces can change the direction of an object.
- **e.** Forces can change the speed of the object
- **f.** Forces can change the shape of an object.

Hooke's law states that **for a helical spring or other elastic material, the extension e is directly proportional to the applied force F, provided the limit of elasticity is not exceeded.**

F = k x e

The following are the important equations to use in Hooke's law calculations:

1. Force = spring proportionality constant x extension
F = k x e

2. Extension = stretched length – unstretched length
e = SL - UL

When more force is applied, the spring overstretches and does not obey Hooke's law. The spring is said to be beyond the limit of proportionality.

Student assessment

1. Define

a. Elasticity

b. Extension

2. State the Hooke's law.

3. **Table 3.3** shows the results obtained during Hooke's law experiment.

Load (N)	0	1	2	3	4
Length (cm)	10	15	20	25	30
Extension (cm)					

Table 3.3

a. Copy and complete the table.

b. Plot a graph of load against length.

c. From your graph, find the length of the spring when a load of 2.5 N is hung on the spring.

d. Plot a graph of load against extension.

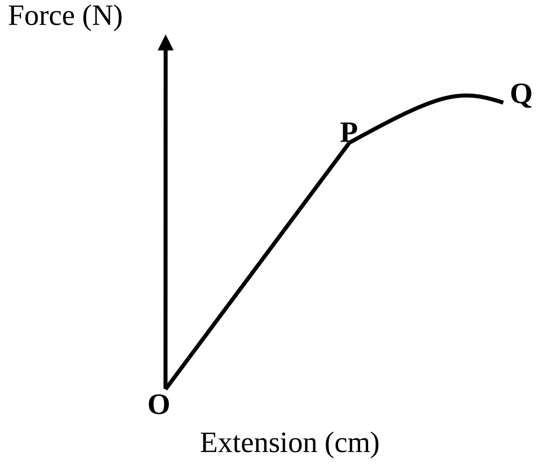
e. From your graph, find

i. The spring proportionality constant k.

ii. The extension caused by a 1.5 N load.

iii. The load that can cause an extension of 18 cm.

4. **Figure 3.10** is a graph of force against extension for a mass on a spring.



a. Describe the shape of the graph.
b. What name is given to point P?
c. In which region does the spring obey Hooke’s law?
d. Give a reason to your answer in 4 (c).
e. What happens to the spring beyond point P?
f. What happens to the spring at Q?

5. The unstretched length of a spring is 20cm. When a 200g mass is hung on the spring its new length is 55cm.
Calculate
a. The extension of the spring.
b. The spring proportionality constant.
c. The load that can cause an extension of 15cm.
d. The extension that can be caused by a force of 10 N.

6. The spring proportionality constant is 0.5N/cm.
Calculate
a. The extension caused by a 5 Nload.
b. The force required to extend the spring by 10cm.

7. Calculate the force needed to stretch a spring of spring proportionality constant 10 N/cm from 5 cm to 10 cm.

8. Copy and complete **Table 3.4.**

Force (N)	**Extension (cm)**	**Spring constant (N/cm)**
5	5	
8		2
	4	6
200	8	

Table 3.4

9. Describe an experiment that you would carry out to verify Hooke's law.

10. A spring is 30 cm long with a mass of 250g on the end. An addition of 100g causes the spring to increases its length by another 2 cm.
Work out
a. The force constant of the spring.
b. The unstretched length of the spring.

11. Explain what happens to the extension of the springs that are in
a. Series.
b. Parallel.

CHAPTER 4

Uniform circular motion

Objectives

At the end of Chapter 4, you must be able to:

- ***Differentiate angular displacement and angular velocity.***
- ***Describe simple experimentations to illustrate centripetal force.***
- ***Apply principles of uniform circular motion.***

4.1 Angular displacement and angular velocity

Bodies can move in a circular path. For example, clothes in a spin dryer, the planets going around the sun, the moon circling the earth and a car turning the corner.
An object which is moving in a circle has **uniform circular motion**.
A uniform circular motion is a motion along a circular path in which there is no change in speed, only a change in direction.

Anything that moves in a circle:

- Has a steady speed
- Has a changing direction
- Has a changing velocity
- Accelerates towards the centre, and yet never gets closer to it.

Figure 4.1 shows a bob tied to a string whirled round in a horizontal circle.
The direction of motion of a bob is changing. The bob can move from point A to point B around the circumference of a circle marking an arc AB. Therefore, the bob is displaced from point A to point B through angle θ. This directional displacement is called **angular displacement**.
An angular displacement is represented by an arc **s**.

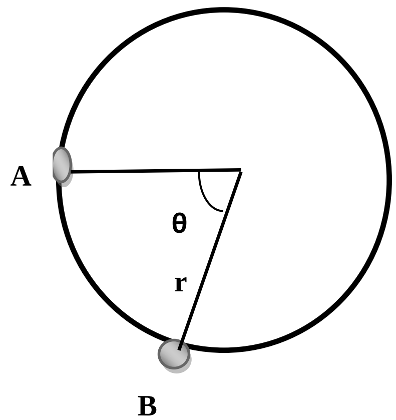


Figure 4.1 angular displacement of an object

B

An angular displacement is given by the formula:

$$s = \Theta r$$

where s is angular displacement in cm, Θ is angle covered by an object in radians (Θ = 2πr) and r is the radius of a circular path in cm.

The rate of change of angular displacement is called **angular velocity**.
Therefore, angular velocity is the angular displacement divide by the time taken to turn through an angle Θ.
Angular velocity has a symbol w and is given by the formula:

$$\text{Angular velocity} = \frac{\text{angular displacement}}{\text{Time}}$$

$$w = \frac{s}{t}$$

Relationship between tangential (linear) velocity and angular velocity

The definition of average velocity is very similar to the definition of angular velocity.
In the case of linear motion, we defined linear velocity as the displacement covered in given time. This was given by the formula given below:

$$\text{Velocity} = \frac{\text{displacement}}{\text{time}}$$

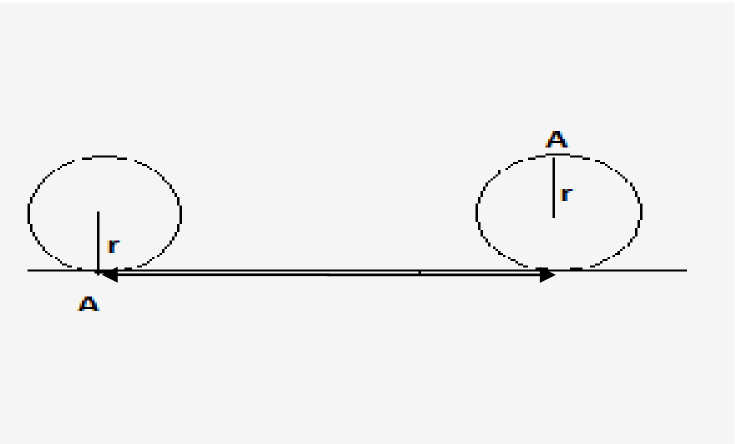
$$v = \frac{d}{t}$$

In a circular motion, we have defined angular velocity as the angular displacement per given time. This is given in the formula:

$$w = \frac{s}{t}$$

Linear velocity and angular velocity can be related in many examples.
One of the examples is shown below:

Let us examine the wheel of radius r that has rolled a distance s.



s

Figure 4.2 relating linear velocity and angular velocity

The arc length traced by the wheel is equal to the distance s that the arc wheel moves. This distance is called **tangential distance**.

Now let us consider a wheel rotating with constant angular velocity was it moves to the right with linear velocity v.

Firstly, define speed at any point on the rim of the wheel as the tangential speed vt. Clearly all points on the rim of the wheel have the same tangential speed. Furthermore, it should be obvious that the tangential speed is equal to the linear velocity v of the wheel.

The angular velocity of the wheel is defined by:

$$w = \frac{\Theta}{t}$$

Whereby Ө is the angular displacement in time t and it is related to the distance the wheel travels by s = rӨ or $\Theta = \frac{s}{r}$

Substituting $\Theta = \frac{s}{r}$

Into the equation $w = \frac{\Theta}{t}$

$$w = \frac{s/r}{t}$$

$$w = \frac{s}{tr}$$

$$w = \frac{s}{t} \times \frac{1}{r}$$

but $\frac{s}{t}$

is the linear velocity of the wheel and is also equal to tangential velocity of any point on the rim of the wheel, vt

So, $w = vt \times \frac{1}{r}$

$w = \underline{vt}$

r

Therefore, tangential speed, **vt = wr**

4.2 Simple experimentations to illustrate centripetal forces

In **Chapter 2**, Newton's first law of motion was stated as **"a body continues to move at a constant velocity unless acted upon by a force."** Remembering that constant velocity means traveling at constant speed in a straight line, we realise that Newton knew that circular motion is natural. Therefore, a force is required to maintain a circular motion.

Let us take the following situations:

1. A car turns a corner. In this case, the force is provided by friction between the tyres and the road.
2. When a ball is whirled at the end of a string.
3. As the earth orbits around the sun, force is provided by gravitational attraction between the two bodies.

In the above three cases, the force required to continue circular motion is directed towards the centre of the circle. This force is called **centripetal force**.

Centripetal force is the force which acts on an object towards the centre of the circle to make an object move in a circle.

More centripetal force is needed if:

a. The mass of the object is increased.
b. The speed of the object is increased.
c. The radius of the circle is reduced.

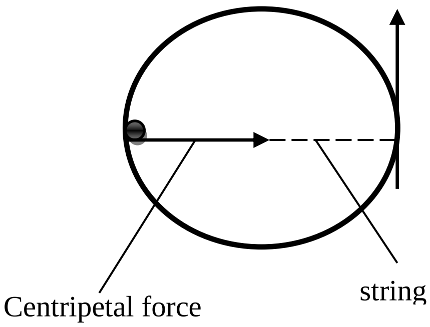


Figure 4.3 centripetal force

If an object moves at a speed v in a circle of radius r, centripetal acceleration will be calculated as:

$$\text{Centripetal acceleration } \mathbf{a_c = \frac{v^2}{r}}$$

Centripetal acceleration is the acceleration of an object in circular motion acting towards the centre of the circle.

Centripetal force is calculated using the following formula:

Force = mass x acceleration

F = m x a

So, if the object moving in a circle has a mass m,

Centripetal force required, $\mathbf{F_c = \frac{mv^2}{r}}$

Worked example

A 2 kg rock swings in a circle of radius 4 m. If its constant speed is 10 m/s, calculate

a. the centripetal acceleration.

b. The centripetal force.

Solution

a. r = 4 m v = 10m/s

$$a_c = \frac{v^2}{r}$$

$$= \frac{10^2}{4}$$

a_c = **25.0m/s²**

b. m = 2 kg v = 10m/s r = 4 m $a_c = 25.0\ m/s^2$

EITHER

$$F_c = \frac{mv^2}{R}$$

$$= \frac{2 \times 10^2}{4}$$

F_c = **50 N**

OR

$F_c = m \times a_c$

$= 2 \times 25.0$

F_c = **50 N**

2. Figure 4.4 shows a skater moving at a velocity of 15 m/s in a circle of radius 30 m. The ice exerts a centripetal force of 450 N.

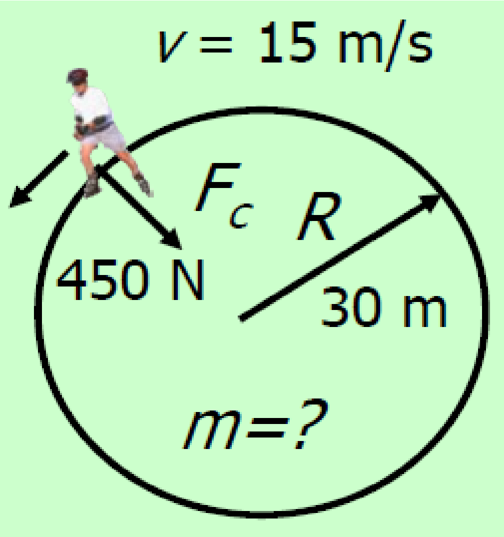


Figure 4.4

What is the mass of the skater?

Solution

Fc= 450 N r = 30 m v = 15 m/s

$$Fc = \frac{mv^2}{r}$$

$$m = \frac{FcR}{v^2}$$

$$= \frac{450 \times 30}{15^2}$$

m = **60.0 kg**

Exercise

In your groups, answer the following questions:

1. A 5kg rock swings in a circle of radius 3 m. If its constant speed is 5 m/s, calculate:

a. The centripetal acceleration

b. The centripetal force

2. The wall exerts a 500 N force on a circular platform. What is the radius of the circular path?

4.3 Applying principles of uniform circular motion

Applications of circular motion in everyday life
In the applications of the principle of uniform circular motion, you will notice that the forces acting on a moving object are not balanced although there is a net force. The resultant force acting on it is called **centripetal force.** Therefore, an object moving in a circular path is not in equilibrium.

Circular motion can be used in the following manner:

1. A car negotiating a flat turn.
   Figure 4.5 shows a car negotiating a flat turn.

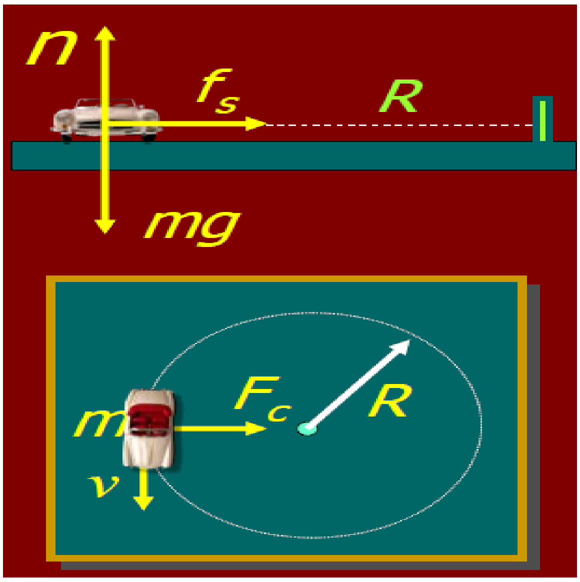


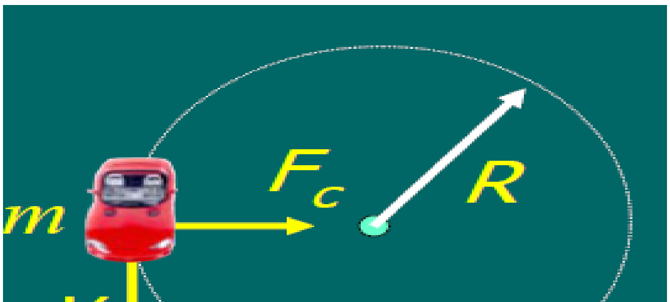
Figure 4.5 a car is negotiating a flat corner

In this situation, the road provides two forces:
Normal contact force (N) – this force balances the weight (mg) of the car.
Static friction (F_s) - the force between the tyres and the road surface.
The centripetal force necessary for the circular motion is generated by the friction between the tyres and the road. The centripetal force is that of static friction (F_s)

$$\mathbf{F_c = F_s}$$

If the friction force is not enough, the car will not go around the bend along the desired path.

2. A car corning on a banked road,
   Figure 4.6 shows a car cornering a banked road.



By banking a curve at the optimum angle, the normal force (n) can provide the necessary centripetal force without the need of friction force.

In **(b)** a car travels around the bend too slowly, it will tend to slide down the slope. In this case, friction will act up the slope to keep the car on course.
In **(c)** a car travels faster. The car will tend to slide up the slope.
In **(d)** friction is insufficient. The car will move up the slope and come off the road.

3. An aircraft banking
When an aircraft is banking, the pilot changes its direction by tipping the aircraft's wings. The vertical component of the lift force (L) on the wings balances the weight while the horizontal component of L provides the centripetal force.

4. The conical pendulum
A conical pendulum consists of a mass m revolving in a horizontal circle of radius R at the end of a cord of length L.

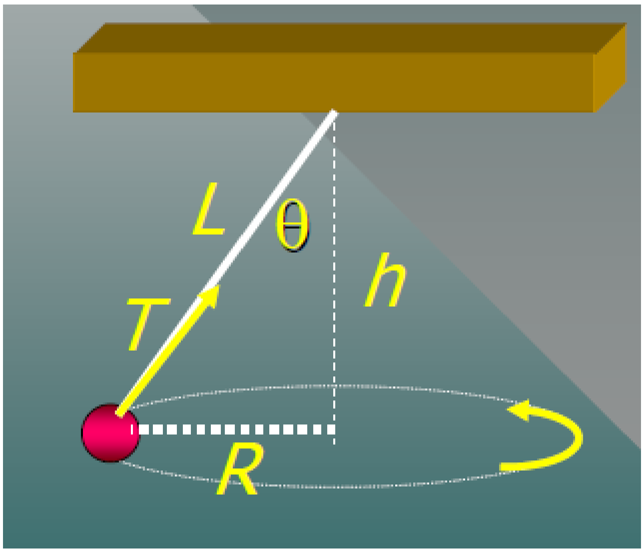


Figure 4.7 a conical pendulum

The vertical component of tension (T) is equal to the weight of the mass while the horizontal component of the tension generates the centripetal force for the circular motion.

5. At a fair ground.
As the cylinder spins, the floor drops away. Friction balances your weight. The centripetal force is generated by the contact force. That is why you feel as though you are being pushed back against the wall but what you are feeling is the push of the wall on your back.

Summary

Uniform circular motion is the motion of an object in a circle at a constant speed. Circular motion of an object is considered in terms of angular velocity.
Angular velocity is the rate of change of angular displacement. Angular displacement is the distance an object moves when following a circular path.
Linear velocity is related to angular velocity because the tangential distance covered by the turning object is equal to the arc covered on the circle.

Centripetal force is the force which acts on an object towards the centre of a circle to keep the object moving in a circle.

Circular motion can be used in highway curves, playground and satellites orbiting on Earth.

Student assessment

1. Define
   - **a.** Angular displacement
   - **b.** Angular velocity
   - **c.** Centripetal force

2. Explain the relationship between tangential (linear) velocity and angular velocity.

3. Explain **one** experiment that can be used to demonstrate objects in a circular motion.

4. State **three** applications of circular motion in everyday life.

5. State **three** factors that affect the size of the centripetal force.

6. Answer the following questions by using either **“increases”** or **“decreases”**. How does the centripetal force change if an object:

a. Has more mass
b. Travels at a slower speed
c. Travels round a tight curve?

CHAPTER 5

Moments of forces

Objectives

At the end of Chapter 5, you must be able to:

- ***Describe moment of force***
- ***Apply moments in everyday life***

5.1 Describing moment of a force

Why is the handle of the door far from the hinge? Why is it difficult to tighten a nut with a finger but it is easy to tighten with a spanner?
The handle of the door is far from the hinge so that you use a smaller force to open the door. A much larger force would be needed if the handle were near the hinge. It is difficult to tighten a nut with a finger but it is easy to tighten with a spanner because with a spanner, you can produce a larger turning effect.
The turning effect of the door is greater when you increase the distance from the handle to the hinge. Similarly, the turning effect is even greater if you increase the force or use a longer spanner. This turning effect is called a **moment of a force.**

Moment of a force is defined as the turning effect of a force from the pivot or fulcrum.
A moment of force about a point is the product of **force F** and the **perpendicular distance d** from the pivot or fulcrum to the line of action of the force.

Moment of a force = Force x perpendicular distance from the pivot or fulcrum

Whereby, force is in Newton (N), perpendicular distance in metres (m) and moment of a force is in Newtonmetres (Nm).

Experiment 5.1

AIM: To investigate the turning effect
MATERIALS: metre rule, I kg mass (10 N force)
PROCEDURE:

1. Hold a metre rule at point A as shown in **Figure 5.1** below.

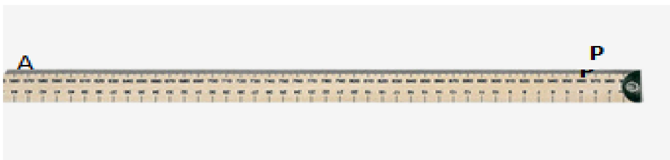


Figure 5.1

2. Suspend a 1kg mass at point P to produce a downward force on the ruler.

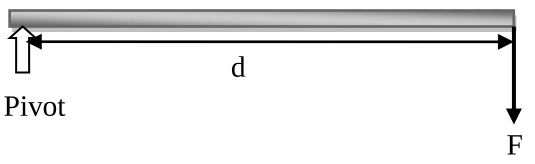
EXPLANATION/CONCLUSION

It will be observed that the mass produces the downward force. The downward force tries to turn the ruler.

Moment of a force is found by using a formula:

Moment of a force = force x perpendicular distance from point A

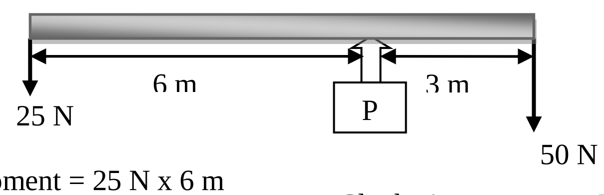
In **Figure 5.2**, the moment of a force F about the pivot P is given by Fd.



Moment of a force F = Fd

Figure 5.2 moment of a force about a pivot P

The moment of a force produces the effect (rotation) about the pivot P. The rotation can either be **clockwise** or **anticlockwise** depending on their direction.



Anticlockwise moment = 25 N x 6 m

Anticlockwise moment = **150 Nm**

Clockwise moment = 50 N x 3 m

Clockwise moment = **150 Nm**

Figure 5.3 clockwise and anticlockwise moments

In Figure 5.3, the 25 N force is trying to turn the ruler anticlockwise and its moment is 25 N x 6 m (150 Nm) while the 50 N force is trying to turn the ruler clockwise and its moment is 50 N x 3 m (150 Nm).

Variables that influence turning effect

Scientific practice indicates the variables that the influence turning effect are the magnitude of the force and the perpendicular distance the force is applied from the pivot.

Experiment 5.2

AIM: To confirm the variables that influence turning effect
MATERIALS: Door, hooks, metre ruler, spring balance
PROCEDURE:

1. Attach the hooks to the door at a measured distance from the turning point, to the side of the door with hinges.
2. Mark next to each hook the distance it is from the turning point.
3. Use a spring balance on each hook to cause the door to open the same space each time.
4. Record how much force was required to cause the door to open.

DISCUSSION
Where is the force required to turn the door:

- **a.** least?
- **b.** greatest?

5.2 Principle of moments for a body in equilibrium

Experiment 5.3

AIM: To verify principle of moments
MATERIALS: metre rule, weights, strings
PROCEDURE:

1. Suspend a metre rule as shown in **Figure 5.4.**
2. Position a weight W_1 tied to a string to the left of the rule.
3. Position a weight W2 tied to a string to the right of the rule and move it until the rule is balanced. Now the rule is said to be in equilibrium.
4. Read and record the distances, d_1 and d_2.

$\mathbf{d_2}$

EXPLANATION

From **Experiment 5.3**, the clockwise moment and anticlockwise moments were equal in all situations. Therefore, for the ruler to be in equilibrium, the clockwise moment (clock wise turning) must be equal to the anticlockwise moment (anticlockwise turning).

Clockwise moment = anticlockwise moment

Force x distance (left hand side) = Force x distance (right hand side)

$$\mathbf{W_1 \times d_1 = W_2 \times d_2}$$

This is known as the **principle of moments.**

The Principle of Moments states that **'for a body to be in equilibrium, the sum of clockwise moments must equal the sum of anticlockwise moments of force about any point.'**

Relationship between force and torque

Figure 5.5 shows a force acting on a rigid body.

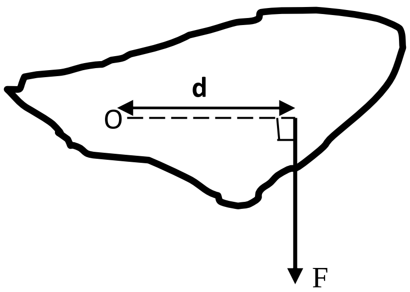


Figure 5.5 torque

A force can act on a rigid body to cause it to turn about an axis which is perpendicular to the paper and passes through O. The effect of the force is determined by its turning moment. The turning moment of a force is called a **torque.**

T = Fd

Where

T = torque (turning moment) in Newtonmetre **Nm**

F = the magnitude of the force in Newton **N**

d = the perpendicular distance of the line of action of the force from the axis in metre **m**

The magnitude of the torque increases with an increase in the size of the force.

Worked example

Calculate the torque of the 5 N force acting on the axis through O, in each case.

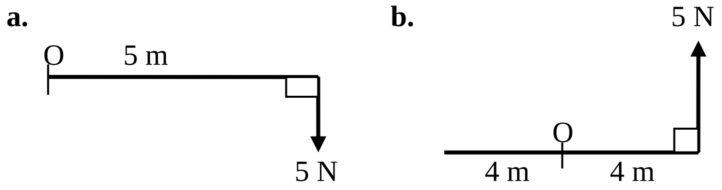


Figure 5.6

Solution

a. T = Fd

= 5 N x 5 m

T = **25 Nm**

b. T = Fd

= 5 N x 4 m

T = **20 Nm**

5.3 Applying principle of moments in our everyday life

Solving problems using principle of moments

Principle of Moments is given as:

Clockwise moments = anticlockwise moments

Force x distance (left hand side) = Force x distance (right hand side)

Worked examples

1. A ruler in **Figure 5.7** is in equilibrium. Calculate the size of the force F.

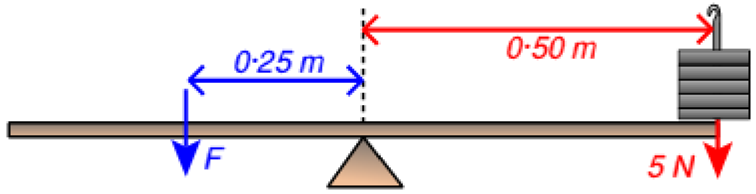


Figure 5.7

Solution

Clockwise moment = 5 N x 0.50 m

Anticlockwise moment = F x 0.25 m

Clockwise moment = Anticlockwise moment

5 N x 0.50 m = F x 0.25 m

$$F = \frac{5\text{ N} \times 0.50\text{ m}}{0.25\text{ m}}$$

F = **10 N**

2. Calculate the distance d in **Figure 5.8** assuming that the bar is in equilibrium.

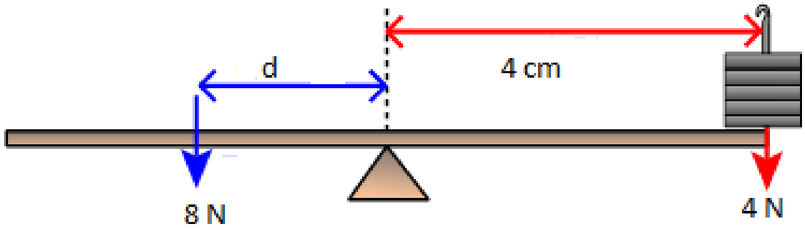


Figure 5.8

Solution

Clockwise moment = 4 N x 4 cm

Anticlockwise moment = 8 N x d

Clockwise moment = anticlockwise moment

4 x 4 cm = 8 N x d

$$F = \frac{4\text{ N} \times 4\text{ cm}}{8\text{ N}}$$

d = **2 cm**

3. Calculate the value of W, if the plank in **Figure 5.9** is in equilibrium.

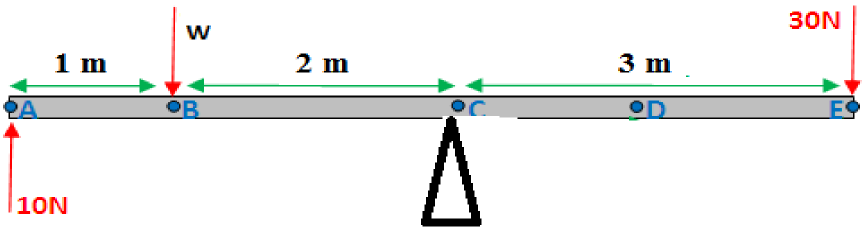


Figure 5.9

Solution

Clockwise moments = (10 N x 3 m) + (30 N x 3 m) = 120 Nm

Anticlockwise moment = W x 2 m

Clockwise moment = anticlockwise moment

120 Nm = W x 2 m

$W = \frac{120 \text{ Nm}}{2 \text{ m}}$

W = **60 N**

4. **Figure 5.10** shows a man of weight 700 N standing on a plank supported by two trestles, A and B. Calculate the upward forces F_1 and F_2.

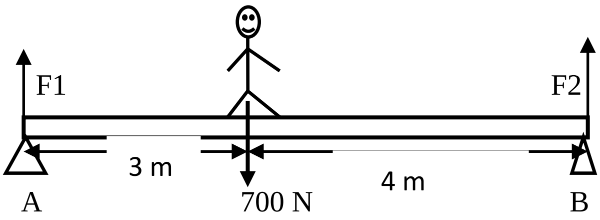


Figure 5.10

Solution

Taking moments about A

Clockwise moment = 700 N x 3 m = 2100 Nm

Anticlockwise moment = F_2 x 7 m

Clockwise moment about A = anticlockwise moment about A

2100 Nm = F_2 x 7 m

$F_2 = \frac{2100 \text{ N m}}{7 \text{ m}}$

F_2 = **300 N**

Taking moments about B

Clockwise moment = F_1 x 7 m

Anticlockwise moment = 700 N x 4 m = 2800 Nm

Clockwise moment about B = anticlockwise moment about B

$2800 \text{ Nm} = F_1 \times 7 \text{ m}$

$F_1 = \dfrac{2800 \text{ N m}}{7 \text{ m}}$

$F_1 = \mathbf{400\ N}$

Exercise 5.1

In your groups, calculate the value of the letters a and b in **Figure 5.11**, if the metal bars are in equilibrium.

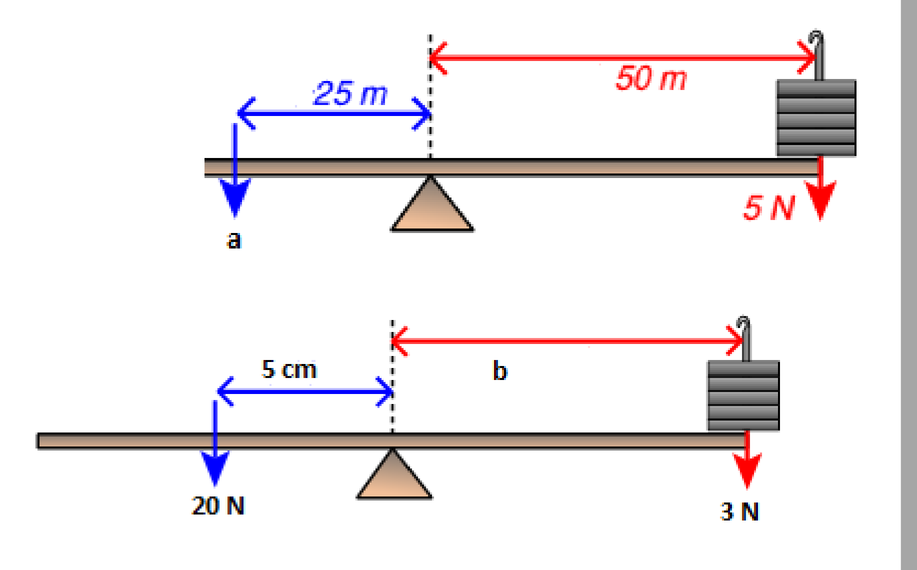
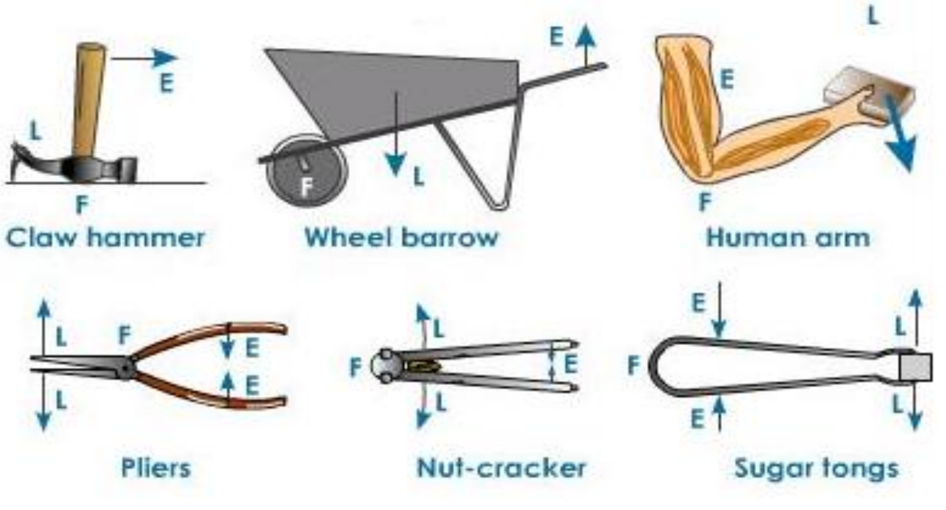


Figure 5.11

The systems involving moments

Moments are used mainly in **levers.**
A **lever** is any device that can turn about a pivot.
In a lever a force called **effort** is used to overcome a resisting force called **load.**

Figure 5.12 are some examples of systems that use the principle of moments of a force.



Centre of mass

Centre of mass is the point on the object where all the mass is said to be focused. The centre of mass acts as though the total mass of the object were at that point. The centre of mass of a rigid object is the same position as its **centre of gravity.**

Centre of gravity is the point through which the earth's gravitational force acts on the object.

Determining centre of mass in lamina

- A **lamina** is a three-dimensional shape that is so thin that it can be considered to be two dimensional. An example of a lamina is a piece of card.

Experiment 5.4

AIM: To identify the centre of mass of a lamina
MATERIALS: retort stand, string, card, pin, mass
PROCEDURE:

1. Cut out the card in an irregular shape.
2. Allow the card to swing freely from a pin fixed in a retort stand.

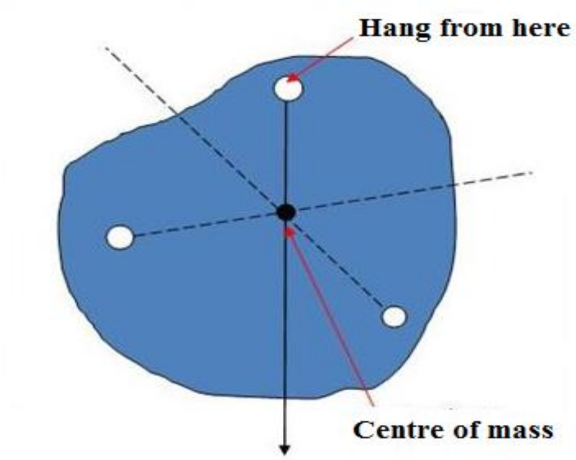


Figure 5.13

3. Hang a mass on a thread from a point on the perimeter of the card as shown in **Figure 5.12.**
4. Mark a line on the card following the path of the thread.
5. Repeat this procedure five times and record the observations.

EXPLANATION
When you repeat the procedure five times, all five lines will cross at the same point on the card. If a pencil is placed on this point it should be possible to precisely balance the card. This point is called the **centre of mass** or **centre of gravity**. The lines that are drawn are called **plumb lines.**

Centre of mass in uniform rods

A uniform rod is the one in which the mass is distributed evenly along its length. For example, a metre rule.
The metre rule can be subdivided into four equal numbered pieces, each of mass m. We can work out an equation to find the midpoint:

$$M = 4\ m$$

$$\text{Mid point} = \frac{4\ m}{2}$$

$$\text{Mid point} = \mathbf{2\ m}$$

Therefore, the centre of mass or centre of gravity **G** is at 2 m as shown in **Figure 5.14.**

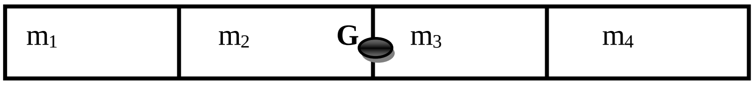


Figure 5.14 centre of mass of a uniform rod

Summary

Moment of a force is defined as the turning effect of a force from the pivot or fulcrum.
Moment of a force = Force x perpendicular distance from the pivot or fulcrum.
The SI unit of the moment of a force is Nm.

Moment of a force depends on the size of a force and the perpendicular distance from where the force is applied to where the pivot is.

The Principle of Moments states that **'for a body to be in equilibrium, the sum of clockwise moments must equal the sum of anticlockwise moments of force about any point.'**

Clockwise moment = anticlockwise moment
Force x distance (left hand side) = Force x distance (right hand side)

The turning moment of a force is called a **torque.**

T = Fd

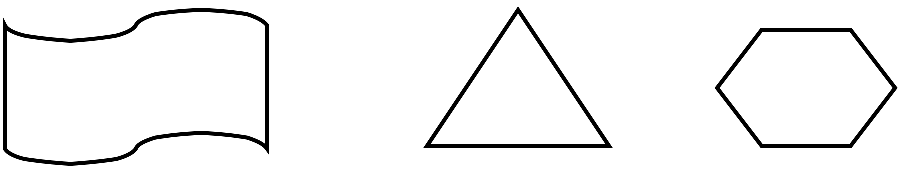
Moments are used mainly in **levers** e.g. crowbar, wheelbarrow, forearm, bottle openers, pair of scissors, hoe, toilet flusher, fork, spatula, bat, teeter-totter, clippers, rake and stapler.
Centre of mass is the point on the object where all the mass is said to be focused. The centre of mass of a rigid object is the same position as its **centre of gravity.**
Centre of gravity is the point through which the earth's gravitational force acts on the object.

Student assessment

1. Define
  a. Moment of a force
  b. Centre of mass.

2. State the principle of moments.

3. Draw plumb lines to find the centre of mass in the following shapes:



(a) **(b)** **(c)**

Figure 5.15

4. State **two** factors that affect the moment of a force.

5. The bar in **Figure 5.15** is in equilibrium, calculate the value of x.

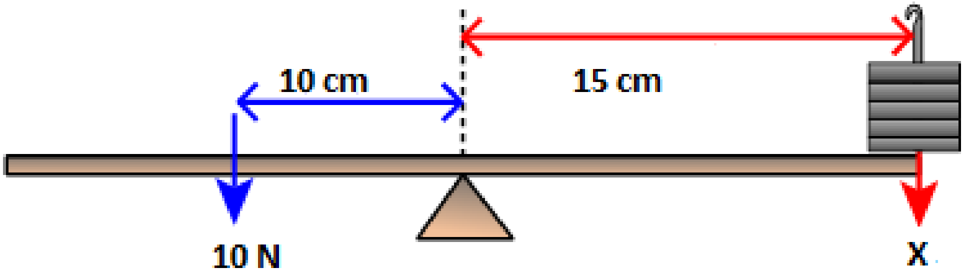


Figure 5.16

5. **Figure 5.17** shows a man of weight 600 N standing on a plank supported by two trestles, P and Q. Calculate the upward forces F_1 and F_2.

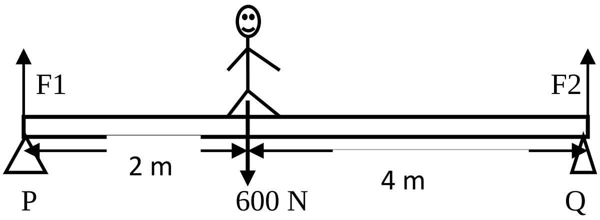


Figure 5.17

6. Describe how you would determine, by experiment, the centre of mass of an irregular shaped cardboard.

7. **Figure 5.18** shows a force of 100 N acting about the axis through O and perpendicular to the paper. Calculate the torque of the force.

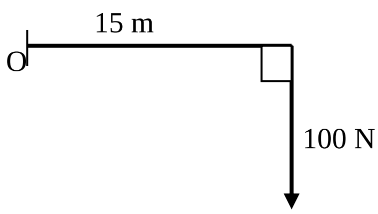


Figure 5.18

8. Describe an experiment that you would carry out to verify the turning effect of a force.

CHAPTER 6

Magnetism and electromagnetism

Objectives

At the end of chapter 6, you must be able to:

- ***Describe magnetisation and demagnetisation***
- ***Describe electromagnetism***
- ***Explain uses of electromagnetism***

6.1 Magnetisation and demagnetisation

Magnetic substances
These are substances that are attracted to a magnet. Only certain substances are magnetic. Examples of magnetic substances are iron, cobalt, nickel, and steel. These substances are known as **ferromagnetic substances** and they can be described as either hard or soft.

Magnetisation

Magnetisation is the process of making a magnetic material become a magnet. Magnetism is induced in these magnetic materials so that they become magnets. The process is then called **magnetic induction** and the magnetism is called **induced magnetism.**

Induced magnetism is the magnetism which is introduced in magnetic materials, for example in steel and iron metals. This is caused by magnetising magnetic materials.

Methods of magnetisation

The following are the methods used to make magnets:

a. Induction

Experiment 6.1

AIM: To demonstrate magnetic induction
MATERIALS: Permanent magnet, iron paper clips.
PROCEDURE:
1. Bring two similar iron paper clips together and observe what happens.
2. Bring one iron paper clip to the pole of a magnet and observe what happens.
3. Then bring the other iron paper clip to the first iron nail. Observe what happens.

RESULTS
If you bring two similar iron paper clips together, nothing happens.
If you bring one iron paper clip to the pole of a magnet it is attracted.
If you bring the other iron paper clip to the first one, it is attracted to the first iron paper clip.

EXPLANATIONS/CONCLUSION
Nothing happens if you bring two similar iron paper clips because the iron paper clips have no magnetic forces. If you bring one iron paper clip to the pole of a magnet it is attracted to a magnet because of the magnetic forces. If you bring the second iron paper clip to the first one, it is attracted because the first iron paper clip has magnetic forces.

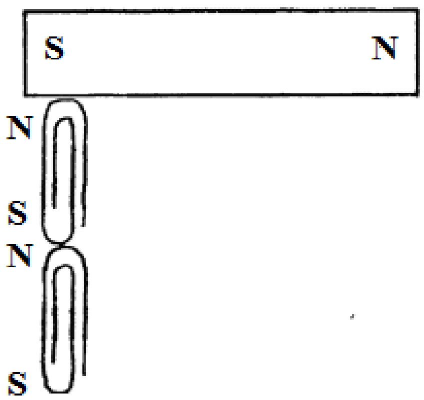


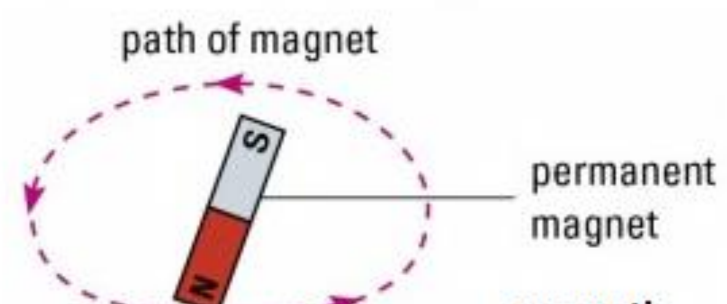
Figure 6.1 magnetising iron paper clips

Therefore, the first iron paper clip becomes a magnet itself. The iron paper clip becomes a magnet by aprocess called **magnetic induction.**

b. Stroking method

A piece of steel or iron metal is stroked by a bar magnet. The stroked side gains magnetism but of opposite polarity. This can be single touch or double touch.

Single touch
This is a method of magnetising a magnetic material by stroking it repeatedly with the pole of a permanent magnet. The magnetic material is stroked from end to end about 20 times in the same direction by the same polarity of a permanent magnet. Magnetism is induced in the object from the magnetic field of the magnet.



After stroking a magnetic material, it gains the opposite polarity.

Double touch

This is a method of magnetising an object by stroking it rapidly from the centre out with the opposite poles of two permanent magnets. Magnetism is induced in the magnetic material from the magnetic field of the magnets. The pole produced at the end of the magnetic material where the stroke ends is of opposite kind to that of the stroking pole.

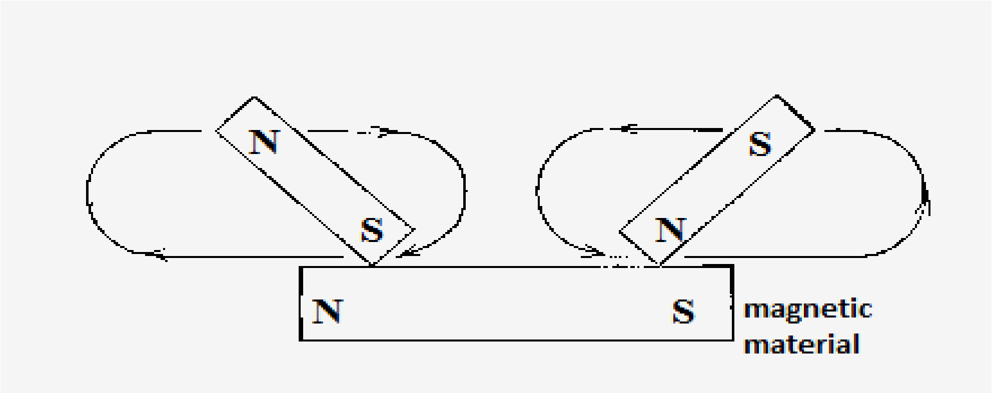


Figure 6.3 double touch stroking method of magnetising

NOTE: A steel metal keeps the induced magnetism and it becomes a permanent magnet. Steel is called **hard magnetic material.**

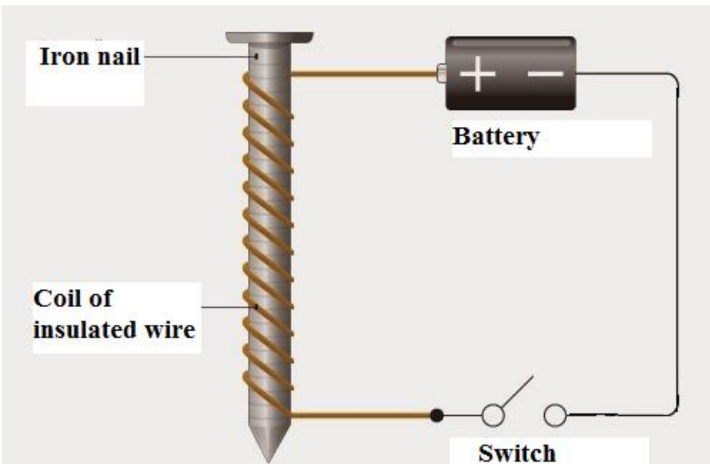
An iron metal loses its magnetism after a short period of time hence it forms a temporary magnet. Iron metal is called a **soft magnetic material.**

c. Electrical method

Experiment 6.2

AIM: To investigate electrical method of making a magnet
MATERIALS: Iron bar, connecting wire, cell, switch, iron nail
PROCEDURE:

1. Form a solenoid (coiled wire) by coiling the wire.
2. Insert an iron bar in a solenoid.
3. Set up the experiment as shown in **Figure 6.4.**



EXPLANATION
When the iron nail is brought closer to an iron bar with the switch open, nothing happens because the metal bar is not a magnet.
When the iron nail is brought closer to an iron bar with the switch closed, it is attracted. Therefore, an iron bar becomes a magnet when electric current goes through the wire.

Demagnetisation

Demagnetisation is the removal of magnetism from an object.

A magnet can get demagnetized by the following methods:

- **a.** Heating strongly
- **b.** Hammering or dropping the magnet
- **c.** Placing a magnet in a coil carrying alternating current
- **d.** Stopping the flow of current in a circuit and in a coil where a metal rod is placed.

Magnetisation and demagnetisation in terms of domain

Ferromagnetic materials consist of dipoles or molecular magnets, which interact with each other. These are all arranged in areas called **domains,** in which they all point in the same direction.
When a material is not magnetised this direction varies from one domain to the next as shown in **Figure 6.5.** The magnetic axes of the domains form closed loops; overall, the magnetic effects of the domains cancel.

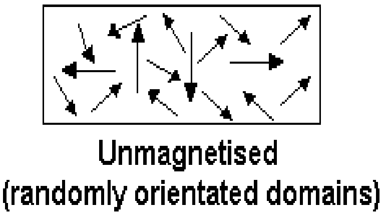


Figure 6.5 unmagnetised ferromagnetic material

When a ferromagnetic material is magnetised, domain axes turn so that more molecular magnets end up with their magnetic axes in the same direction as shown in **Figure 6.6.** The poles of each molecule cancel out the effects of opposite poles nearby, but uncancelled or ‘free’ poles are left at both ends. The ‘free’ poles around each end of the material together produce the effect of a single North pole or South pole just in the end.

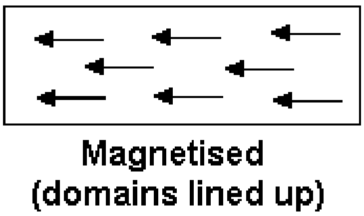


Figure 6.6 magnetised ferromagnetic material

Exercise 6.1

In your groups, answer the following questions:

1. Define
a. ferromagnetic materials
b. domains.

2. Explain **two** ways in which a ferromagnetic material can be magnetised.

3. Explain the difference between
a. a soft ferromagnetic material and a hard ferromagnetic material.
b. a temporary magnet and a permanent magnet.

4. State **three** ways in which a magnet can be demagnetised.

6.2 Electromagnetism

If current is passed through a conductor, it produces magnetism. This is through the deflection of the compass needle pointer. **Experiment 6.1** is used to investigate the relationship between current and magnetism.

Experiment 6.1

AIM: To investigate a current carrying wire
MATERIALS: connecting wire, compass, card, dc supply.
PROCEDURE:

1. Arrange the wire passing vertically through the card.
2. Close the switch and observe what happens to the compass on the card.
3. Move the compass 360^0 around the wire and note how the compass changes.
4. Reverse the current and observe what happens to the compass on the card.
5. Repeat the experiment by increasing the number of cells.
6. Observe what happens to the compass needle point.

RESULTS
When the switch is closed, the compass needle is deflected.
When a compass needle pointer is moved 360^0 around the wire it deflects in the same direction.
Reversing the current reverses the direction in which the compass needle points.
Increasing the number of cells increases the size of deflection of the compass needle pointer.

EXPLANATION/CONCLUSION
The compass needle is deflected because of the presence of the magnetic field. The compass needle pointer points in the direction of the magnetic field.
A compass needle pointer forms a magnetic field pattern when moved around at 360^0, as shown in **Figure 6.7.**

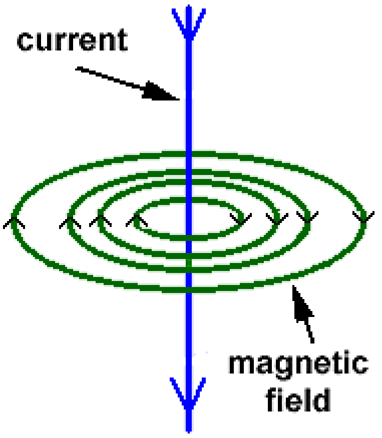


Figure 6.7 magnetic field around a conductor

Reversing the direction of current also reverses the direction of deflection because the direction of magnetic field lines reverses.
Increasing the number of cells increases the size of deflection because the size of the magnetic field is increased.

The directions of current and magnetic field are found by using the following:

a. Maxwell's Corkscrew Rule

This rule relates to the direction of the magnetic field to the direction of the current. Maxwell's Corkscrew rule was imagining a right-handed person screwing a right handed screw along the wire. **The direction of the screw is the direction of current, whilst the direction of the motion of the thumb gives the direction of lines of force.**

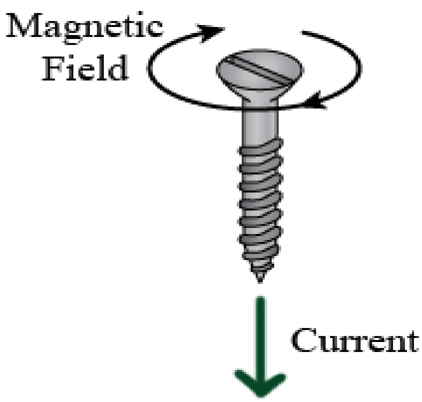


Figure 6.8 Maxwell's Corkscrew rule.

b. Right hand grip rule

The directions of current and magnetic field are found by using the right-hand grip rule i.e the thumb points in the direction of current and the fingers point in the direction of magnetic field.

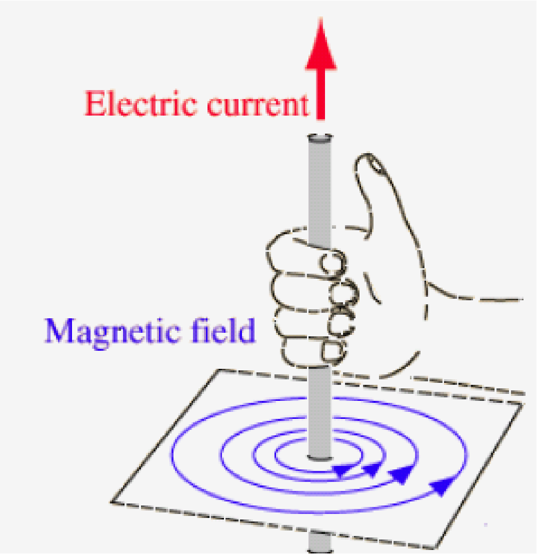


Figure 6.9 right hand grip rule

Magnetic field due to current in a loop

When a current flows into a loop, a magnetic field is created around the loop. **Figure 6.10** shows a magnetic field pattern produced by a current flowing in a loop.

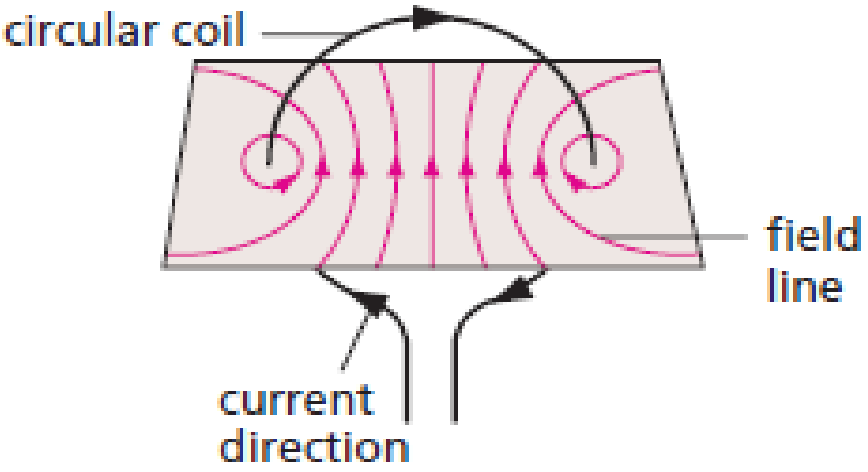


Figure 6.10 magnetic field in a loop

The field pattern around the coil produces two magnetic poles. One is the North Pole and the other faces the South Pole.

Magnetic field in a solenoid

A solenoid is a long-coiled length of wire. It is made up of several turns of wire. A magnetic field pattern is produced around a solenoid when a current is flowing through it as illustrated in **Figure 6.11.**

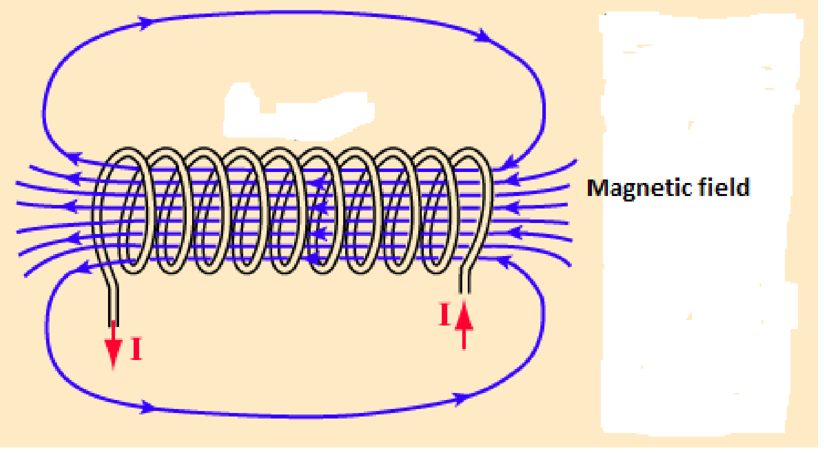


Figure 6.11 magnetic field pattern around a solenoid

The strength of magnetic field produced in a solenoid can be increased by:

- **a.** Increasing the number of turns in a solenoid.
- **b.** Increasing the amount of current flowing in a solenoid.
- **c.** Placing a ferromagnetic material e.g. iron in a solenoid.

Force on a current carrying conductor

Experiment 6.3

AIM: To determine the effect of placing a current carrying conductor in a magnetic field of a bar magnet.

MATERIALS: Connecting wires, two magnets, power supply.

PROCEDURE:

1. Place a conductor between two magnets.
2. Connect each end of a conductor to a power supply and allow an electric current to flow through the wire.

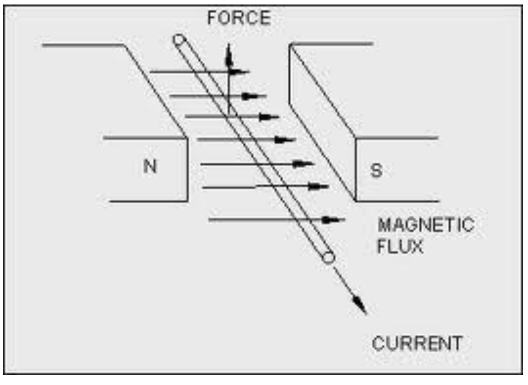


Figure 6.12

RESULTS
The observations would show that the conductor is moved up when the current was in one direction and moved down when the direction of the current is reversed.

EXPLANATIONS
When current flows through a conductor, a magnetic field is produced. Placing the current carrying conductor in a magnetic field causes a force to be exerted in the conductor because of the interaction between two magnetic fields. The North pole of the magnetic field in a conductor repels the North pole of the magnetic field in a bar magnet. The South pole of the magnetic field in a conductor repels the South pole of the magnetic field in a bar magnet.

CONCLUSION
The above results lead to the conclusion that a force is provided on a current-carrying conductor in a magnetic field of a bar magnet.

Fleming's left-hand rule

A scientist called Fleming summarised the relationship between the direction of the magnetic field, the current in the wire and the direction that the wire would move in a rule called **Fleming's left hand rule.**
Fleming's left hand rule is used to find the directions of magnetic field, current and force.

If the thumb, first finger and second finger are held at right angles to each other, then

- The thu**M**b represents the direction of **M**ovement (force).
- The **F**irst finger represents the direction of magnetic **F**ield.
- The se**C**ond finger represents the direction of **C**urrent.

The direction of force or push can change by the following:

a. Reversing the direction of the magnetic field.
b. Reversing the direction of current.

The size of the force applied on the wire can be increased by the following:

a. Increasing the amount of current.
b. Using a stronger bar magnet.
c. Increasing the length of the wire which is within the magnetic field.

Applying Fleming's left hand rule

Fleming summarized the relationship between the direction of the magnetic field, the current in the wire and the direction that the wire would move into. This lead into an effect called the motor effect. Therefore, Fleming's left hand rule is applied in electric motors and moving coil galvanometer.

Electric motor
An electric motor consists of a coil in the magnetic field.
An electric motor is a device that converts electrical energy into kinetic energy (energy of movement).
An electric motor uses the turning effect of a conductor when it is placed in a magnetic field.

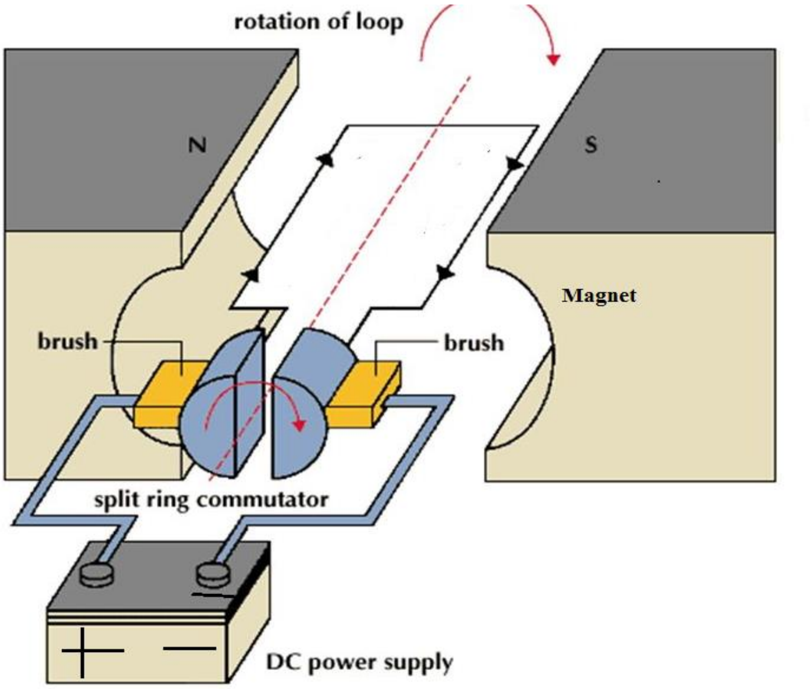


Figure 6.14 electric motor.

When the switch is closed, current flows through the coil and produces a magnetic field. The magnetic field produced in the coil and that in the permanent magnet interact. The interaction of the magnetic fields causes a push on the left side of the coil. The coil rotates in a clockwise direction and stops at a vertical position. But its momentum or inertia carries it forward. The motor keeps on rotating, hence the motor effect.

The direction of rotation of the motor can be changed by:

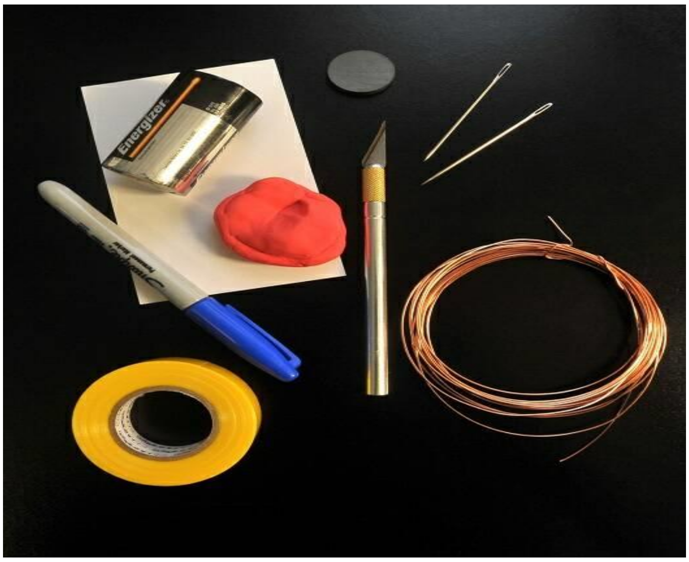
- **a.** Reversing the direction of the magnetic field.
- **b.** Reversing the direction of the current.

The speed of rotation of the coil can be increased by:

- **a.** Increasing the current.
- **b.** Increasing the number of turns in the coil.
- **c.** Increasing the strength of a permanent magnet.
- **d.** Increasing the area of the coil placed in the magnetic field.

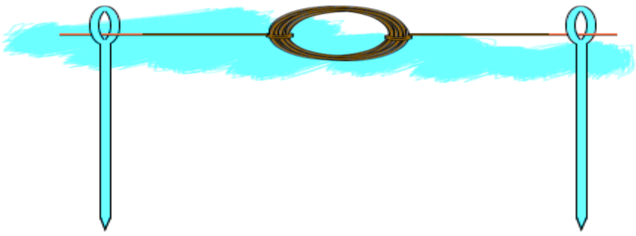
PROJECT

AIM: To make a simple motor
MATERIALS: D battery, insulated 22G wire, 2 large-eyed, long, metal sewing needles (the eyes must be large enough to fit the wire through), modeling clay, electrical tape, hobby knife, Small circular magnet, thin marker

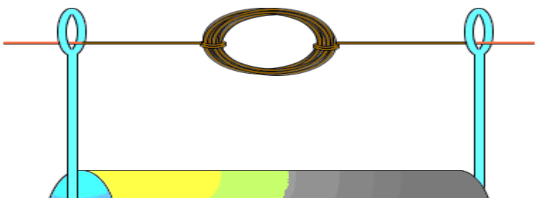


PROCEDURE

5. Thread each loose end of the wire coil through the large eye of the needle. Try to keep the coil as straight as possible without bending the wire ends.



6. Lay the D battery sideways on a flat surface.
7. Stick some modeling clay on either side of the battery so it does not roll away.
8. Take 2 small balls of modeling clay and cover the sharp ends of the needle.
9. Place the needles upright next to the terminals of each battery so that the side of each needle touches one terminal of the battery.



RESULT

The motor will continue to spin when pushed in the right direction.

EXPLANATION

The metal, needles, and wire created a closed loop **circuit** that can carry current. Current flows from the negative terminal of the battery, through the circuit, and to the positive terminal of the battery. Current in a closed loop also creates its own **magnetic field**, which you can determine by the **"Fleming's Right Hand Rule."**

In our case, current travels through the coil you created, which is called the **armature** of the motor. This current induces a magnetic field in the coil. The two magnetic fields interact. The interaction between two magnetic fields causes a push on the coil. The coil continues rotating due to inertia.

Moving-coil galvanometer

A moving-coil galvanometer consists of a coil of many turns of enameled copper wire wound into aluminium foil as shown in **Figure 6.15.**

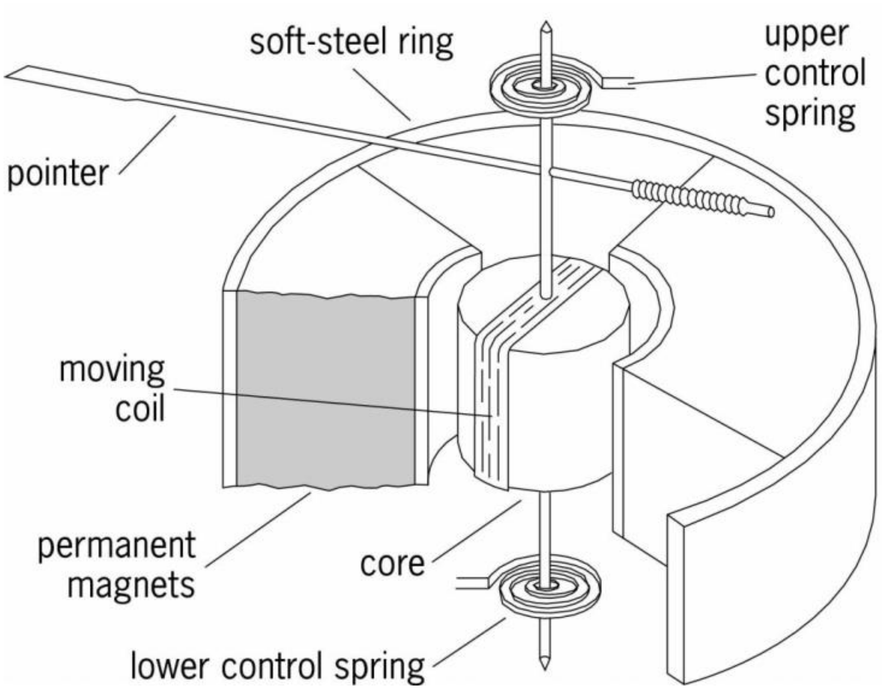


Figure 6.15 moving-coil galvanometer

A moving-coil galvanometer uses the Fleming's left hand rule and uses the same ideas as the electric motor.
When current flows through the coil, it produces a magnetic field. The magnetic field in the coil interacts with the magnetic field in the permanent magnet. The interaction between two magnetic fields causes the coil to rotate. The rotation causes the pointer to move across the scale.

The speed of rotation of the coil and the twisting of the pointer can be increased by:

a. Increasing the size of the current. The larger the amount of current, the faster the rotation of the coil and the larger the twist of the pointer. The scale has numbers that show the size of current. Therefore, a moving-coil galvanometer measures current. It measures very small current in milliamperes (mA).
A galvanometer can also be changed and have a suitable scale to measure small voltages in millivolts (mV).
b. Increasing the number of turns in the coil.
c. Increasing the strength of a permanent magnet.
d. Increasing the area of the coil placed in the magnetic field.

The direction of rotation of the coil and twisting of the pointer can be changed by:

c. Reversing the direction of the magnetic field.
d. Reversing the direction of current.

Disadvantages of moving-coil galvanometer are:

- Cannot measure alternating current. The frequency of the alternating current is much greater than the frequency at which the coil can oscillate.

▪ Cannot measure a large current. It can easily break the suspension wire with a large current.

Moving-coil loudspeaker

The moving-coil loudspeaker has three main parts:

1. A cylindrical permanent magnet. It produces a strong radial magnetic field.
2. A voice coil which is free to vibrate in the radial magnetic field.
3. A stiff paper cone attached to the coil.

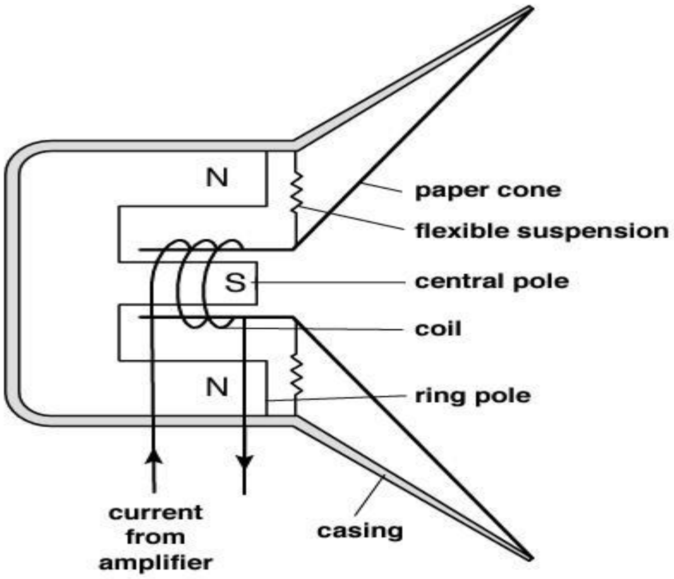


Figure 6.16 moving-coil loud speaker

When magne

the coil in accordance with Fleming's left hand rule.

When the "to-and-fro" of an alternating current is passed through the coil it makes the paper cone vibrate, and the sound waves are given out as a result.

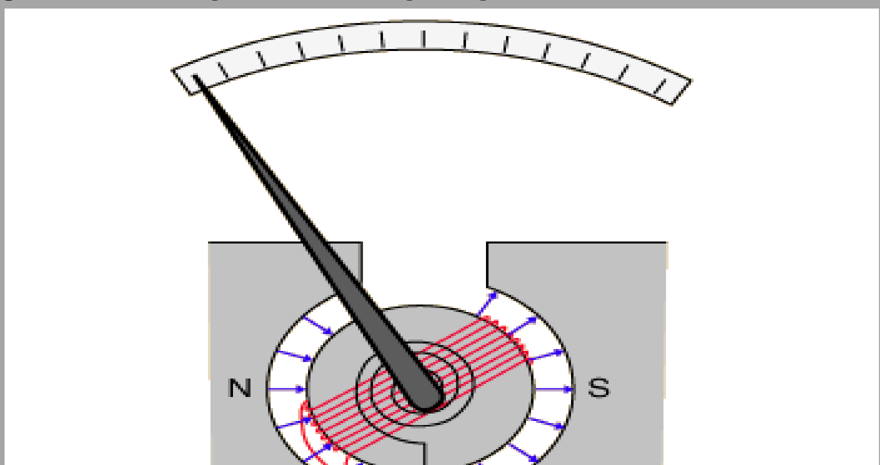
Exercise 6.2

In your groups, answer the following questions:

1. With the aid of well labeled diagrams, discuss how the following work:

a. a motor **b.** a moving-coil loudspeaker

2. Figure 6.17 is a diagram of a moving coil galvanometer.



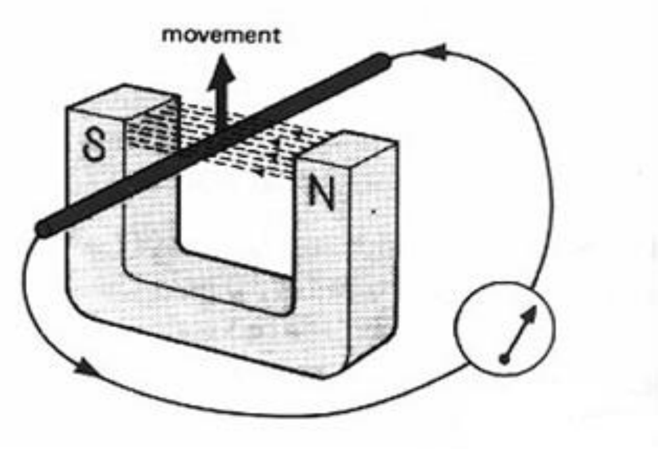
6.3 Uses of electromagnetism

If a current carrying wire can produce a magnetic field, can a magnetic field produce current in a wire? This question was first answered, experimentally, by Michael Faraday as **Experiments 6.4 and 6.5. show below:**

Experiment 6.4

AIM: To produce emf from a magnetic field.
MATERIALS: magnet, wire, galvanometer.
PROCEDURE:

1. Arrange the apparatus as shown in **Figure 6.18**.
2. Connect the ends of the wire to a very sensitive centre-zero galvanometer.



OBSERVATIONS

1. Procedure **3**: The pointer of the galvanometer deflects to the right.
2. Procedure **4**: The pointer of the galvanometer deflects to the left.
3. Procedure **5**: The pointer of the galvanometer deflects to the right then left continuously.
4. Procedure **6**: The pointer of the galvanometer deflects faster to the right then left continuously.

EXPLANATIONS

The pointer of the galvanometer is deflected to the right when the wire is moved down quickly, at right angles to the magnetic field because emf is being forced to flow through the wire. This is achieved through the cutting of the wire on the magnetic field. This type of emf is called **induced emf**. The process by which this current is induced is called **electromagnetic induction.**

Changing the direction of movement of the wire changes the direction of the deflection of the pointer because the direction of emf changes. Moving the wire continuously deflects the pointer to-and-fro continuously, therefore the induced emf is **alternating current** (current whose direction in a circuit changes at regular intervals).

Increasing the speed of the moving wire increases the speed of deflection of the pointer because the magnitude (size) of the induced emf increases. This shows that a quicker movement induces a larger emf in a moving wire.

CONCLUSION

Therefore, observations have confirmed that magnetic field produces current or emf in the wire. This means that the amount of induced emf in a wire can be increased by:

- Moving the wire at higher speed up and down at right angles to the magnetic field.
- Increasing the length of the wire which cuts the magnetic field.
- Increasing the strength of a bar magnet.

Directions of magnetic field, induced current or emf and motion of a wire can be found by using **Fleming's right hand rule.**

If the thumb, the first finger and the second finger are mutually at right angles to each other:

- The thu**M**b represents the direction of **M**otion of the wire.
- The **F**irst finger represents the direction of the magnetic **F**ield.
- The se**C**ond finger represents the direction of **C**urrent or induced emf.

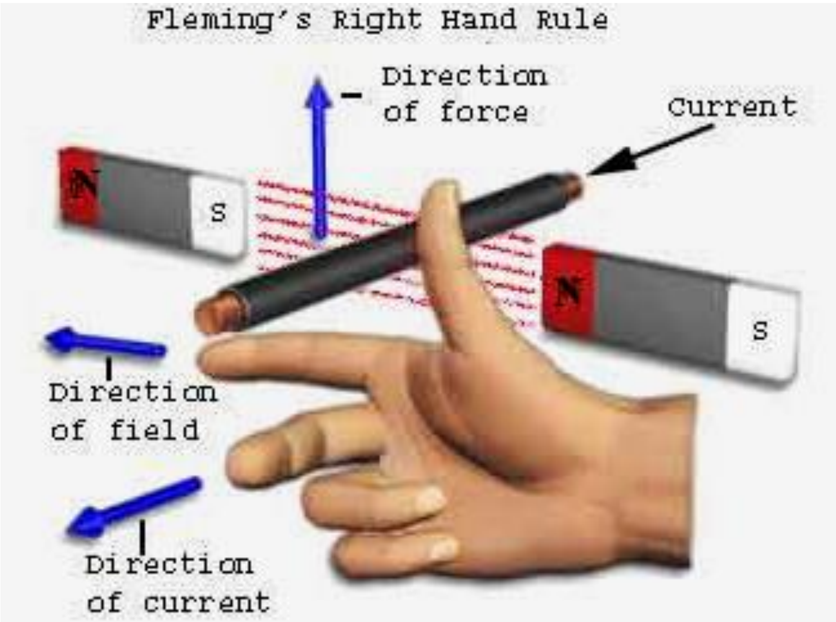


Figure 6.19 Fleming's right hand rule.

Experiment 6.5

AIM: To illustrate electromagnetic induction

MATERIALS: Solenoid, bar magnet, galvanometer

PROCEDURE:

1. Set up the experiment as shown in **Figure 6.20** below

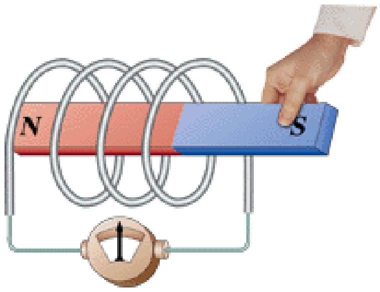


Figure 6.20

DISCUSSIONS

From **experiment 6.5:**

1. Explain your observations in procedures 2, 3 and 4.
2. What conclusion can you draw from these observations?
3. Explain what will happen to the pointer of the galvanometer when
   - **a.** The bar magnet is continuously moved in and out of a permanent solenoid at a higher speed.
   - **b.** A stronger bar magnet is used.
   - **c.** The number of turns in a stationary solenoid is increased.

Laws of electromagnetic induction

Faraday's law

Faraday suggested that emf is induced in a conductor whenever it cuts magnetic field lines (moving across them, but not when it moves along them or it is at rest).

Faraday's law states that **the magnitude (size) of the induced electromotive force in a conductor is proportional to the speed of motion of the magnet.**

Lenz's law

Lenz's law states that **an induced electromotive force always acts to oppose the cause.** Therefore, an induced current always flows in a direction such that it opposes the change producing it.

Generators

Generators make use of electromagnetic induction and they are based on the principle that a current can be induced in a coil by rotating it in a magnetic field.
Generators are of different sizes. For example, dynamos are small generators that provide current for cycle lights and alternators are huge generators that supply electricity to homes and industries.
Generators can either be a.c. generators or d.c. generators.

The AC generator

The basic structure of an ac generator includes a coil plus two slip rings as shown in **Figure 6.21.**

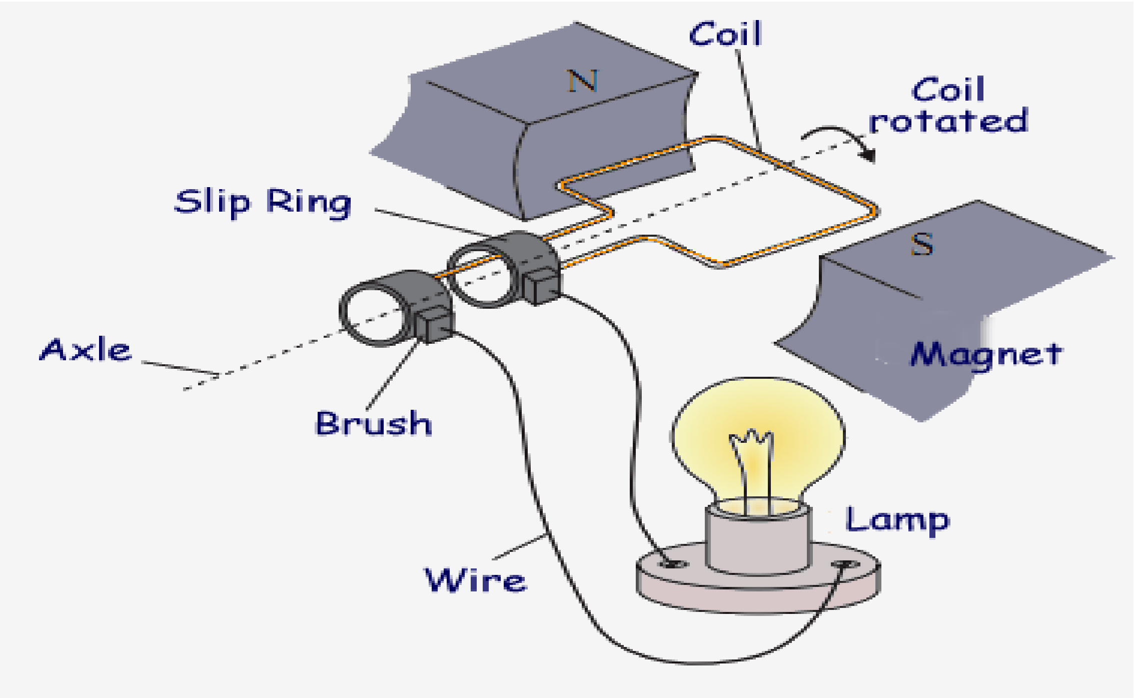


Figure 6.21 Ac generator

An a.c generator is made of a coil that rotates within a permanent magnet.
When a coil rotates between the poles of a magnet, an emf or current is induced in it because the coil cuts the magnetic field. The induced current is taken to the external circuit through the brushes. The output current is in the form of a.c. The alternating current, so produced, changes direction as the coil turns through 360^0. The value is at peak when the coil is cutting most magnetic field lines. It falls away to zero as the coil moves out of the region and then begins to rise again but in the opposite direction as the coil moves back into the maximum region of magnetic field.

The alternating current produced is illustrated by the diagram and the graph in **Figure 6.22.**

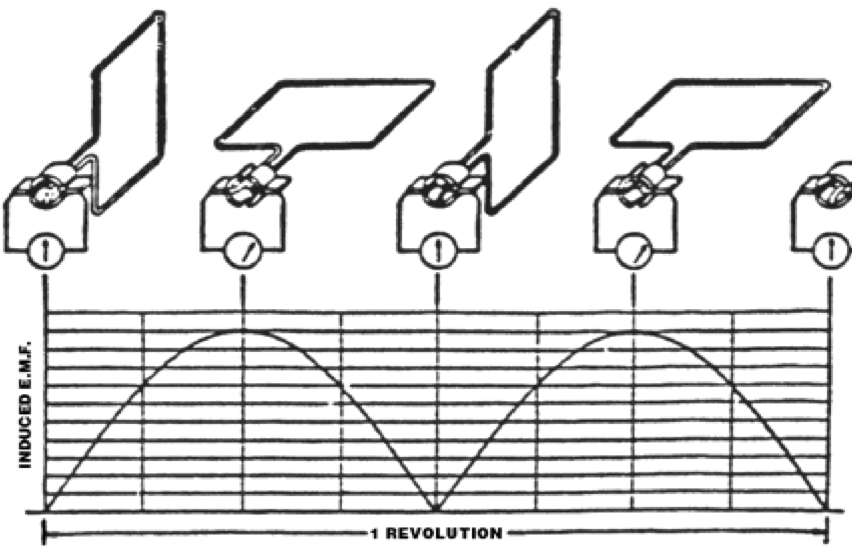
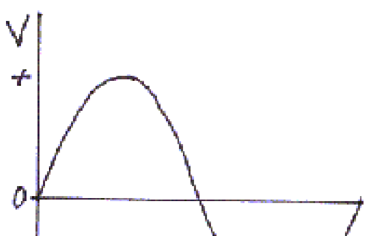


Figure 6.22(a) production of generator's AC output emf



The ways of increasing the magnitude (size) of induced current are:

- Increasing the strength of a magnet.
- Increasing the speed of rotation of a coil.
- Increasing the number of turns of a coil.
- Increasing the length of the coil which is within the magnetic field.

NOTE: Input energy to an a.c. generator is kinetic energy (rotation) and the output energy is electrical energy. Therefore an a.c. generator is a device that converts kinetic energy to electrical energy.

The DC generator

An ac generator becomes a dc generator if its slip rings are replaced by split ring commutator, like that in a d.c. motor. The brushes are arranged so that as the coil goes through the vertical position, the changeover of contact occurs from one half of the split ring to the other. The reversing of the connections with the outside circuit every time the coil passes through the vertical makes the current in the outside circuit always flow in the same direction, hence, direct current (dc). One brush is always positive and the other negative.

Figure 6.23 is a diagram of a d.c. generator which in reality is just a d.c. motor worked in reverse. Instead of a current being passed through the coil to produce rotation, the coil is rotated to produce a current.

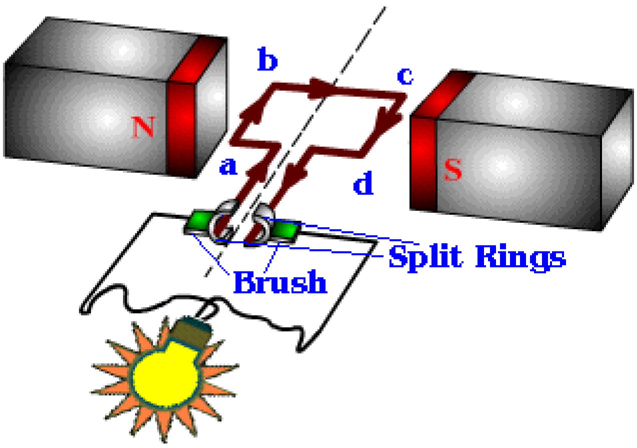


Figure 6.23 a simple d.c. generator

The d.c. generator current output is shown in **Figure 6.24**.

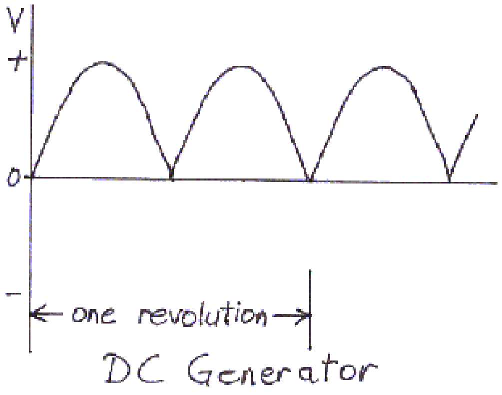


Figure 6.24 d.c. generator current output

Exercise 6.3

In your groups, answer the following questions:

1. State Fleming's left hand rule.
2. Figure 6.25 is a coil of wire held between the poles of a magnet. The end of the coil is connected to a milliammeter.

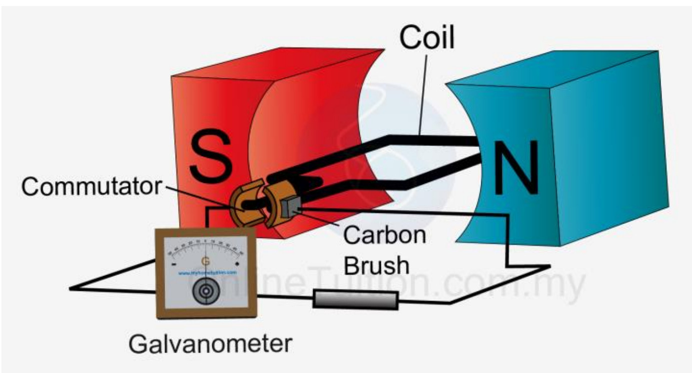


Figure 6.25

a. When a coil is rotated, explain why the milliammeter gets deflected.
b. State **two** ways of increasing the deflection of a milliammeter.
c. State the device that uses this effect.

3. With the aid of well labeled diagrams explain the differences between an electric motor and a generator.

4. Describe a simple experiment to illustrate electromagnetic induction.

Transformers

The appliances that we use in our homes require different amount of voltages to operate.
For example: A radio requires 12 V while a TV requires a huge internal voltage.
To obtain a range of voltages we use a device called transformer. A **transformer** is a device which changes voltage from one level to another. It can change either high voltage to low voltage or low voltage to high voltage.

A transformer consists of two coils (solenoids). The coil that is connected to the power supply is called the **primary coil** and the one connected to the load (output) is called the **secondary coil**.
The coil is wound on soft iron core. Energy is continuously transferred from the primary coil to the secondary coil.

Experiment 6.6

AIM: To demonstrate mutual inductance.
MATERIALS: thin copper wire, a.c. power supply, galvanometer.
PROCEDURE:

1. Make two coils as shown in **Figure 6.26**.
2. One side of the coil must be connected to the a.c. supply while the other side of the coil must be connected to a galvanometer.

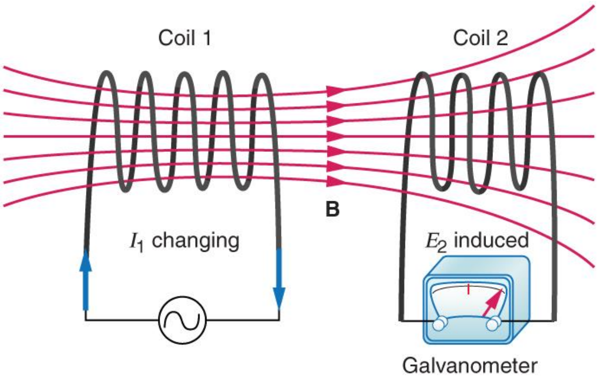


Figure 6.26

3. Close the switch. Observe what happens to the galvanometer.

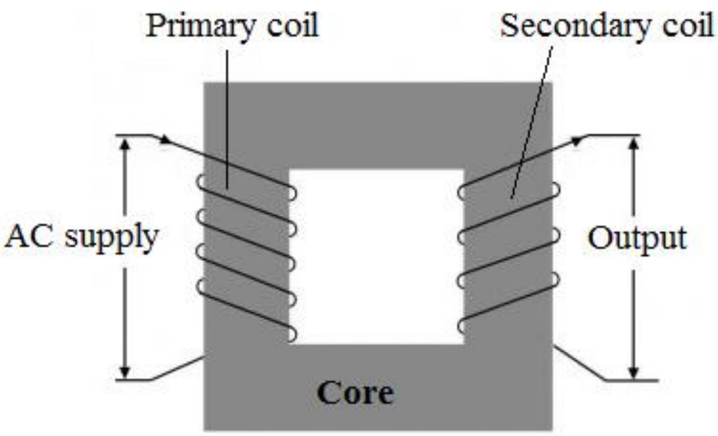
RESULT
When the switch is closed the pointer on the galvanometer gets deflected.

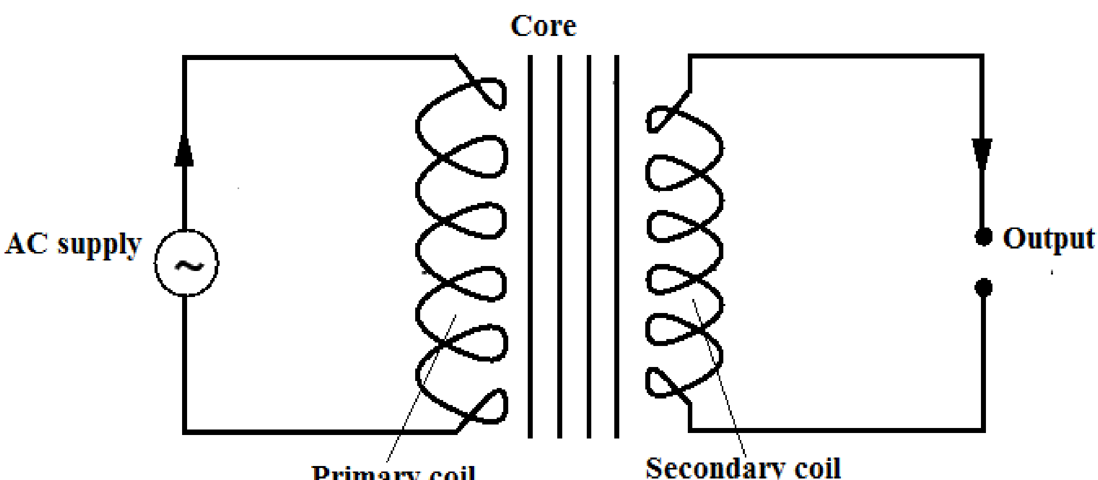
EXPLANATION
The pointer on the galvanometer gets deflected because the emf is induced in the coil connected to the galvanometer.

When alternating current flows through the primary coil, alternating magnetic field is produced. This alternating magnetic field cuts the secondary coil. The cutting of alternating magnetic field on the secondary coil induces emf in the secondary coil, which causes deflection on the pointer of a galvanometer. This type of induction is called **mutual inductance**.

Mutual inductance is the induction of an electromotive force in a coil of wire by changing the current in a different coil.

How a transformer works
Figure 6.28 shows a circuit diagram while **Figure 6.28** shows a circuit symbol of a transformer.





When alternating current passes through the primary coil it produces an alternating magnetic field in the core. The magnetic lines of force rise and fall. This causes the lines of force to cut the secondary coil. The cutting of lines of force on the secondary coil induces emf in the secondary coil. The process is called **mutual inductance.**
The amount of emf induced in the secondary coil depends on the turns ratio in the two coils. The turns ratio of a transformer is given as:

$$\frac{\text{Number of turns in the primary coil}}{\text{Number of turns in the secondary coil}} = \frac{\text{voltage in the primary coil}}{\text{voltage in the secondary coil}}$$

$$\frac{NP}{NS} = \frac{VP}{VS}$$

$$\frac{\text{Number of turns in the primary coil}}{\text{Number of turns in the secondary coil}} = \frac{\text{current in the secondary coil}}{\text{current in the primary coil}}$$

$$\frac{NP}{NS} = \frac{IS}{IP}$$

Types of transformers

a. A 'step-up' transformer

A step-up transfer is a transformer that transforms low voltage to high voltage or steps up voltage. It has greater number of turns in the secondary coil compared to the primary coil.

NS > NP

Figure 6.29 shows the symbol and the circuit diagram of a step-up transformer.

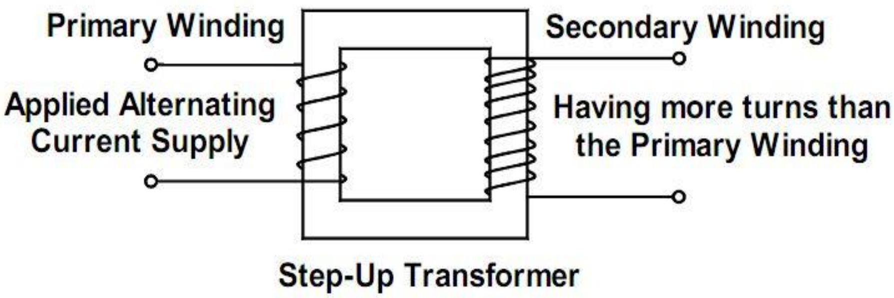


Figure 6.29 a circuit diagram of a step up.

b. A ‘step-down’ transformer

A step-down transformer is a transformer that transforms high voltage to low voltage or steps down voltage. It has less number of turns in the secondary coil compared to the primary coil

NS < NP.

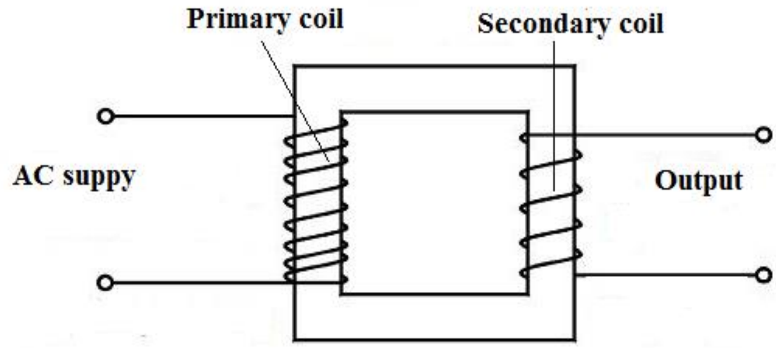


Figure 6.30 the circuit diagram of a step down transformer.

RESULTS

The output voltage is less than the input voltage.

PROJECT

Do this project under the supervision of your teacher because AC is very dangerous.

AIM: To make a simple transformer

MATERIALS:


Iron rods


Copper wire


Voltmeter


Ammeter

PROCEDURE:

1. Take a thick iron core and cover it with a thick paper and a larger number of turns of thin copper wire on thick paper (e.g. 60 turns). This makes the primary coil.
2. Cover the primary coil with a sheet of paper and wind relatively smaller number of turns (e.g. 20 turns). This makes the secondary coil.
   This type of transformer is step-down transformer.
3. Connect the primary coil to AC main and measure the input voltage and current using AC voltmeter and ammeter.
4. Measure the output voltage through the secondary coil.
5. Check if the turns ratio and voltage ratio are the same.
6. Repeat with other turns ratios.

The output current is more than the input current.
The turns ratio and the voltage ratio are the same.

EXPLANATION/ CONCLUSION

The output voltage is less than the input voltage because the number of turns in the secondary coil is less than the number of turns in the primary coil since it is a step-down transformer. The output current is more than the input current because there is less resistance in the secondary coil than in the primary coil since the number of turns in the secondary coil is less than the number of turns in the primary coil.
The turns ratio and the voltage ratio are the same because of the turns ratio formula shown below:

$$\frac{\text{Number of turns in the primary coil}}{\text{Number of turns in the secondary coil}} = \frac{\text{voltage in the primary coil}}{\text{voltage in the secondary coil}}$$

$$\frac{\mathbf{NP}}{\mathbf{NS}} = \frac{\mathbf{VS}}{\mathbf{VP}}$$

Electrical power transmission

Electrical power transmission is done in a grid system. A grid system is a network of cables, most supported by pylons. The grid system connects the power stations to consumers.
Figure 6.31 is a grid system connecting Nkula falls to consumers.

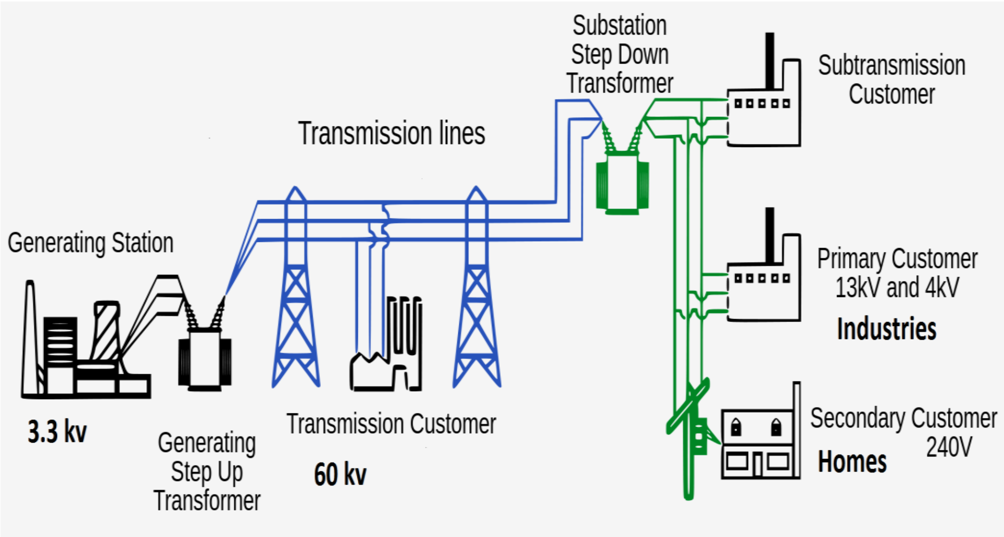


Figure 6.31 grid system

At Nkula falls power station, electricity is generated at 3,300 V (3.3 KV) and stepped up in a step-up transformer to 60,000 V (60 KV) to be sent over long distances on the super grid. Later, the voltage is stepped down in step-down transformers at substations, for distribution to industries. The voltage going to homes and schools is further stepped down to 240 V in step-down transformers.

Power is always transmitted at very high voltage and very low current (e.g. 60, 000 V at 1 A) to minimise power losses in form of heat.

Power loss = I^2R

Efficiency of a transformer

Input power = VP x IP
Output power = VS x IS

Efficiency is the ratio of the useful output power to input power, expressed as percentage.

$$\textbf{Efficiency} = \frac{\textbf{output power}}{\textbf{Input power}} \times 100\%$$

$$\textbf{Efficiency} = \frac{\textbf{VS X IS}}{\textbf{VP X IP}} \times 100\%$$

For an ideal transformer, efficiency is 100% since output power equals input power.
Input power = output power

VP X IP = VS X IS

But this is not true of practical transformers. In practical transformers, there is always loss of power and energy, therefore the efficiency is less than 100% because output power is less than the input power

Power loss is due to the following factors:

- **a.** Coils give off heat when current flows through them due to the resistance of windings.
- **b.** Some energy is used to magnetise and demagnetize the core.
- **c.** Some energy is lost through eddy current in the core. The iron core is in the changing magnetic field in the primary. Currents, called **eddy currents**, are induced in it which cause heating.
- **d.** Leakage of field lines. When a core has an air gap, not all the magnetic lines of force produced by the primary may cut the secondary.

Power losses can be minimised in the following ways:

- **a.** Applying oil in the coil to reduce the amount of heat produced.
- **b.** Using a small iron core that can easily be magnetised and demagnetised.

c. Laminating the coil to reduce eddy currents.

Environmental impact of power generation and transmission

Power generation and transmission has the following environmental impact:

Hydroelectric power
Causes flooding. Building a dam causes environmental damage

Nuclear power
The waste from nuclear fuel is very dangerous to the environment and stays radioactive for thousands of years.

Fossil fuels
When the fuels burn, their waste gases pollute the atmosphere. Fossil fuels produce carbon dioxide gas and carbon monoxide gas when they burn which may cause global warming.

Solar power
Solar power requires large area, causes land wastage.

Geothermal energy
Geothermal energy can cause volcanic eruptions since it is done in volcanic regions.

Biomass
Biomass requires large area, causes land wastage.

Transformer calculations

Worked examples

1. A transformer has 66 turns in the primary coil and 660 turns in the secondary coil. The voltage in the primary circuit is 240V. Calculate the voltage in the secondary coil and then state the type of transformer.

Solution

NP = 66 turns VP = 240V NS = 660 turns VS =?

Using the turns ratio:

$$\frac{NP}{NS} = \frac{VP}{VS} \quad \text{or} \quad \frac{NS}{NP} = \frac{VS}{VP}$$

$$\frac{NS}{NP} = \frac{VS}{VP}$$

$$\frac{660 \text{ turns}}{} = \frac{VS}{}$$

66turns 240V

$VS = \frac{660 \text{ turns} \times 240 \text{ V}}{66 \text{ turns}}$

VS = **2400V**

Therefore, the transformer is a step-up transformer.

2. The current in the primary coil of a transformer is 5A and the voltage in primary coil is 220V. The voltage on the secondary coil is 10V.

Calculate:

a. the power taken from the supply

b. the current in the secondary coil? (Assuming it is 100% efficient).

Solution

VP = 220 V IP = 5 A VS = 10 V IS =?

a. Power taken from the supply = VP x IP = 220V x 5 A

Input power = **1100 W**

b. Current in the secondary coil

VP X IP = VS x IS

220V x 5 A = 12V x IS

$IS = \frac{220\text{V} \times 5\text{A}}{10\text{V}}$

IS = **110A.**

Exercise 6.4

In your group, answer the following questions:

1. With the aid of a well labeled diagram explain how

a. a step-down transformer works.

b. a step-up transformer works.

2. Figure 6.32 shows a transformer.

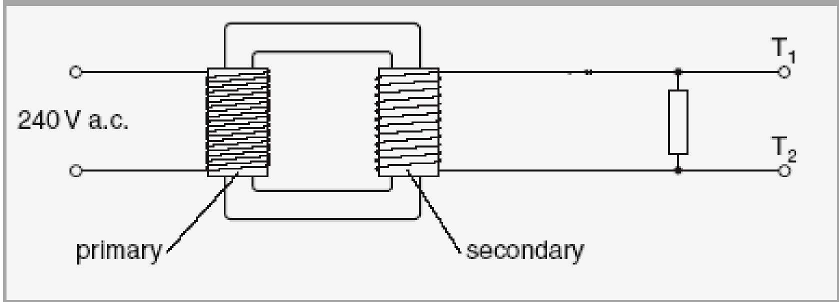


Figure 6.32

The transformer produces an output of 15 V across the secondary coil. The number of turns in the primary coil is 4000.

a. Name the type of a transformer shown above.

b. Calculate the number of turns in the secondary coil.

Summary

Magnetisation is the process of making a magnetic material become a magnet.
A magnetic material is made a magnet by the following methods:

- **a.** Induction
- **b.** Stroking
- **c.** Electrical method

A magnetic material can get demagnetized by the following methods:

- **a.** Heating strongly.
- **b.** Hammering or dropping the magnet.
- **c.** Placing a magnet in a coil carrying alternating current.
- **d.** Stopping the flow of the current in a circuit and in a coil where a metal rod is placed.

When current-carrying wire is placed at right angles to a magnetic field, it will experience a force in the direction found by using Fleming's left hand rule. This has the motor effect and it is used in dc motors, moving-coil galvanometers and moving coil loudspeaker.
A dc motor is a device that converts electrical energy to mechanical energy.

A wire that is moving at right angles through a magnetic field will cause a current to flow (induced) in that wire. The effect is called **generator effect** and is applied in ac generators, dc generators and transformers.
A generator is a device that converts mechanical energy to electrical energy.

Student assessment

1. Define
- **a.** Magnetisation.
- **b.** Demagnetisation.
- **c.** Electromagnetic induction

2. Explain the following

a. A current-carrying wire is pushed in a magnetic field.

b. A transformer works on alternating current rather than direct current.

c. Power is transmitted at very high voltage and very low current.

3. State **three** methods of

a. Magnetising a magnetic material

b. Demagnetising a magnet

4. Desscribe

a. Fleming's left hand rule.

b. Fleming's right hand rule.

5. State

a. Faraday's law.

b. Lenz's law.

6. **Figure 6.33** is a simple dc motor.

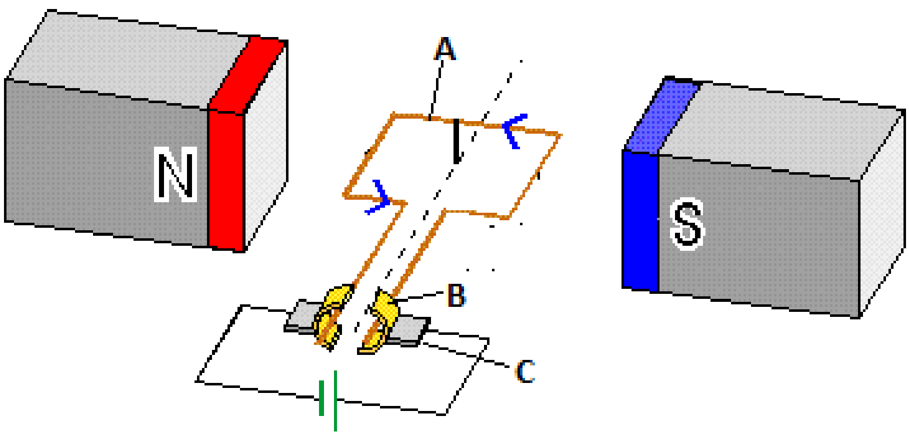


Figure 6.33

a. Name the parts labeled

i. A

ii. B

iii. C

b. Describe the working of a dc motor.

c. State **two** ways of reversing the direction of rotation of the motor.

d. State **three** ways of increasing the speed of rotation of the motor.

7. With the aid of a well labeled diagram, explain the working of

a. An ac generator

b. A dc generator

8. In an ac generator, state three ways of increasing the magnitude of the induced emf

9. A transformer has an output of 12 V when supplying a current of 1.0 A. The current in the primary coil is 0.2 A and the transformer is 100% efficient.

a. Explain what is meant by 100% efficient.

b. **i.** Calculate the output power of the transformer.

ii. The voltage applied across the primary coil.

10. With the help of a labeled diagram, explain how

a. A step-down transformer works.

b. A step-up transformer works.

11. a. Draw a labeled diagram consisting of a solenoid, a magnet, a sensitive ammeter and connecting wires to demonstrate electromagnetic induction.

b. Explain how the arrangement is used to produce an induced current.

c. Without changing the arrangement, state

i. how you can produce an induced current in the opposite direction to the original current.

ii. a larger induced current.

12. A transformer is needed to step down a 240 V ac supply to a 10 V ac output.

a. Draw a labeled circuit diagram of a suitable transformer.

b. Explain how the input voltage is changed to output voltage.

c. The output current is 2 A. Calculate the power output.

13. Figure 6.34 is a diagram of a transformer.

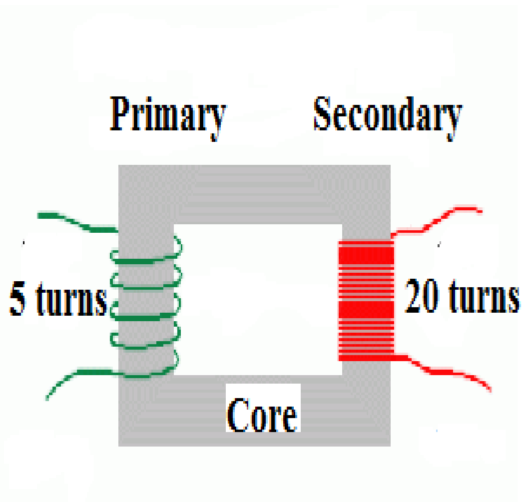


Figure 6.34

a. What type of transformer is shown in **Figure 6.34?**
b. Give a reason for your answer in **13 (a).**
c. If the input voltage is 240 V, the number of turns in the secondary coil is 20 turns and the primary coil is 5 turns, calculate the output voltage.

CHAPTER 7

Introduction to digital electronics

Objectives

At the end of Chapter 7, you must be able to:

- ***Discuss semiconductor devices.***
- ***Discuss electronic components and their uses.***
- ***Describe analogue and digital electronics.***
- ***Describe the operations of basic logic gates.***

7.1 Semiconductor devices

Band theory

A **band theory** is a theory which explains why conductors, semiconductors and insulators are different in conduction. The difference in conduction of different materials is due to the difference in the number of free electrons, the conduction band, and the difference in the forbidden gap.

The following are the structures of a conductor, semiconductor, and an insulator, showing their conduction bands at room temperature.

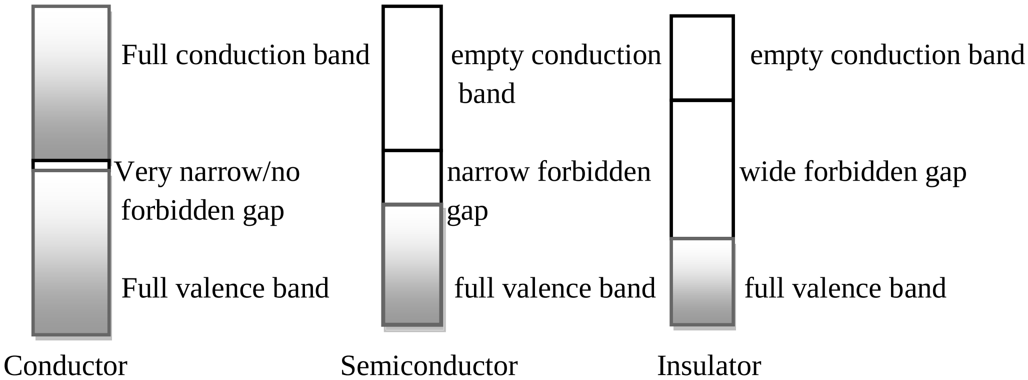


Figure 7.1 conduction bands of materials at room temperature.

Conduction band: It consists of free electrons. It is the conduction band electrons that conduct electricity.
Valence band: This is the outer shell, which is always full of electrons.
Forbidden band: This is the gap between the valence band and the conduction band.

In a conductor, the conduction band is full of free electrons. There is very narrow or no forbidden gap. In a conductor, electrons are very free to flow.

In a semiconductor, there are no electrons in a conduction band. The forbidden gap is smaller compared to that of an insulator. This allows electrons at a certain point to jump from the valence band to the conduction band.

For example: At room temperature, the conduction band has very few free electrons. Therefore, some electrons pass through the forbidden gap to the conduction band. If the temperature is increased, there is even more thermal excitation of electrons into the conduction band and the conductivity increases.

In an insulator, the conduction band is empty. The forbidden gap is too wide for any electron to cross to the conduction band. Hence insulators do not conduct.

Semiconductors

Semiconductors are materials whose electrical conductivities are higher than those of insulators but less than those of conductors. Semiconductors have their electrons fixed in their lattice and these electrons are made loose by some physical changes. Examples of semiconductors are silicon, germanium, cadmium sulphide, indium antimonide and gallium arsenide.

Improving the conductivity of a semiconductor

The conductivity of a semiconductor can be improved through the following methods:

a. Increasing their temperature

Electrons in semiconductors are made free to flow by increasing their temperature. Increasing the temperature of a semiconductor causes these electrons to shake loose and enable the semiconductor to conduct. When the temperature has increased, the electrons in the valence band gain kinetic energy and jump from the valence band to the conduction band.

b. Doping

Doping is the process of adding impurities to a semiconductor to improve its conductivity. Doping increases the number of charge carriers available for conductions. This has been explained on extrinsic semiconductors.

Types of semiconductors

a. Intrinsic semiconductors

An intrinsic semiconductor is a material that is a semiconductor on its own without anything added to it. This is a pure semiconductor. The conduction band in intrinsic semiconductor is empty at very low temperature. Any increase in temperature causes the electrons to start flowing. Examples of intrinsic semiconductors are germanium and silicon.

b. Extrinsic semiconductors

An extrinsic semiconductor is a semiconductor to which impurities are added through the process called **doping.** Extrinsic semiconductors are impure semiconductors.

Types of doping

There are two types of doping.

- **i.** Donor doping
- **ii.** Acceptor doping

Donor doping

Donor doping generates free electrons in the conducting band.

This is done by adding impurity atoms that have more number of valence electrons to a pure semiconductor with less number of valence electrons. For example, adding impure atoms that have five valence electrons (group 5 element e.g. phosphorous) to a semiconductor that has four valence electrons (group 4 e.g. silicon).

Doping a silicon semiconductor by phosphorous

The impurity atom phosphorous forms covalent bonds with silicon but since silicon only have four valence electrons; one spare valence electron is produced. This free electron produced enters the band as an electron as shown in **Figure 7.2.**

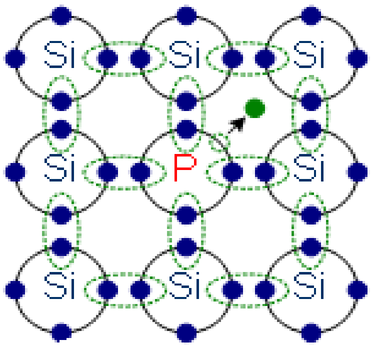


Figure 7.2 doping silicon with phosphorous.

Since the free electron has a negative charge, the doped semiconductor material is known as **n-type semiconductor material.** In this material, the majority carriers are electrons while minority carriers are protons.

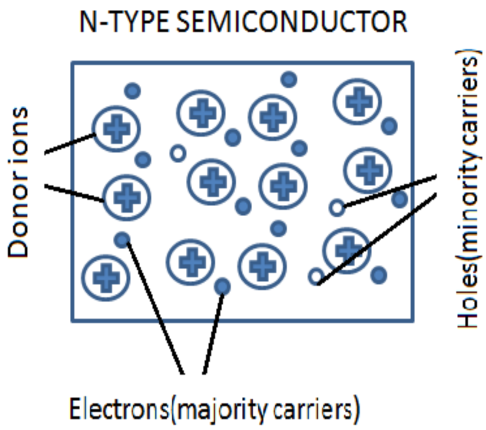


Figure 7.3 N-type material

Acceptor doping

Acceptor doping produces a hole in a semiconductor material.

In acceptor doping, a semiconductor material is doped with an impurity with less valence electrons, e.g. doping a group four semiconductor with a group three material.

Doping a silicon semiconductor material with a boron

Boron forms covalent bond with silicon atom but the bond lacks one electron for a complete outer shell. This will create a vacancy called a hole as shown below in **Figure 7.3**.

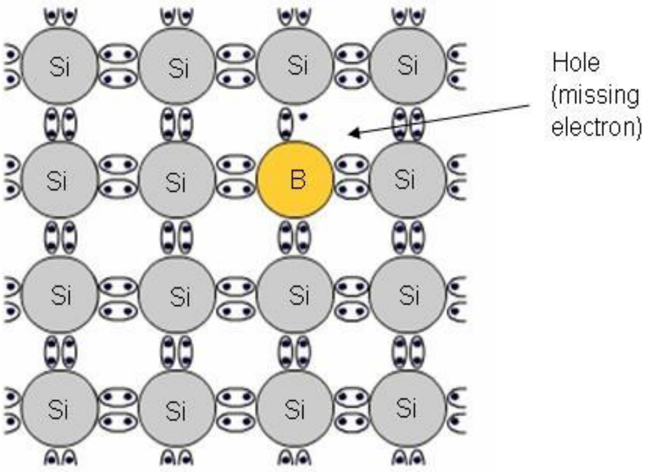


Figure 7.4 doping silicon with Boron.

Holes are said to have positive charges. Therefore, acceptor doped material is called **p-type semiconductor**. Holes are the majority carriers in the p-type material while electrons are minority carriers. In p-type semiconductor, impurities accept free electrons from a semi conductor, hence the name acceptor doping.

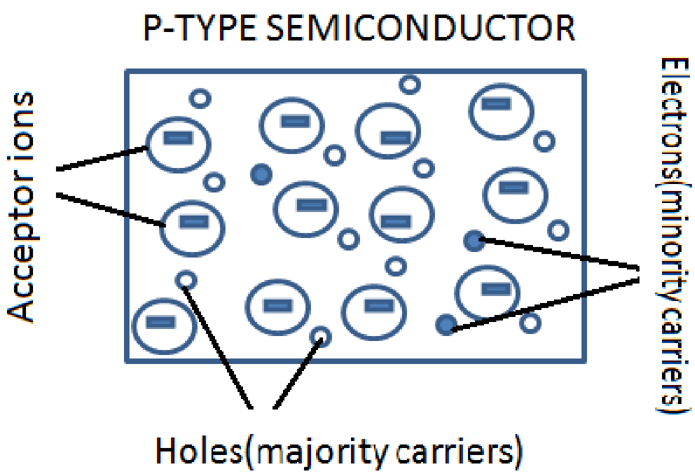
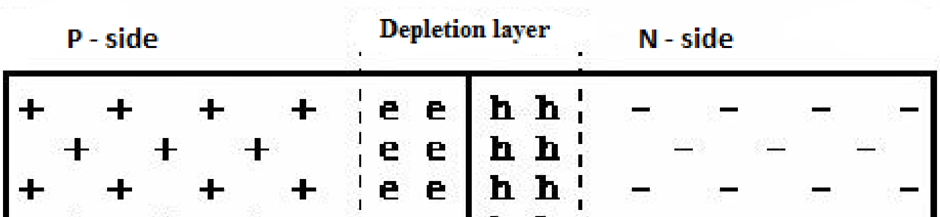


Figure 7.5 P-type material

P-N Jun

P-n junction is formed by a p-type semiconductor material and an n-type semiconductor material. In a p-n junction, electrons are attracted to the p-type side. Electrons diffuse across the depletion region.



Application of P-N junction

P-N junction is used in diodes and transistors.

Operation of a P-N junction diode

A **diode** is a two-terminal device that conducts current in one direction.
Diodes are electronic parts made by joining together p-type and n-type materials forming a p-n junction. Electrons move from n-type material to p-type material. Therefore, diodes conduct electricity in only one direction.

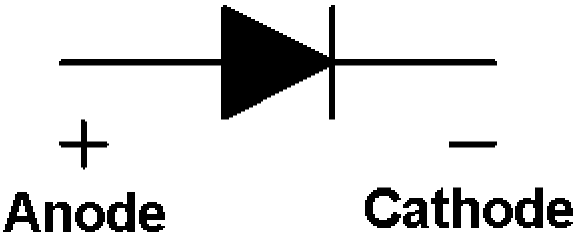
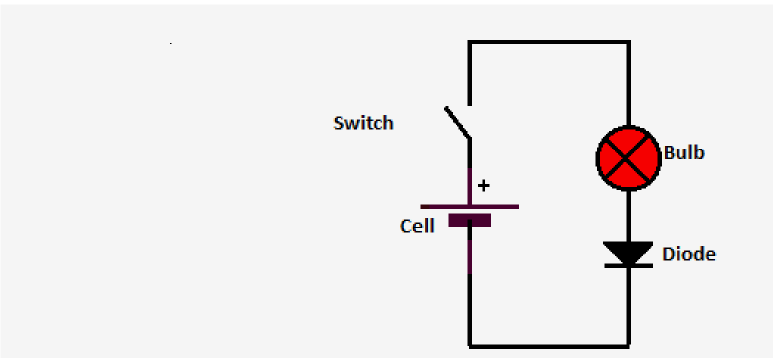


Figure 7.7 symbol of a diode

Experiment 7.1

AIM: To investigate the function of a diode
MATERIALS: diode, cells, bulb, connecting wires, switch.
PROCEDURE:

1. Set up the experiment as shown in **Figure 7.8.**



DISCUSSIONS

What happens when

- **a.** The switch is closed in **Figure 7.8**?
- **b.** The direction of current is reversed?
- **c.** The diode is turned to face the opposite direction?

From Experiment 7.1, we learn that the bulb lights up only when the diode faces a certain direction in the circuit. When the direction of current is changed, or is turned around it, the bulb does not light up. Therefore, a diode allows current to flow in one way.

Forward biasing a diode

A diode is said to be forward biased when its positive terminal is connected to the positive side of the power supply while its negative terminal is connected to the negative side of the power supply. P-type is connected to the positive side of the supply while N-type is connected to the negative side of the supply.

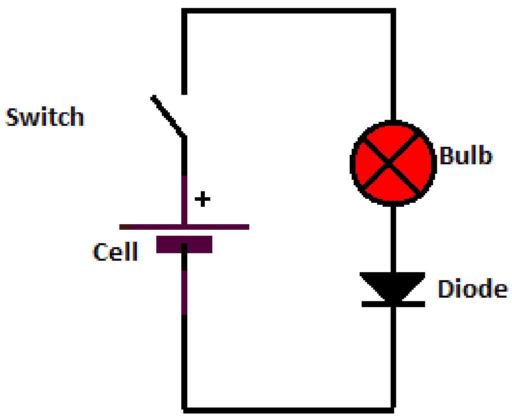


Figure 7.9 forward biased diode.

Figure 7.10 is a sketch of current-voltage characteristics for a forward biased diode.

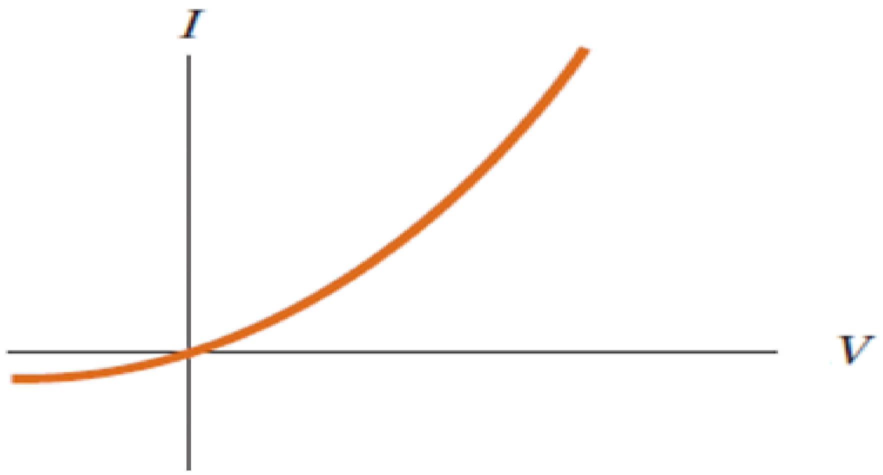


Figure 7.10 current-voltage sketch for a forward biased diode

Reverse biasing a diode
A diode is said to be reverse biased when its positive terminal is connected to the negative side of the power supply while its negative terminal is connected to the positive side of power supply. P-type is connected to the negative side of the supply while the n-type is connected to the positive side of the supply.

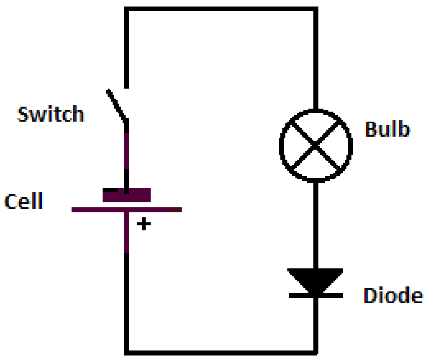


Figure 7.11 reverse biasing a diode.

Effect of reverse biasing a diode
When a diode is reverse biased electrons and holes flow in opposite direction. This widens the depletion region between n-type and p-type materials. As the gap widens the resistance also increases, hence no current flows in the diode.

Exercise 7.1

In your groups, answer the following questions.

1. Explain the differences between conductors, semiconductors, and insulators in terms of band theory.

2. Explain two ways of improving the conductivity of a semiconductor.

7.2 Electronic components and their uses

Here are some of the components used in electronic circuits:

Capacitor

Symbol of a capacitor is shown in **Figure 7.12.**

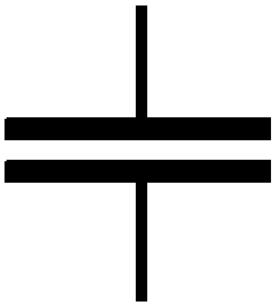


Figure 7.12 symbol of a capacitor

Uses of a capacitor

- Used to store small amounts of electric charge.
- Used for smoothing out current changes.

- Used to pass on signals from one circuit to another.
- Used to tune circuits so that they respond to signals of one frequency.

Light Dependent Resistors (LDR)

The light dependent resistor is a resistor whose resistance depends on light intensity.

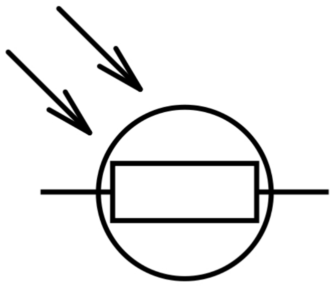


Figure 7.13 symbol of light dependent resistor

When the amount of light intensity falling on an LDR increases, its resistance decreases and vice versa. The LDR makes part of a potential divider. The LDR has low resistance in daylight and allows more current to switch on the transistor in the circuit. The LDR has high resistance in the dark and allows low current to switch off the transistor in the circuit.

Diodes

Diodes allow current to flow in one direction only.

Uses of a diode

A diode is used as a switch. When the diode is forward biased, it has very low resistance. Current flows through it and switches on the bulb as shown in **Figure 7.9.** When a diode is reverse biased, it has very high resistance. Current does not flow through it and switches off the bulb as shown in **Figure 7.11.**

It is also used as a rectifier. It changes alternating current to direct current.

Light-emitting diodes (LEDs)

Some diodes emit light when current flows through them.

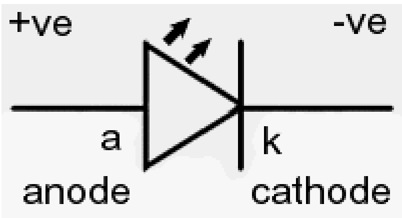


Figure 7.14 symbol of a light emitting diode

Light emitting diodes are used as indicator lamps on electrical and electronic equipments. If an appliance is ON the LED gives light and if the appliance is OFF the LED does not give light.

Thermistors

A **thermistor** is a resistor whose resistance depends on temperature. It is a temperature-dependent resistor.

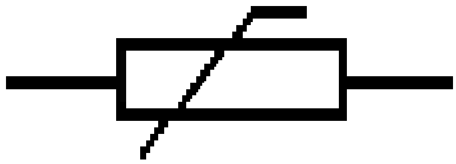


Figure 7.15 symbol of a thermistor

When the temperature on a thermistor increases, its resistance decreases and vice versa. The thermistor makes part of a potential divider. The thermistor has low resistance at high temperature and allows more current to switch on the transistor in the circuit. The thermistor has high resistance at low temperature and allows low current to switch off the transistor in the circuit.

Inductor

An **inductor** is a passive electronic component that stores energy in the form of a magnetic field. It consists of a wire loop or coil.

Figure 7.16 Symbol of an inductor

Transistors

A **transistor** is a three-terminal device that conducts current in both directions.
A transistor is made by joining two p-n junctions joined back to back.

Therefore, we have **p-n-p transistors and n-p-n transistors.**
A transistor has three terminals namely; base (B), emitter (E) and collector (C).

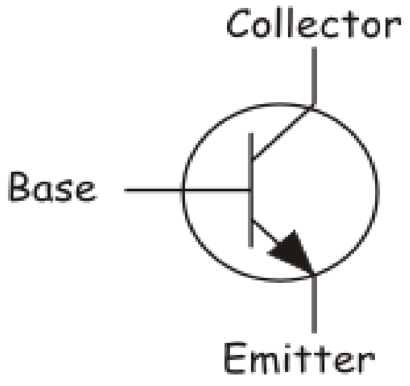


Figure 7.17 symbols of a transistor

The arrow shows the direction of current.

Uses of a transistor

Transistor is used as a switch.
When a transistor is connected in a circuit, it can be used as a very sensitive, fast-acting switch. A transistor can turn on and off electrically. This is done by varying the base current. If we connect a transistor in a circuit without the voltage and current, the bulb does not light up because there is no current which flows to the base of a transistor to switch it on. We say, the transistor has a blocking effect. So, it is switched off. If a battery is connected between the base and the emitter of a transistor as shown in **Figure 7.18**, the bulb lights up.

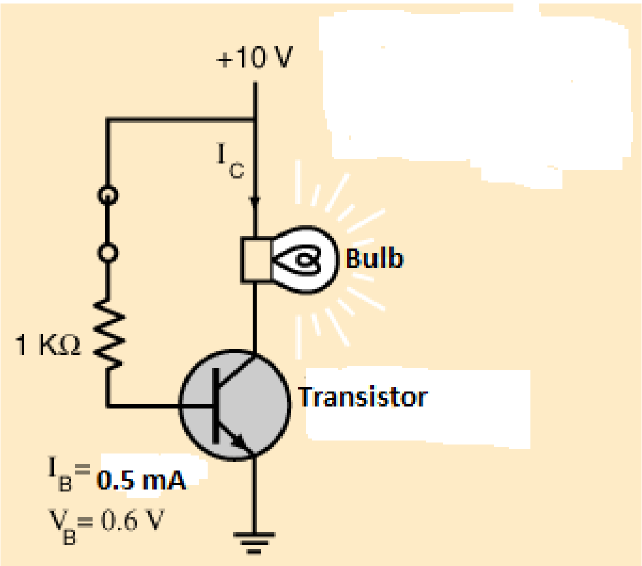


Figure 7.18 a transistor connected to a battery

When a small battery is connected between the base and the emitter of a transistor, a small amount of current flows in the base of the transistor. This current switches on the transistor and the bulb lights up.

The transistor can switch on under the following conditions:

- The + and – connections to the battery must be in the right way.
- The voltage between the base and emitter (vbe) must be at least 0.6 V.
- The base current (I_b) must be at least 0.5 mA.

NOTE: A resistor is connected to the base of a transistor to limit current. The resistor is used to protect the transistor from damage and ensure that there is correct potential difference at the base.

The special resistors (light dependent resistor and thermistor) can be used to vary the base current of the transistor.

Transistor is used as an amplifier

An **amplifier** is a device that magnifies the input. A transistor magnifies small input signal to produce larger output signal. The input might be current or voltage or sound. **Figure 7.19** is a circuit which can be used to demonstrate that a transistor acts as a current amplifier.

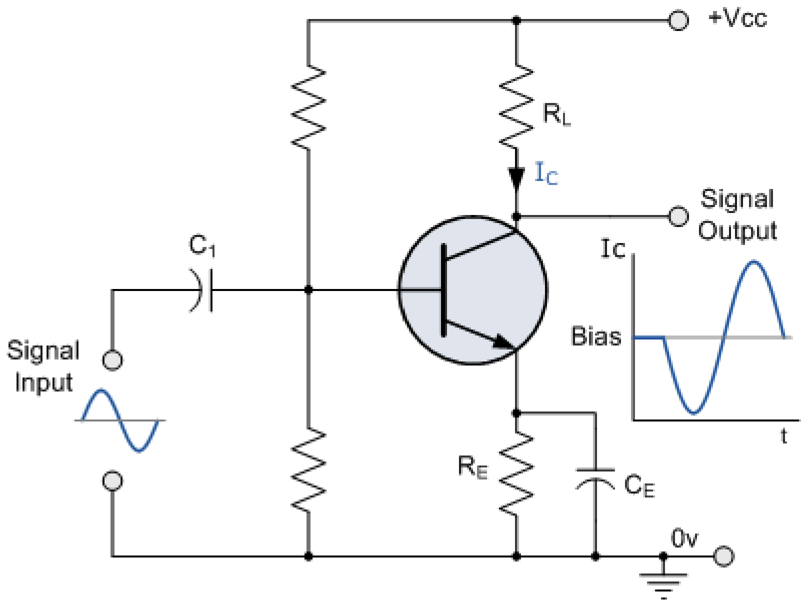


Figure 7.19 transistor used as an amplifier

When the switch is closed a small base current I_b of 0.5 mA flows in the base of a transistor, which in turn allows larger collector current I_c of 50 mA. The small changes in the base current control large changes in the collector current. Therefore, the transistor acts as a current amplifier.

Exercise 7.2

In your groups, answer the following questions:

1. State **two** uses of each of the following electronic devices:
a. capacitor **b.** diode **c.** thermistor

2. With the aid of a well labeled diagram describe
a. forward biased diode **b.** a reverse biased diode

3. Name an electronic component which
a. stores a small amount of electric charge .
b. emits light when a small amount of current flows through it.

7.3 Analogue and digital circuits

Digital electronics

Digital electronics have given rise to calculators, digital watches, micro computers and many more. Digital systems are concerned only with the presence of two values 1 and 0, whereby 1 is a high or on and 0 is a low or off. The system that uses 1 and 0 is called a **binary system**. The signals that have only two states – on and off are called **digital signals**.

Differences between analogue and digital circuits

Analogue circuits produce a continuous varying signal. This signal is called **analogue signal.**

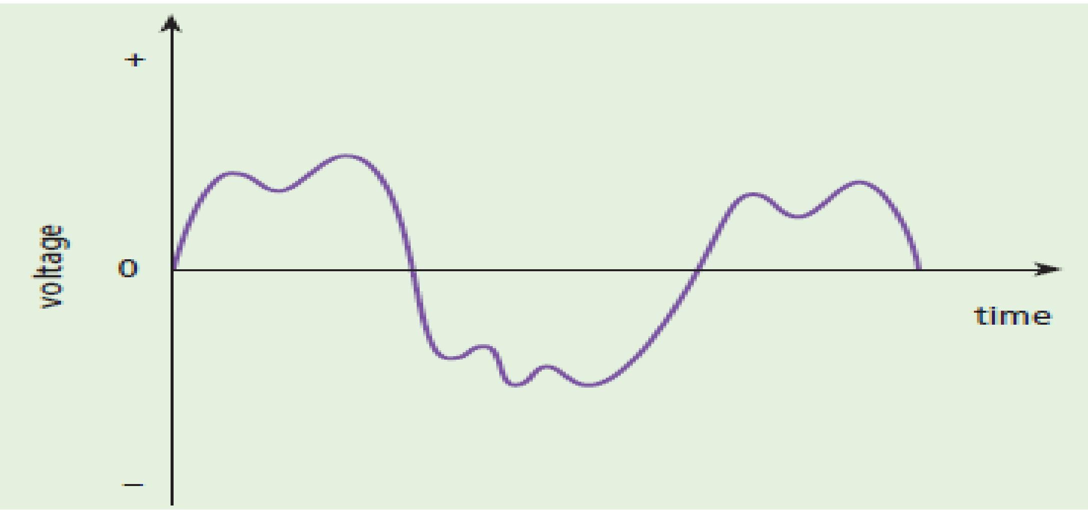


Figure 7.20 analogue voltage signal

During transmission, the analogue signal has the following problems:
Signals lose power as they travel along. This effect is called attenuation.
Signals are spoilt by noise. Signals have low quality when they reach their destination.

Figure 7.21 shows an analogue display.

Figure 7.21 analogue display

Digital circuits produce two numbers, 1's and 0's. These numbers are called **binary codes.**

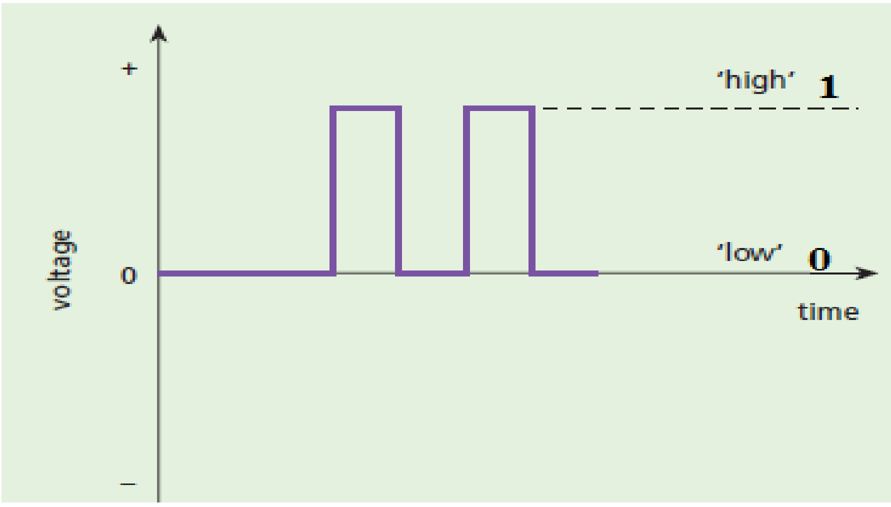


Figure 7.22 digital signal

Digital signals are transmitted as a series of pulses.
Digital signal has high quality because it does not lose power and it is not spoilt by noise.

Figure 7.23 shows a digital display.

Figure 7.23 digital displace

Diodes in half wave rectification

A **rectifier** is a component which can be used to change alternating current (ac) to direct current (dc). This process is called **rectification**. **Figure 7.24** shows a diode being used as a rectifier in a circuit.

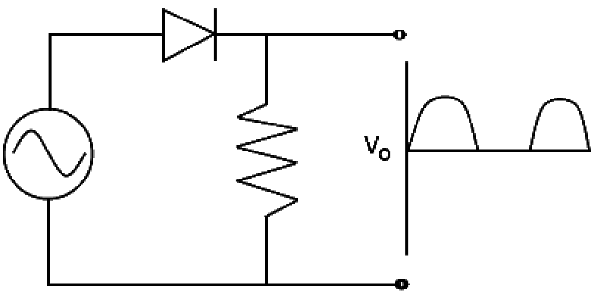


Figure 7.24 a diode in a half-wave rectification

The diode is used as a rectifier because it only allows the forward alternating current and blocks the backward alternating current. Therefore, the current at the output flows one way only, hence direct current.

In **Figure 7.24** it is shown how the circuit changes the AC input to DC output. This can be displayed on the cathode ray oscilloscope. The bottom half of the output waveform is missing. The current flows in surges and has short periods of no current in between. This is called **half-wave rectification.**

Diodes in full-wave rectification

Figure 7.25 shows four diodes connected in a bridge network. This reverses the negative (backward) parts of the AC, instead of just blocking them. The flow of current is always forward. This process is called **full-wave rectification.**

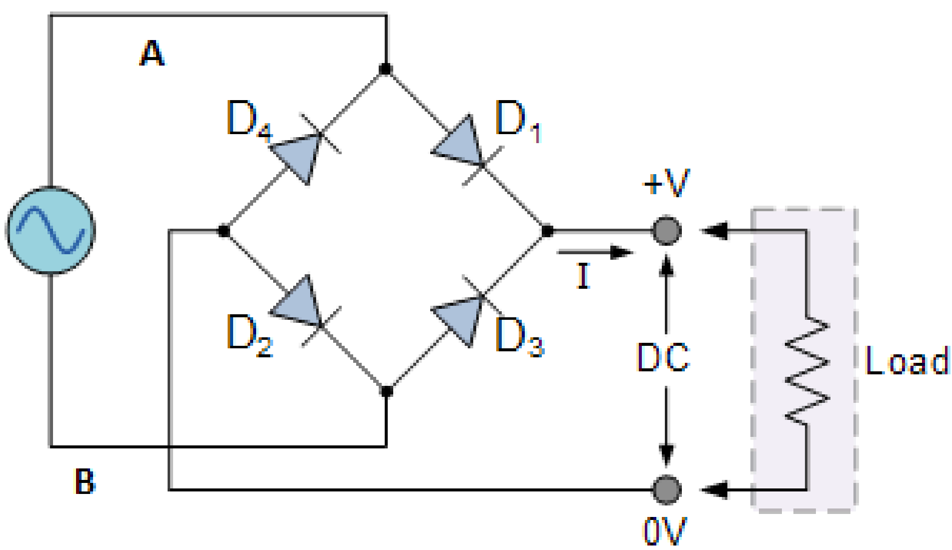


Figure 7.25: a diode in full-wave rectification

A full-wave rectification maintains the DC output for either the positive or negative cycle of input voltage. In a full-wave rectification, one pair of diodes conducts while the other pair does not. If the current flowing through A is positive and B is negative the pair of diodes D_1 and D_2 conduct, while diodes D_3 and D_4 do not conduct.

If the current flowing through A is negative and B is positive the pair of diodes D_3 and D_4 conduct, while diodes D_1 and D_2 do not conduct. The overall effect is that the current always flows through the transistor in the same direction.

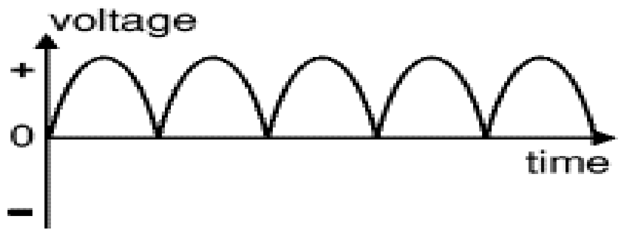
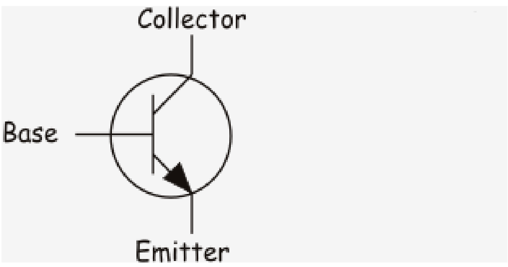


Figure 7.26 full wave rectification

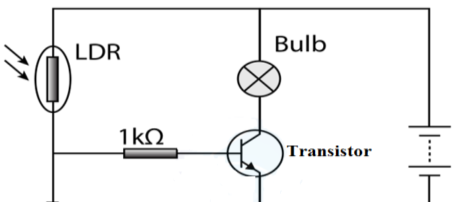
Bipolar transistor

A bipolar transistor is manufactured by joining the N-type material, P-type material, and N-type material, forming N-P-N transistor. A transistor is a three-terminal device that conducts current in both directions. A transistor is made by joining two p-n junctions joined back to back. A transistor has three terminals namely, base (B), emmiter (E) and collector (C).



The arrow shows the direction of curr

Figure 7.28: light

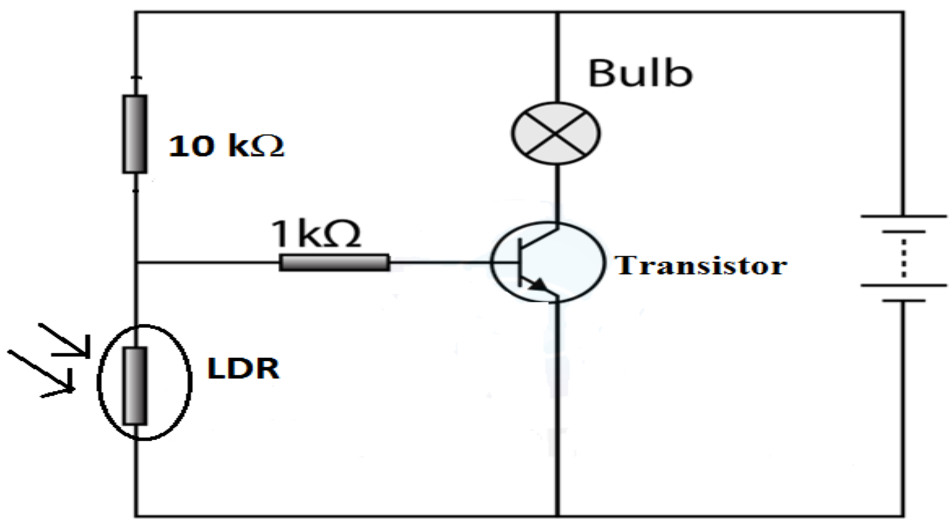


A light operated switch

Figure 7.28 is a circuit containing a light-dependent resistor (LDR).

In daylight, light shines on the LDR, its resistance decreases and more current flows in the base of the transistor. This current is enough to switch the transistor on and the bulb lights up. In darkness, the resistance of the LDR increases and less current flows to the base of the transistor. This current is not enough to switch on the transistor. The bulb does not light up.

Modification of the circuit is done so that the transistor is switched on at different light intensity. This is achieved by connecting the circuit as shown in **Figure 7.29.**



Wopping the positions of the LDR and R enables the transistor to switch on in darkness. Therefore, the bulb lights up when there is low light intensity (in darkness). The LDR is part of the potential divider. In darkness, the resistance of the LDR rises, and so does its share of the battery voltage. The voltage across the LDR is high enough to switch the transistor on and the bulb lights up.

In daylight, the resistance of the LDR is low, and so is its share of the battery voltage. The voltage across the LDR is too low to switch the transistor on and the bulb does not light up.

This circuit can be used to

- Switch on a burglar alarm when a light beam is cut.
- Switch on a car's parking lights at dusk.
- Switch on the street lamps when there is darkness.

Exercise 7.3

In your groups, answer the following questions:

1. With the aid of diagrams, explain the difference between analogue and digital circuits.

2. Explain the characteristics of analogue and digital signals.

3. With the aid of well labeled diagrams explain the application of the diode in
a. a half-wave rectification **b.** a full-wave rectification

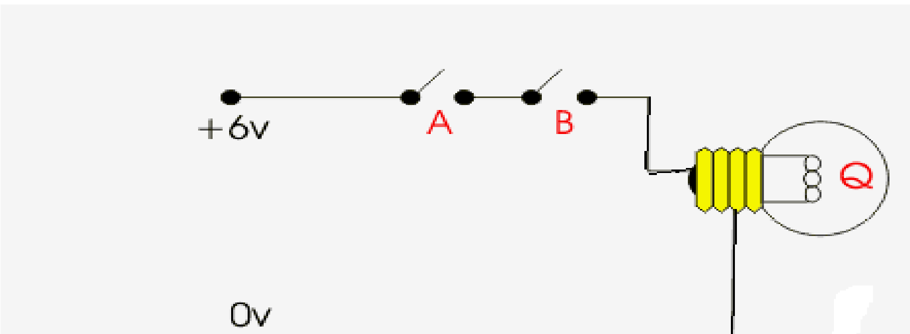
4. With the help of a diagram, discuss how a light operated switch works.

7.4 Basic logic gates

Logic circuits

Digital electronics is based on the use of logic circuits. Logic circuits can be found in video recorders, security lamps, alarm systems, washing machines just to mention a few. These logic circuits are controlled by electronic switches called **logic gates**. The switches are the basic building block of all logic circuits. If the switches are in the right condition, the logic circuit will work.

Let us start by looking into a simple switching system in **Figure 7.30.**



The switches A and B are inputs of the system. Each switch can have only one of the two states: either open or closed. The output of the system, the bulb, also has only one of the two states: either ON or OFF.

When the switch is closed, it means it has a high potential (+ 6 V) and a logic 1 while an open switch has a low potential (0V) and a logic 0.

When the bulb is ON, it means it has a high potential (+6V) and a logic 1 while a bulb which is off means it has a low potential (0 V) and a logic 0.

Logic 0 stands for OFF
Logic 1 stands for ON

From **Figure 7.28**, if both switches are closed the bulb comes ON but if either switch is open the bulb stays OFF.
The results of every possible switch setting are shown in the **truth table**.

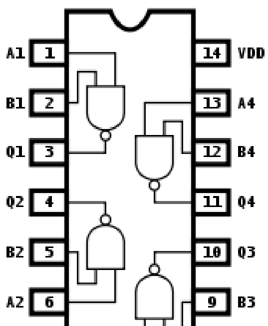
Table 7.1 the truth table showing the results

Switches		**Bulb**
A	B	Q
Open	Open	OFF
Open	Closed	OFF
Closed	Open	OFF
Closed	Closed	ON

Table 7.2 the truth table showing logic values

Switches		**Bulb**
A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

Logic gates work electronically using tiny transistors as switches. Logic gates are manufactured as integrated circuits (ICs) as shown in **Figure 7.31.** Each chip in an IC holds several gates.

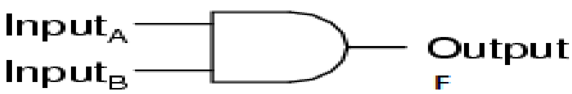


Types of logic gates

The following are the main types of logic gates:

1. **AND gate**

The output is ON if both input A AND input B are ON.

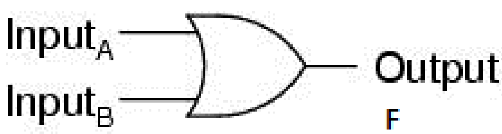


A	B	Output (F)
0	0	0
0	1	0
1	0	0
1	1	1

Figure 7.32 AND gate

2. **OR gate**

The output is ON if either input A OR input B is ON.



Truth table

A	B	Output (F)
0	0	0
0	1	1
1	0	1
1	1	1

3. NOT gate

The output is ON if the input is NOT ON. This type of gate is called an inverter because it changes OFF to ON, and ON to OFF.

4. NAND gate

A NAND gate is equivalent to an AND gate followed by a NOT gate. The output is ON if input A and input B are NOT both ON.

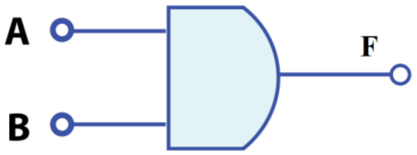
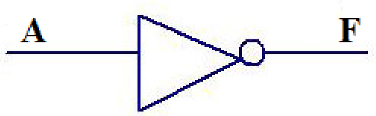


Figure 7.35 NAND gate



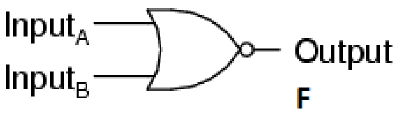
TRUTH TABLE

INPUT	OUTPUT
A	F
0	1
1	0

1	0	0
1	1	1

5. NOR gate

A NOR gate is equivalent to an OR gate followed by a NOT gate. The output is ON if neither input A NOR input B is ON.



A	B	Output(F)
0	0	1
0	1	0
1	0	0
1	1	0

Figure 7.36 NOR gate

Using logic gates

Logic gates can be used when using a recorder as shown in **Figure 7.37**.

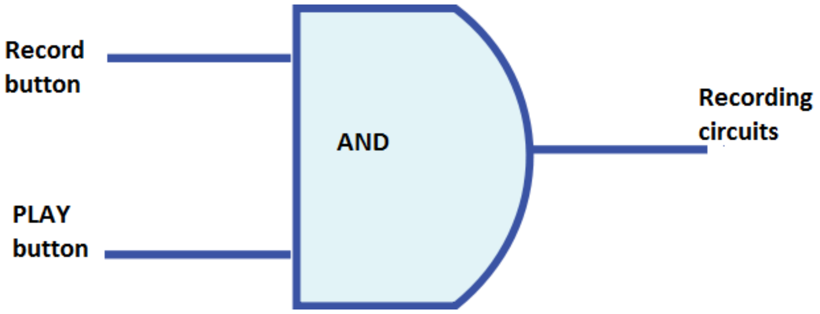


Figure 7.37 a gate used in a recorder

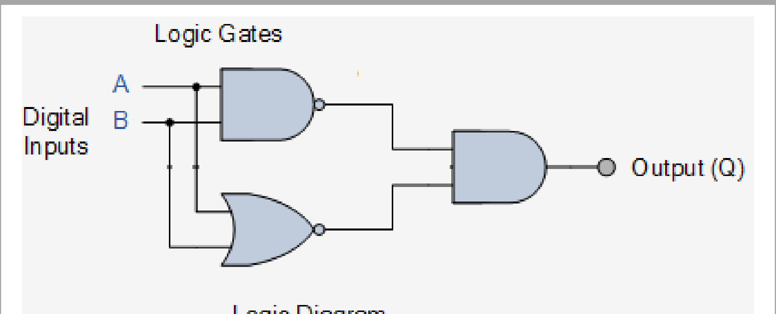
In **Figure 7.37**, the recorder will only start recording if the RECORD and the PLAY buttons are pressed together (ON)

Exercise 7.4

In your groups, answer the following questions:

1. Name the logic gate which is used in each case:
a. the output ON when both inputs are OFF
b. the output ON when both inputs are ON.

2. Use the combinations of logic gates in **Figure 7.38** to draw a truth table.



Summary

A **band theory** is a theory which explains why conductors, semiconductors and insulators are different in conduction. Conductors allow electrons to flow freely because they have no forbidden gap. Insulators do not conduct because the forbidden gap is too wide for any electron to cross to the conduction band. Semiconductors have conductivity between that of a conductor and an insulator because the forbidden gap is smaller which allows electrons at a certain point to jump from the valence band to the conduction band.

Conductivity of a semiconductor is improved by increasing its temperature and doping.
Types of semiconductors are intrinsic (pure) and extrinsic (impure) semiconductors.

A diode is a two-terminal electronic device which is formed by a P-N junction. It conducts current in one direction. It is used as a rectifier and a switch.

Examples of other electronic devices are capacitors, inductors, transistors, light dependent resistors, photovoltaic cell, logic gates and thermistors.

Analogue circuits produce a continuous varying signal.
Digital circuits produce two numbers, 1's and 0's.
A transistor is a thre-terminal electronic device which conducts in both directions. It is used as a switch and an amplifier.

Logic gates are electronic switches which control the logic circuits. The types of logic gates are AND gate, OR gate, NOT gate, NOR gate and NAND gate.

Student assessment

1. Define the following terms
   a. Semiconductors.
   b. Digital electronics.
   c. Rectification.

2. Explain the difference between
   a. A conductor and an insulator.
   b. Analogue and digital circuits.
   c. Half wave rectification and full wave rectification.
   d. Intrinsic and extrinsic semiconductors.

3. Name an electronic device which is used to
   a. Change alternating current to direct current.
   b. Store an electric charge.
   c. Switch on an alarm system in a circuit.
   d. Show that current is flowing in an appliance.

4. **a.** Define the term "doping."
   b. Explain how p-type and n-type materials are formed during doping.

5. Explain why
   a. Conductors conduct electricity.
   b. Insulators do not conduct electricity.
   c. The conductivity of a semiconductor increases with an increase in temperature.
   d. The conductivity of a semiconductor increases with doping.

6. Draw a circuit diagram in which a bulb, a cell and a diode are connected in series such that the diode is:
   a. Forward biased.
   b. Reverse biased.

7. State **three** uses of diodes.

8. State **two** properties of semiconductors.

9. **a.** Define a rectifier
   b. Explain why a diode is referred to a rectifier.

10. **Figure 7.39** below is a symbol for a transistor.

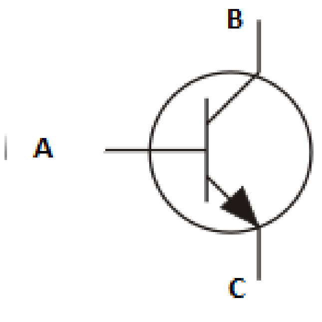


Figure 7.39

a. Name the terminals A, B and C.
b. Explain how a transistor is used as a current amplifier.
c. Discuss how a light operated switch works.

11. Explain the difference in conductivity between conductors, insulators, and semiconductors, according to the band theory.

12. Explain how the conductivity of a semiconductor varies with:
a. temperature
b. the addition of impurities.

13. Draw a circuit diagram to show how a light dependent resistor and a transistor could be used to switch on a small bulb
a. During the day
b. During the night

14. Explain the operation of the following logic gates:
a. AND gate
b. NAND gate
c. OR gate
d. NOR gate

15. Figure 7.40 is a diagram showing arrangement of logic gates.

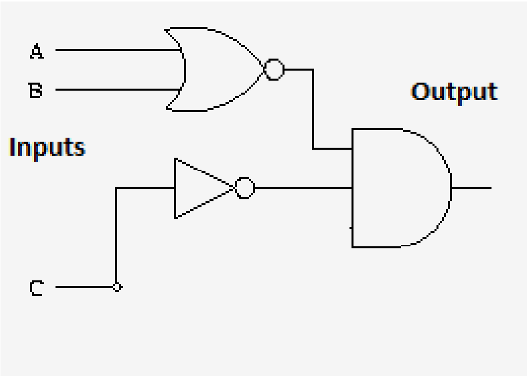


Figure 7.40

a. Name the logic gates A and B.
b. Write the truth table for the arrangement.

16. Name the components from which logic gates are made.

17. a. Draw the symbol for an AND gate.
b. Label the inputs and the output.

c. Describe the action of an AND gate with two inputs.

CHAPTER 8

Electromagnetic waves

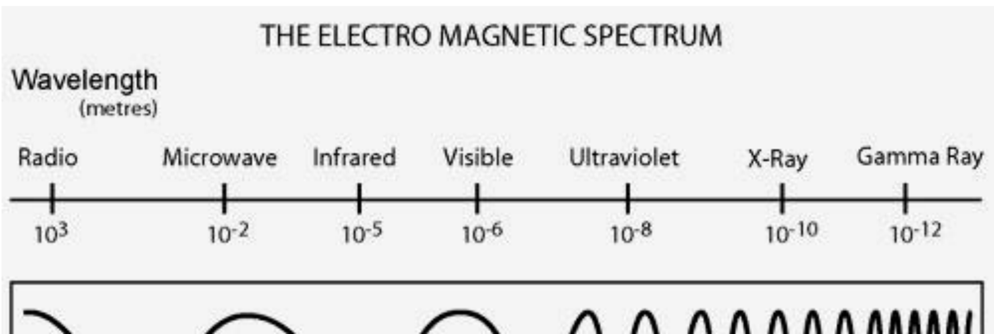
Objectives

At the end of Chapter 8, you must be able to:

- ***Describe the electromagnetic spectrum.***
- ***Explain the properties of electromagnetic waves.***
- ***Describe the methods of detecting electromagnetic waves.***
- ***Describe the applications of electromagnetic waves.***
- ***Apply wave equation in solving problems concerning electromagnetic waves.***

8.1 Electromagnetic spectrum

Electromagnetic waves come from a whole variety of sources. Electromagnetic waves are found in a band called **Electromagnetic Spectrum.**



The electromagnetic waves that make up the electromagnetic spectrum are light waves, radio waves, infra-red, micro waves, ultraviolet waves, x-rays and gamma rays.

Wavelength, frequency, and energy in an electromagnetic spectrum

Wavelength in an electromagnetic spectrum

The range of wavelengths is huge. The radio waves have The longest wavelength which is in kilometres while gamma rays have the shortest wavelength which is less than one-billionth of a millimetre.

Frequency in an electromagnetic wave

The electromagnetic waves with longest wavelength have lowest frequency, e.g. radio waves, while the electromagnetic waves with the shortest wavelength have highest frequency, e.g. gamma rays.

Energy in an electromagnetic spectrum

The electromagnetic waves with longest wavelength and lowest frequency have lowest energy, e.g. radio waves while the electromagnetic waves with the shortest wavelength and highest frequency have highest energy, e.g. gamma rays.

Sources of electromagnetic spectrum

Electromagnetic waves are emitted when electrically charged particles change energy (either from low energy to high energy or from high energy to low energy). This usually takes place in an atomic structure. When electrons move from one energy level to another, energy is released in form of electromagnetic wave.

It can also take place when electrons oscillate around the energy levels. This changes their kinetic energy. The greater the speed of oscillation, the higher the frequency (f = V/ λ), the shorter the wavelength and the greater the energy.

Types of electromagnetic waves

Radio waves

Radio waves have the longest wavelengths in the electromagnetic spectrum. They are produced when electrons oscillate. The electrons produce electricity which oscillates in Arial or Antenna. Radio waves are used for transmission of sound and picture information in radio and television.

Micro waves

Micro waves are used for satellite communication and radar. They can also be used for heating food in a micro wave. In a micro wave oven, the food is heated because it contains water which is a stronger absorber of micro waves.

Gamma radiation

Gamma radiation is produced from transitions within the excited nucleus of an atom, and usually results from some previous radioactive emission. Gamma radiation can also result from fission and fusion reactions or the destruction of a particle. Gamma radiation is used in treating cancer because it kills cancer cells since its rays are more penetrating. They are also used for sterilising food and medical equipment as they can also kill bacteria.

X-ray radiation

X-rays and gamma rays are not different. X-rays are produced when fast moving electrons lose energy very rapidly. Shorter wavelength x-rays are very penetrating. Therefore, they can pass through dense metals like lead. Longer wavelength x-rays are less penetrating, and can therefore pass through flesh, but not through the bone. This makes the bones to show up on an x-ray photograph. X-rays are used in medicine.

Ultraviolet radiation

Ultraviolet radiation is produced when there is high temperature due to large energy changes in electrons of an atom. The sun produces a large amount of ultraviolet radiation, most of which is absorbed by the ozone layer in the upper atmosphere and the remaining absorbed by our skin. Ultraviolet radiation is used by our skin in the production of vitamin D, (although excess vitamin D is harmful, and can cause some skin diseases and damage the retina). It is also used to cause fluorescence which gives out visible light.

Infra-red radiation

Infra-red radiation is produced when there are small energy changes in an atom or molecular vibrations. An object gives more infra-red radiation as its temperature rises. Infra-red is used for haze photography. It is also used by earth resource satellites to determine the health of crops.

Visible light
This is produced when an object is at very high temperature. At such, temperature the object becomes hot, hence produces visible light. Visible light is used for a photographic film which is formed on the retina in the eye. It also causes photosynthesis in plants.

Exercise 8.1

In your groups, answer the following questions:

1. Examples of electromagnetic waves are light waves, radio waves, infra-red radiation, micro waves, ultraviolet waves, x-rays, and gamma rays.
Put the electromagnetic waves in order of increasing
a. Wavelength **b.** Frequency **c.** Energy

2. Explain how electromagnetic waves are emitted from particles.

3. Name the electromagnetic wave which
a. can pass through dense metals **b.** is visible to the eye
c. is emitted by hot objects **d.** is used for satellite communication.

8.2 Properties of electromagnetic waves

Common properties of electromagnetic waves

Electromagnetic waves have certain fundamental properties in common. The common properties of all electromagnetic waves are:

- They have the same speed in air and space. Space is a vacuum, with no air, solid or liquid particles. The speed of electromagnetic waves in air and space is 300 000 km/s or 3×10^8m/s.
- They can travel in a vacuum.
- They are electromagnetic and electric.
- They are transverse in nature.

- Electric and magnetic fields oscillate together but are perpendicular to each other and the electromagnetic wave moves in a direction perpendicular to both of the fields.

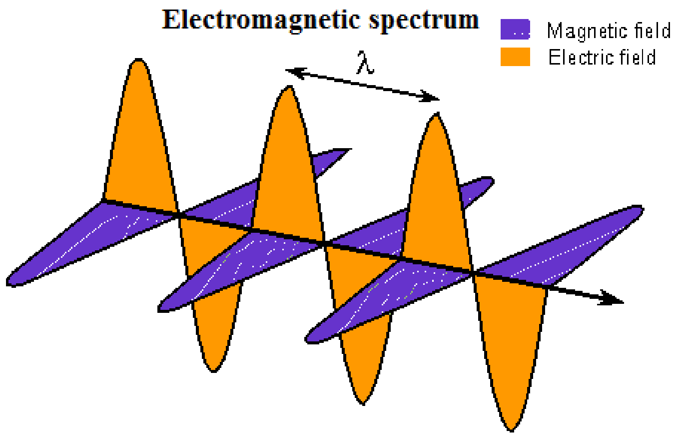


Figure 8.2 electromagnetic waves

- They obey the wave equation ($V = f \times \lambda$)
- Under suitable condition, they can be reflected, refracted and diffracted and polarized.
- All their frequencies do not change when they travel from one medium to another because their frequencies depend only on their source.

8.3 Methods of detecting electromagnetic waves

Experiment 8.1

AIM: To detect infrared and ultraviolet radiation
MATERIALS: Very hot filament (carbon-arc or quartz-iodine lamp), rock salt prism, white screen, thermopile, galvanometer, thermometer with a blackened bulb, photographic film, fluorescent paint.
PROCEDURE:

1. Set up an experiment as shown in **Figure 8.3.**

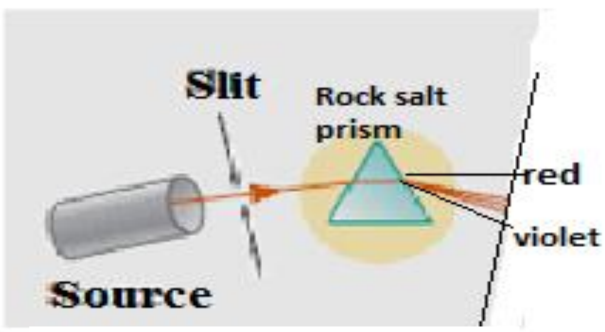


Figure 8.3

2. Observe what happens on the screen.
3. Move a thermopile connected to a sensitive galvanometer towards the red end of the spectrum and then into the dark region beyond the red end. Observe what happens on the galvanometer.
4. Move the blackened bulb of a thermometer towards the red end of the spectrum and then into the dark region beyond the red end. Observe what happens.

RESULTS/EXPLANATION

The following can be the observations in **experiment 8.1:**

- White light from a very hot filament passes through the prism and forms a visible spectrum on the white screen.
- Moving a thermopile connected to a sensitive galvanometer towards the red end of the spectrum and then into the dark region beyond the red end registers tiny currents. This current is registered because of the invisible radiation that falls on the thermopile.
- Move the blackened bulb of a thermometer towards the red end of the spectrum and then into the dark region beyond the red end shows a rise in temperature. Temperature rises because the infrared falls on the black painted bulb when it is moved beyond the red end.
- Moving a piece of photographic film towards the violet end of the spectrum and then into the dark region beyond the violet end blackens the film. The film becomes blackened because it is exposed to ultraviolet light beyond the violet end.
- Moving a piece of card coated with a fluorescent paint towards the violet end of the spectrum and then into the dark region beyond the violet end makes the fluorescent paint to glow. The fluorescent paint glows because it absorbs ultraviolence beyond the violet end.

CONCLUSION

An increase in detector's readings (galvanometer and a thermometer) when it is placed just beyond the red end of the spectrum shows the presence of the invisible radiation called **infrared.**

Blackening on the photographic film and the glowing of the fluorescent paint when placed just beyond the red end of the spectrum shows the presence of the invisible radiation called **ultraviolet radiation.**

Table 8.1 shows the detectors of the electromagnetic waves.

Table 8.1 detectors of electromagnetic waves

Electromagnetic wave	**Detectors**
Gamma ray	Geiger-Muller tube

x-rays	Photographic plate and gold leaf electroscope
Ultraviolet	Fluorescent and photovoltaic cell
Visible light	Eye, photocells, camera, and light sensitive diode
Infrared	Thermopile and phototransistors
Microwave	Wave guide tubes
Radio wave	Aerial, diodes, and earphone

8.3 Applications of electromagnetic waves

Electromagnetic waves have a range of uses. **Table 8.2** shows some of the uses of electromagnetic waves.

Table 8.2 some uses of electromagnetic waves

Electromagnetic wave	**Detectors**
Gamma ray	Detecting flaws in metal casings Sterilisation Medicine to treat cancer
x-rays	Radiography Radiology Detecting flaws in metals Diffraction to find crystal structure Detection of art forgeries
Ultraviolet	Treatment of skin complaints Killing bacteria Fluorescent lighting Burglar alarms Automatic counting in industry
Visible light	Reflection Photography Dispersion (splits into different colours)
Infrared	Cooking Heating Drying Photography Photocopiers
Microwave	Radar communication

	Microwave cooking
Radio wave	Communication and navigation

Exercise 8.2

In your groups, research the internet on

1. Methods of detecting electromagnetic waves.

2. Uses of electromagnetic waves.

8.4 Applying wave equation in electromagnetic waves

A wave equation is given as:

$$c = f \times \lambda$$

Where **c** is the velocity or speed in m/s, **f** is frequency in Hz and **λ** is wavelength in m.

Worked examples

1. Vizala Broadcasting Corporation broadcasts a wave of speed 3×10^8 m/s on a frequency of 1.5×10^6 kHz. Find the wavelength of this wave.

Solution

$c = 3 \times 10^8$ m/s $f = 4 \times 10^6$ Hz $\lambda = ?$

$c = f\lambda$

$\lambda = \dfrac{c}{f}$

$= \dfrac{3 \times 10^8 \text{ m/s}}{1.5 \times 10^6 \text{ Hz}}$

$\lambda =$ **200 m**

2. United radio station emits radio waves of wavelength 300 m. Calculate frequency of a radio wave if its speed is 3×10^8 m/s.

Solution

$c = 3 \times 108$ m/s $\lambda = 300$ m $f = ?$

$c = f \times \lambda$

$f = \underline{c}$

$$f = \frac{v}{\lambda}$$

$$f = \frac{3 \times 10^8 \text{ m/s}}{300 \text{ m}}$$

$$f = \mathbf{1 \times 10^6 \text{ m}}$$

Exercise 8.3

In your groups, answer the following questions:

1. Mapemphero radio station emits radio waves at a frequency of 10 MHz.
a. Calculate its frequency in Hertz.
b. Calculate its wavelength if its speed is 3×10^8 m/s.

2. The wavelength of a microwave is 100 m. Calculate its frequency given the speed of electromagnetic waves = 3×10^8 m/s.

Summary

All electromagnetic waves are found in an electromagnetic spectrum. Examples of these electromagnetic waves are radio waves, microwaves, infra-red, visible light, ultra-violet radiation, x-rays, and gamma rays.

In the electromagnetic spectrum, the higher the frequency the shorter the wavelength and the higher the energy. The lower the frequency, the longer the wavelength and the lower the energy.

Common properties of electromagnetic waves are:

- They have the same speed in air and space. Space is a vacuum, with no air, solid or liquid particles.
- The speed of electromagnetic waves in air and space is 300 000 km/s or 3×10^8 m/s.
- They can travel in a vacuum.
- They are electromagnetic and electric and at right angles.
- They are transverse in nature.

- They obey the wave equation.

  $V = f \times \lambda$

Electromagnetic waves can be detected by suitable detectors e.g. thermopile, phototransistor, photographic film, gold leaf electroscope and the eye.

Student assessment

1. List **three** different types of electromagnetic waves.
2. Write down **three** properties common to all electromagnetic waves.
3. The speed of infra-red radiation is 3×10^8 m/s. What is the speed of ultraviolet radiation in air?
4. Which electromagnetic wave is used for local radio and TV transmission?
5. The frequency of a micro wave is 100 kHz. Calculate its wavelength given speed of electromagnetic waves is 3×10^8 m/s.
6. Name **two** detectors for
   a. Infra-red radiation
   b. Ultraviolet light
   c. Visible light
7. Which electromagnetic wave(s) can be detected by
   a. Geiger-Muller tube?
   b. Photographic films?
   c. Fluorescent paint?
8. What are the sources of the following electromagnetic waves:
   a. Radio waves?
   b. X-rays?
9. Write a short description of radio waves, microwaves, infra-red, visible light, ultra-violet radiation, x-rays, and gamma rays.
10. **Table 8.4** shows the arrangement of the electromagnetic waves in an electromagnetic spectrum.

Gamma ray	X- ray		Visible light		Microwave	

Table 8.4

a. Fill in the missing electromagnetic waves.
b. Which electromagnetic wave has
- **i.** The shortest wavelength?
- **ii.** The longest wavelength?
- **iii.** The lowest frequency?
- **iv.** The highest frequency?
- **v.** The lowest energy?
- **vi.** The highest energy?

11. A radio station emits radio waves of wavelength 100 m.
Calculate frequency of a radio wave if its speed is 3×10^{8} m/s.

CHAPTER 9

Light and lenses

Objectives

At the end of Chapter 9, you must be able to:

- ***Describe converging and diverging lenses.***
- ***Determine the focal length of a converging lens.***
- ***Explain image formation by converging lens.***
- ***Describe image formation using ray diagrams.***
- ***Solve problems involving the lens and magnification formulae.***

9.1 Converging and diverging lenses

Lenses (singular: lens) are usually made of glass or clear plastic.
Lenses produce images similar to those produced by curved mirrors but they do so by refraction rather than reflecting the light.
There are **two** types of lenses namely:

- Convex (converging) lens.
- Concave (diverging) lens.

Convex (converging lenses)

Convex lenses are lenses that are thicker in the middle than on the edges.
Figure 9.1 shows the three shapes of the converging lens.

Figure 9.1 shapes of converging lenses.

A converging lens is used to converge or bring together parallel rays of light passing through them. The parallel rays of light falling on the converging lens converge on the principal focus or focal point on the other side of it as shown in **Figure 9.2.**

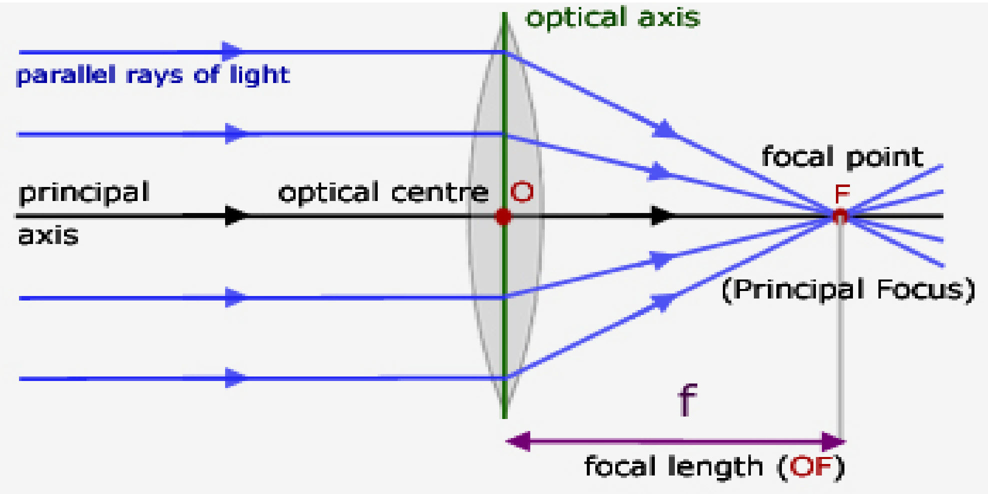


Figure 9.2 parallel rays passing through the converging lens

Concave (diverging lenses)

Diverging lenses are lenses that are thinner in the middle than on the edges. **Figure 9.3** shows three shapes of diverging lens.

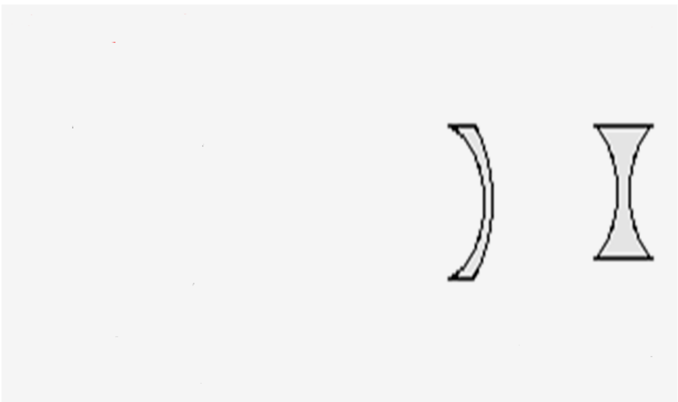


Figure 9.3 side views of concave lens.

Diverging lens causes parallel rays falling on it to diverge so that they appear to have come from the principal focus from the same side as the rays enter as shown in **Figure 9.4.**

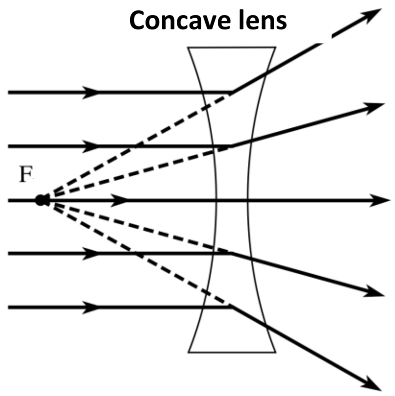


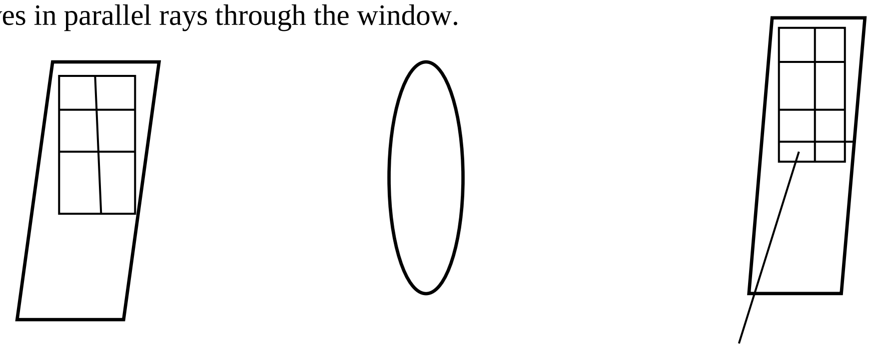
Figure 9.4 parallel rays of passing the diverging lens

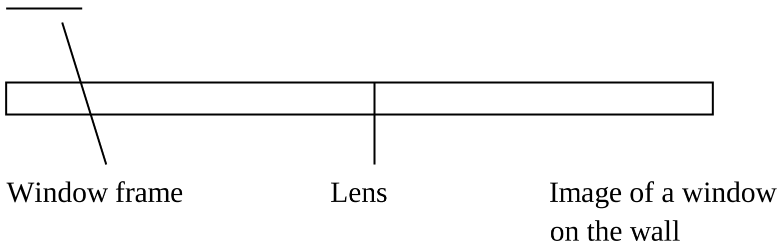
9.2 Determining the focal length of a converging lens

Experiment 9.1

AIM: To find the focal length of a converging lens using a distant object
MATERIALS: Converging lens, metre rule, white paper (screen on the wall), window frame (object).
PROCEDURE:

1. Set up the apparatus as shown in **Figure 9.5** where sunlight coming from the sun arrives in parallel rays through the window.





RESULTS/EXPLANATION
When the lens is moved, an image is formed on the paper. This image is real and inverted. The distance from the paper to the lens is called the **focal length** of the lens. Focal length of the lens depends on the thickness of the lens.

Thick lens has shorter focal length
Thin lens has longer focal length

Experiment 9.2

AIM: To find the focal length of a converging lens by the plane mirror method.
MATERIALS: Pointed light source with a screen attached to it, converging lens, lens holder, metre ruler, plane mirror.
PROCEDURE:

1. Set up the apparatus as shown in **Figure 9.6.**

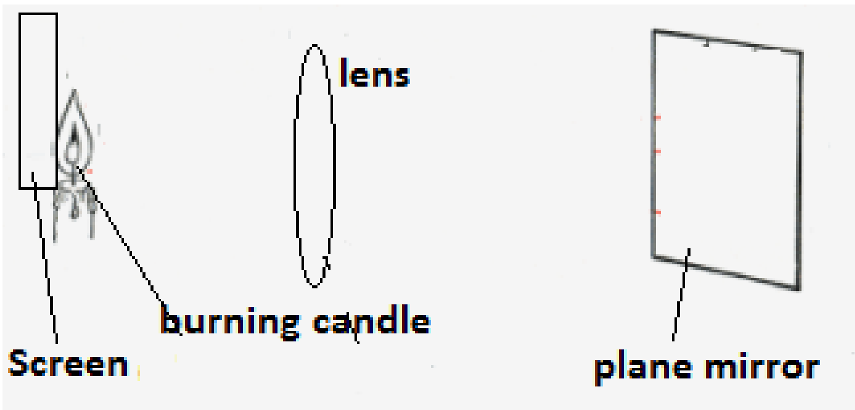


Figure 9.6

2. Move the pointed light source so that a sharp, real and inverted image is formed alongside the object.
3. Measure the distance from the centre of the lens to the image. This distance is called **focal length (f).**

EXPLANATION

Experiment 9.2 uses the principle of reversibility. A point source of light placed at the focal point F of the converging lens will give a parallel beam of light emerging from the lens. Placing a plane mirror perpendicular to the parallel beam will reflect the beam through the converging lens to form an image at **F** coincident with the object.

Experiment 9.3

AIM: To find the focal length of a converging lens by using graphical method.
MATERIALS: Converging lens, lens holder, metre ruler, candle (object), matches, screen.
PROCEDURE:

1. Arrange the apparatus as shown in **Figure 9.7.**

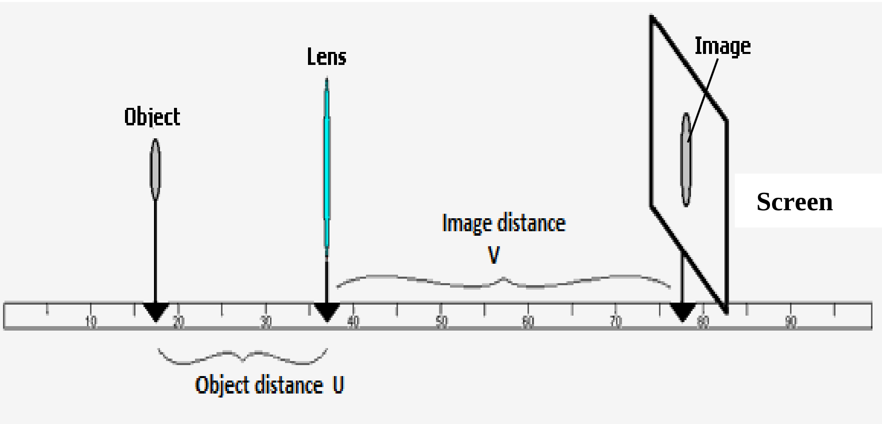


Figure 9.7

2. Light the candle (object).
3. Move the candle (object) until it is 25 cm from the lens. This distance is called **object distance, U.**
4. Move the screen until a clear image of the object is formed on the screen.
5. Measure the distance from the centre of the lens to the image on the screen. This distance is called **image distance, V.**
6. Repeat the experiment with other object distances e.g. 30 cm, 35 cm, 40 cm, 45 cm, and 50 cm.
7. For each object distance, measure the image distance.
8. Record the results in **Table 9.1**.

Object distance, U (cm)	**Image distance, V (cm)**	**U + V (cm)**	$\frac{1}{u}$	$\frac{1}{v}$
25				
30				

DISCUSSIONS

Use your results in **experiment 9.3** to answer the following questions:

1. Complete the table by filling in all the columns.
2. Plot a graph of (u + v) against u.
3. Describe the shape of the graph in 2.
4. Now plot a graph of $\frac{1}{u}$ against $\frac{1}{v}$
5. Describe the shape of the graph in 4.

Interpreting the graphs from experiment 9.3

A graph of (u + v) against u

The graph line of (u + v) against u will be as shown in **Figure 9.8.**

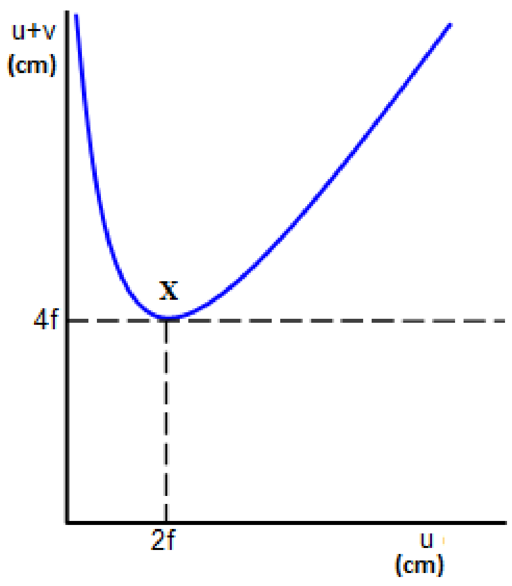


Figure 9.8 a graph of (u + v) against u

The graph has a minimum (lowest) point given the letter **X**. this point is produced when the object is at 2f. An object at 2f will form an image at 2f.

At point X:

- u = 2f
- v = 2f
- u + v = 4f

Therefore, focal length = $\frac{\text{value of } (u + v) \text{ at } X}{4}$

Or f = $\frac{\text{value of } u \text{ at } X}{2}$

A graph of 1/u against 1/v

A graph of 1/u against 1/v will be as shown in **Figure 9.9.**

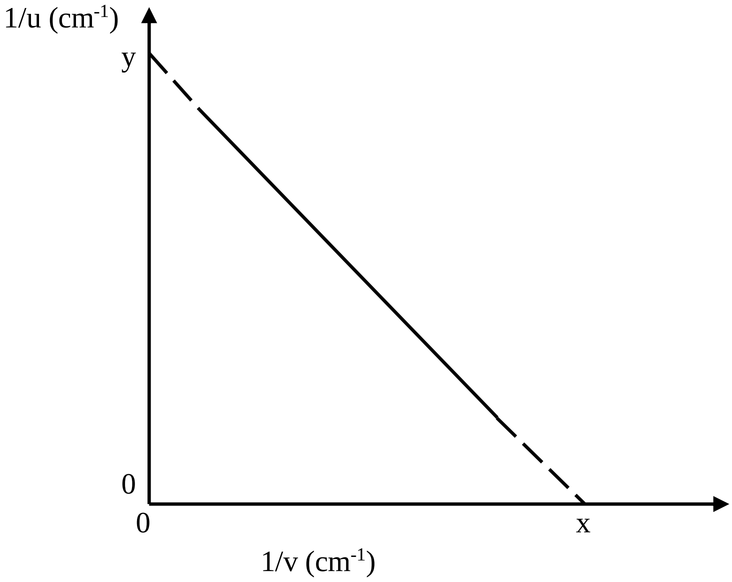


Figure 9.9 a graph of 1/u against 1/v

At x-intercept:

$$\frac{1}{v} = 0$$

$$\frac{1}{u} = \text{the value at x-intercept}$$

$$u = \frac{1}{\text{value at x-intercept}}$$

Therefore, u gives the value of focal length of a converging lens.

f = u

At y-intercept:

$$\frac{1}{u} = 0$$

$$\frac{1}{v} = \text{the value at x-intercept}$$

$$v = \frac{1}{\text{value at x-intercept}}$$

Therefore, v gives the value of focal length of a converging lens.

f = v

Exercise 9.1

In your groups, use the graphs of (u + v) against u and 1/u against 1/v to find the focal length of the converging lens.

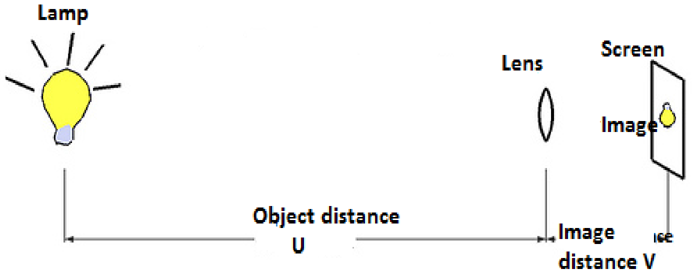
9.3 Converging lens and the formation of the image

Convex lens is used to form an image.
An **object** is a real thing while an **image** is a picture of a real thing.

Experiment 9.4

AIM: To investigate the formation of an image by the converging lens.
MATERIALS: Lamp, object, converging lens, metre rule, screen.
PROCEDURE:

1. Arrange the apparatus as shown in **Figure 9.10.**



2. Switch on the lamp.
3. Observe what happens on the screen.

RESULTS/EXPLANATIONS

When the lamp is switched on it produces light which illuminates the object. The rays of light from an object are refracted by the converging lens. The converging lens converges the rays of light and an image is formed on the screen.

CONCLUSION

Therefore, the image is formed on the screen by the converging lens.

Position and nature of the image

Position of the image

The position of the image is found by measuring the distance between the lens and the screen. This distance is called **image distance, V**.

Nature or characteristic of the image formed

The image which is formed by the converging lens has the following characteristics:

1. Either **Real** or **Virtual**

A real image is the image which can be shown on the screen.
A virtual image is the image which cannot be shown on the screen.

2. Either **Magnified** or **Diminished.**

A magnified image is the one that is bigger than its object.
A diminished image is the one that is smaller than its object.

$$\text{Magnification, } m = \frac{\text{image distance (distance from the lens to the screen)}}{\text{Object distance (distance from the lens to the object)}}$$

$$M = \frac{V}{U}$$

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

$$M = \frac{hi}{ho}$$

3. Either **Erect** or **Inverted.**

An erect image is the one that is upright (points in the same direction as its object).
An inverted image is the one that is upside down (points in opposite direction to its object).

9.4 Drawing ray diagrams

The position, size, and nature of the image can be found by drawing ray diagrams.

The following symbols are used in light ray diagrams.

U object distance (in cm or cm) - distance between the centre of the lens and the object

V image distance (in cm or m) - distance between the centre of the lens and the image.

f focal length (in cm or m) – distance between the centre of the lens and the focal point F.

F principal focus or focal point (no units)- the point on the principal axis when the ray of light passes through.

F is the same distance as the focal length; **2F** is double the focal length.

Principal rays

The following three principal rays are used in geometrical constructions of ray diagrams to find the positions and sizes of images:

1. A ray which passes through the optical centre of the lens is not bent (undeviated).

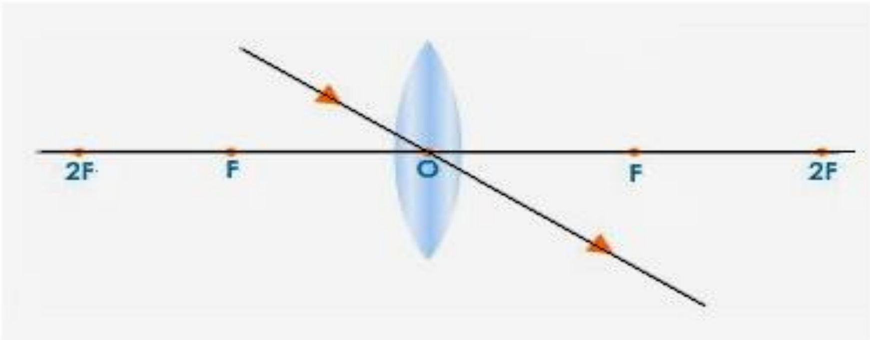


Figure 9.11 a ray of light passing through the optical centre

2. A ray which is parallel to the principal axis passes through the focal point (principal focus) after refraction through the lens.

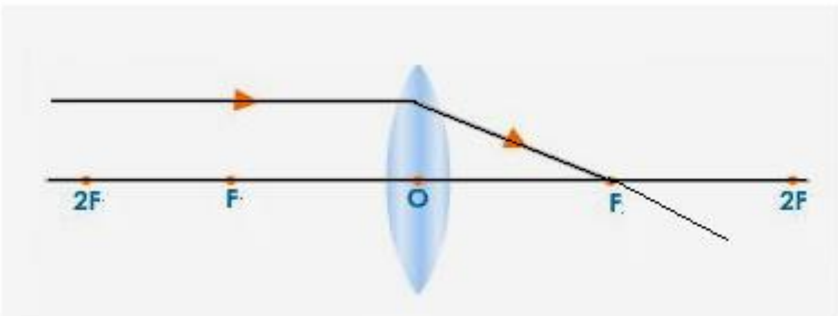


Figure 9.12 a ray of light parallel to the principal axis before the lens

3. A ray which passes through the focal point F before the lens emerges (leaves the lens) parallel to the principal axis.

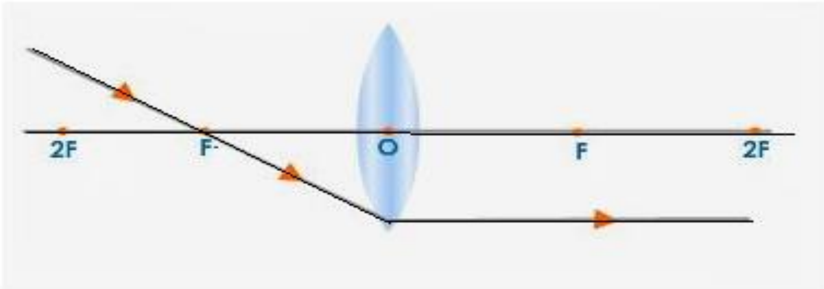


Figure 9.13 a ray of light from F emerges parallel to the principal axis.

The position of the image is found by joining at least two principal rays.

Examples of ray diagrams

Object at a distance beyond twice focal length (beyond 2F).

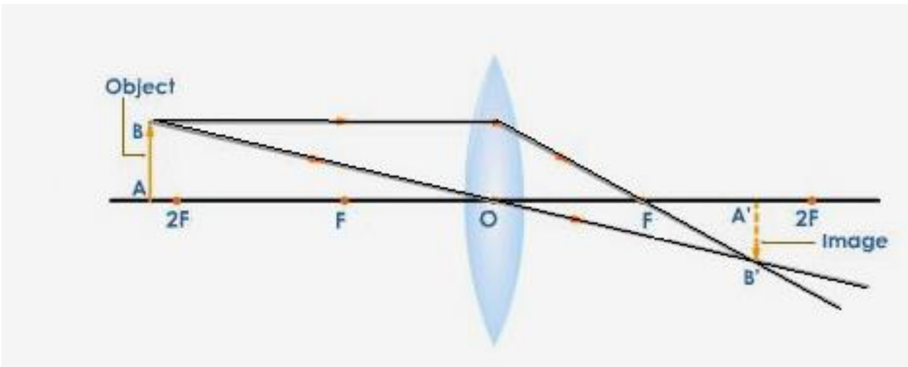


Figure 9.14 an object placed behind 2F

The characteristics or nature of the image formed are:

- The image is real.
- The image is inverted and located between F and 2F.
- The image is smaller than the object (diminished).

Application: Cameras, telescopes, and eyes.

Object at 2F

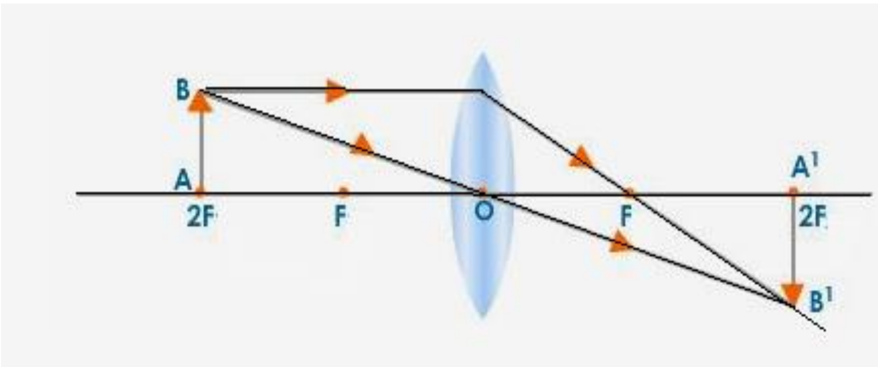


Figure 9.15 an object placed at 2F

The nature or characteristics of the image formed are:

- The image is real.
- The image is inverted (upside down)
- The image is of the same size as the object. The object is located at 2F and the image is formed at 2F.

Application: Camera and terrestrial telescopes**.**

Object between F and 2F

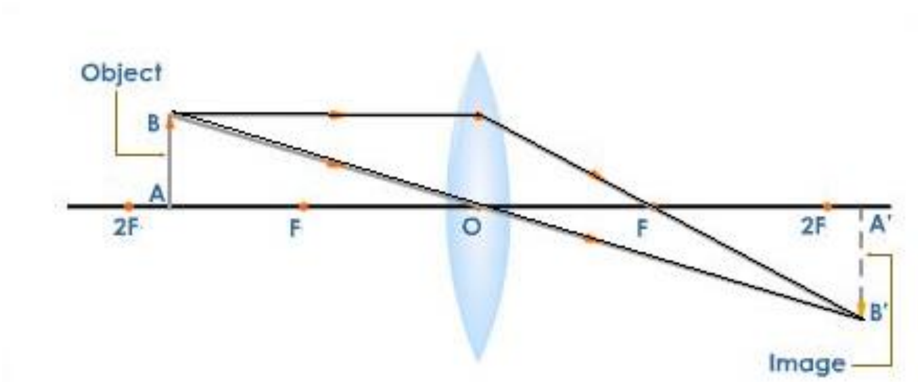


Figure 9.16 an object placed between F and 2F

The nature or characteristics of the image formed are:

- The image is real.

- The image is inverted (upside down).
- The image is magnified and located beyond 2F.

Application: Compound microscope, slide projector and motion picture projector.

Object at F

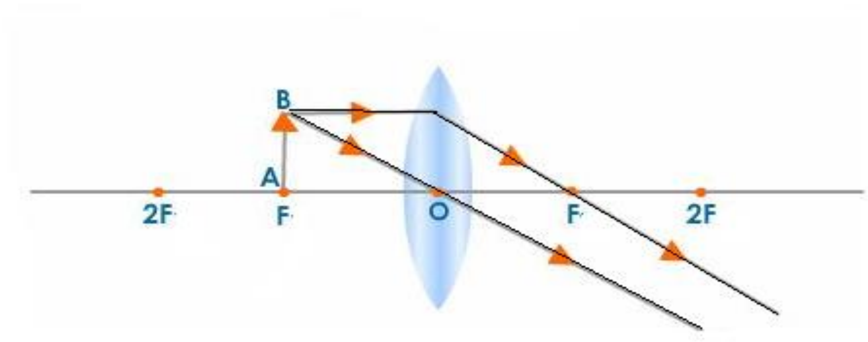


Figure 9.17 an object placed at F

The nature or characteristics of the image formed are:

- The image is virtual (not formed on the screen since rays are parallel when they leave the lens).
- The image is formed at infinity
- The image is upright.
- The image is magnified.

Application: Search/spotlights and eyepiece telescope

Object between F and Lens.

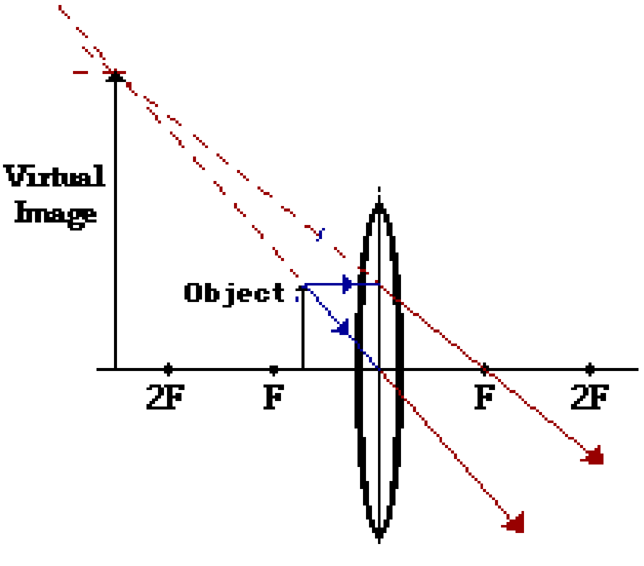


Figure 9.18 an object placed between F and the lens

The nature or characteristics of the image formed are:

- The image is virtual.
- The image is upright.
- The image is enlarged.
- The image is formed and located on the same side of the object.

Applications: binoculars, microscopes, simple magnifiers, and telescopes.

Drawing ray diagrams to scale

Ray diagrams can be drawn to scale to improve the accuracy.

Worked examples

1. A 3 cm high object is placed 18 cm in front of the converging lens of focal length 6 cm.

a. Draw a ray diagram to find the position of an image formed (scale 1cm:3 cm on both axes)

b. Describe the nature of an image formed.

c. Calculate the magnification of the image.

Solution

a. u = 18cm, to scale u= 6cm

f= 6cm, to scale f = 3 cm

ho = 3cm, to scale ho = 1cm

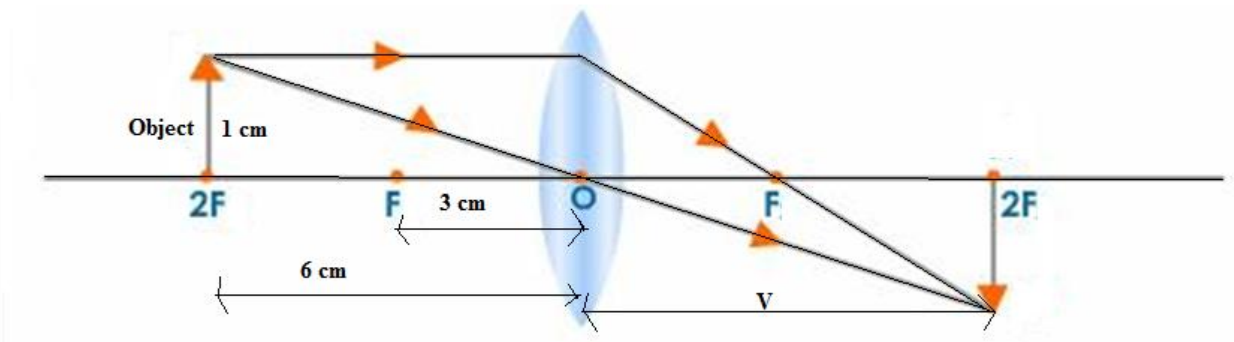


Figure 9.19

b. The image is real, inverted and of the same size as its object.

c. Magnification = $\frac{V}{U}$

$$M = \frac{6\text{ cm}}{6\text{ cm}}$$

M = **x 1**

2. An object 2 cm high is placed 4 cm in front of a converging lens of focal length of 5 cm.
a. Draw a ray diagram and find the position of the image formed.
(using a scale of 1cm: 2 cm on both axes).
b. Describe the nature of the image formed.
c. Calculate the magnification of the image.

Solution

a. u = 4 cm, to scale u = 2 cm
f = 5 m, to scale f = 2.5 cm
ho = 2cm, to scale ho = 1cm

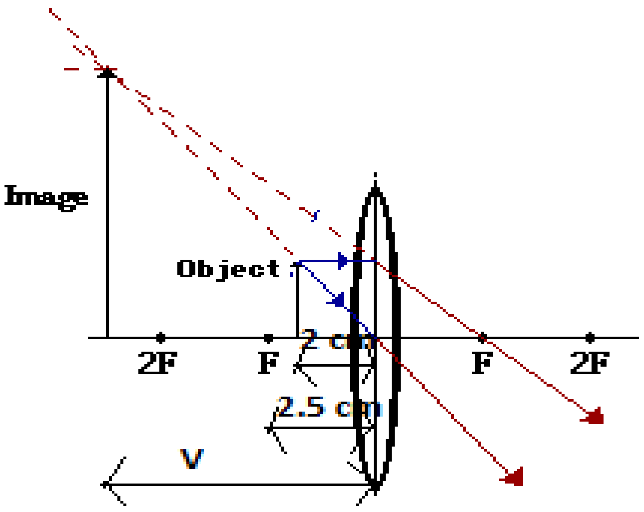


Figure 9.20

b. Upright, magnified, not real (virtual)
c. Magnification = $\frac{hi}{ho}$

$$M = \frac{10\text{ cm}}{1\text{ cm}}$$

M = **x 10**

Exercise 9.2

In your groups, answer the following questions:

1. Discuss the difference between each of the following pair:

a. object and image **b.** real image and virtual image.

2. An object 3 cm high is placed 10 cm away from a converging lens of focal length 5 cm.

a. Draw a ray diagram to find the position of an image formed.
(Use a scale 1cm: 2 cm on both axes).

b. State the nature of the image formed.

c. Calculate the magnification of the image.

3. An object 5 cm tall is placed 15 cm from a converging lens of focal length 10 cm.

a. Draw a ray diagram to scale to find the size and position of the image formed.

b. Calculate the magnification in this case.

c. What would happen to the size of an image if the object was moved gradually

i. away from the lens? **ii.** toward the lens?

9.5 The lens formula

In **Experiment 9.4**, the distance between the lens and the object (object distance, **u**) can be changed and the distance between the lens and the screen (image distance, **v**) can also be adjusted so that the image is sharply in focus. It can be proved that **u**, **v** and the focal length **f** are related by the formula:

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

Derivation of the lens formula

If an object is placed at 2F, the image is also formed at 2F. Image is real, inverted and of the same size as the object as shown in **Figure 9.21.**

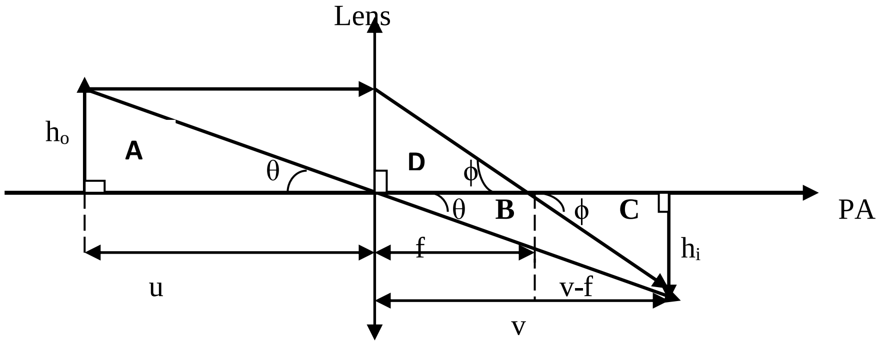


Figure 9.21 ray diagram of an object placed at 2F.

From **Figure 9.21** above, the object and the image are perpendicular to the principal axis (PA).

In triangle A: $\tan\theta = \frac{h_o}{u}$

In triangle B: $\tan\theta = \frac{h_i}{v}$

In triangle C: $\tan\phi = \frac{h_i}{v-f}$

In triangle D: $\tan\phi = \frac{h_o}{f}$

But triangle A is congruent to triangle B and triangle C is congruent to D

The equations will be combined as shown below, and then h_i is made the subject in each case:

$$\frac{h_o}{u} = \frac{h_i}{v} \qquad \frac{h_i}{v-f} = \frac{h_o}{f}$$

$$h_i = \frac{vh_o}{u} \qquad h_i = \frac{h_o(v-f)}{f}$$

Now the equations are combined since hi is common:

$$\frac{h_o(v-f)}{f} = \frac{vh_o}{u}$$

Dividing both side by ho, the equation becomes:

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

This can also be written as:

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

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

Dividing by v throughout the equation becomes:

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

Lens formula: $$\mathbf{\frac{1}{f} = \frac{1}{v} + \frac{1}{u}}$$

This formula can be used to solve different problems involving f, u and v.

Worked Examples

1. An upright object is placed 20cm in front of a converging lens of focal length 10cm. Using lens formula calculate the image distance.

Solution

u= 20 cm f = 10 cm v=?

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

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

$$\frac{1}{v} = \frac{1}{10} - \frac{1}{20}$$

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

v = **20 cm**

2. An object is placed 10 cm in front of a converging lens of focal length 15 cm. Calculate
   - **a.** The position of the image formed.
   - **b.** The magnification of the image.

Solution

a. u = 10cm f = 15cm V=?

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

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

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

$$\frac{1}{v} = \frac{-5}{150}$$

$$v = \frac{-150}{5}$$

v = **-30cm**

The negative sign means that the image is virtual.

b. Magnification, $M = \frac{v}{u}$

$$M = \frac{30\ cm}{10\ cm}$$

M = **x 3**

3. Calculate the focal length of a converging lens if an object placed at a distance of 20 cm forms an image at a distance of 40 cm.

Solution

u = 20 cm v = 40 cm f = ?

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

$$\frac{1}{f} = \frac{1}{20} + \frac{1}{40}$$

$$\frac{1}{f} = \frac{3}{40}$$

$$f = \frac{40}{3}$$

f = **13.3 cm**

Exercise 9.3

In your groups, calculate the value of

1. f if u = 25 cm and v = 37 cm

2. u if v = 40 cm and f = 10 cm

3. v if u = 30 cm and f = 15 cm

9.6 Applications of lenses in various optical devices

Optical devices that use lenses are a camera, projector, and telescope.

A simple camera

Parts of a camera and their functions

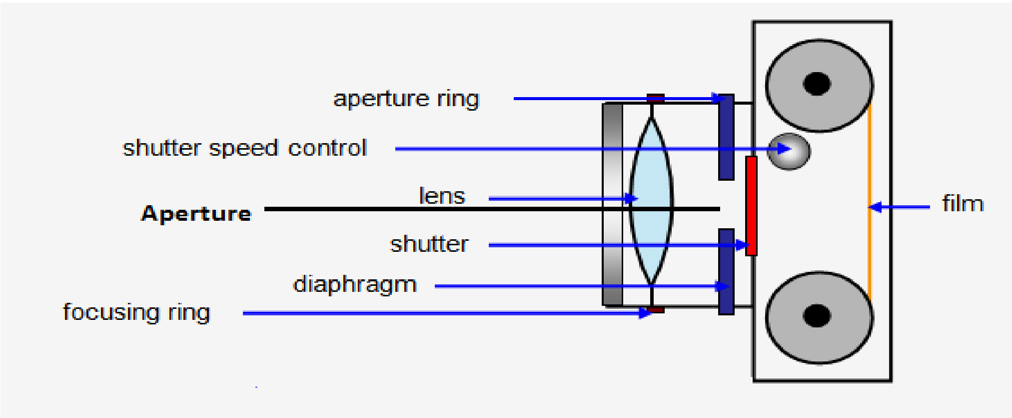


Figure 9.22 a simple camera

Figure 1

i. **The converging lens:** refracts rays of light and form inverted image on the film.

ii. **The aperture:** a hole through which light rays enter the camera.

iii. **The focusing ring:** helps to focus an image so that a clear image is formed.
The focusing ring moves the lens towards or away from the firm until a clear image is formed.

iv. **The diaphragm** controls the size of the aperture. The aperture is made narrow on a brighter day so that less light is allowed in. When there is less light, the aperture is made wider so that more light enters the camera.

v. **The shutter:** allows light into the camera by opening and prevents light from entering the camera by closing.

vi. **The shutter button** is used to release the shutter to open and later close alone.

vii. **The film** is used to keep the picture of the image for the later processing. The film is coated with a silver bromide (AgBr) which reacts to light very quickly. The silver bromide re-distribute (rearranges) itself according to the amount of light reflected by the object. Brighter areas on the object will make silver atom to cluster there, than in darker areas of the object.

Recall that brighter areas of an object reflex more light than darker areas.
This means that the darker areas of a negative will be brighter on a picture after printing and vice versa.
The normal of light entering a modern camera is controlled by two ways:

a. By changing the aperture size (as already explained)
b. By changing the speed of opening and closing the shutter.

The time of opening and closing the aperture varies from 1/15 s (0.067s) to 1/1000s (0.001 s). This time is called the **exposure time.**
The shorter the exposure time, the smaller the amount of light entering the camera and vice versa. This means that in a bright sunshine a shorter exposure time would be used.

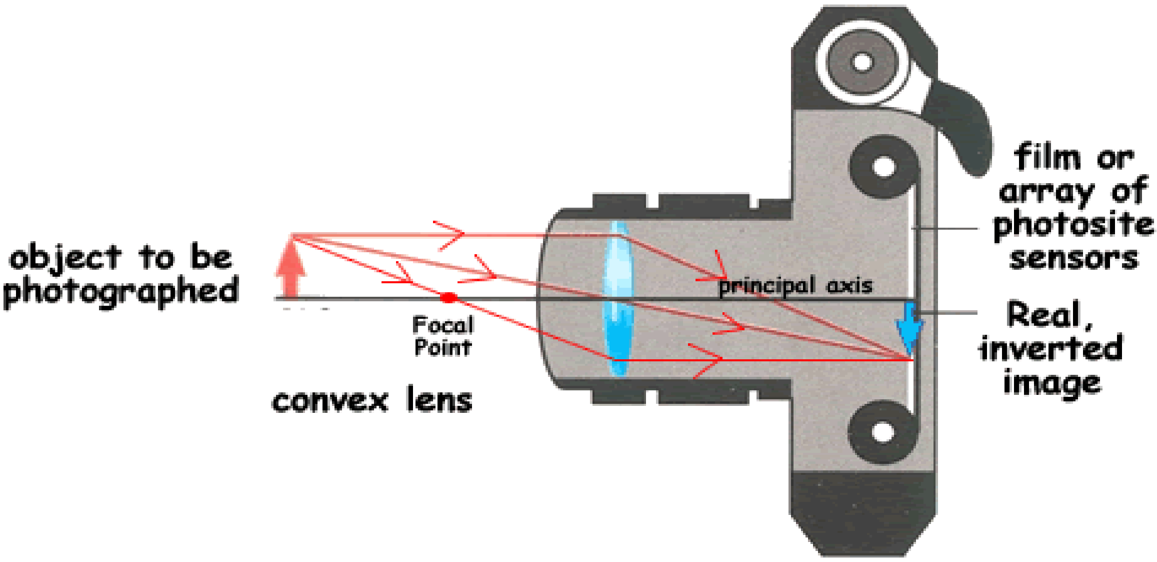


Figure 9.23: ray diagram to locate the position and size of an image formed by a camera

PROJECT

AIM: To make a lens pinhole camera.
MATERIALS: a pinhole camera that was made in Book 2, a nail and converging lens.
PROCEDURE:

1. Enlarge the whole of a pinhole camera that we made in Book 2 using a nail.
2. Bring a converging lens in front of the whole.
3. Scan the objects around you.
4. Check if you get better images. If not, then try to move the lens to and fro.

The projector

In a projector, the object is placed between F and 2F and it is always inverted.
Therefore, the image that is formed is upright and magnified.
But the source of light is behind the object. The object is usually a transparent film slide
Generally, the projector is arranged as shown in **Figure 9.24**.

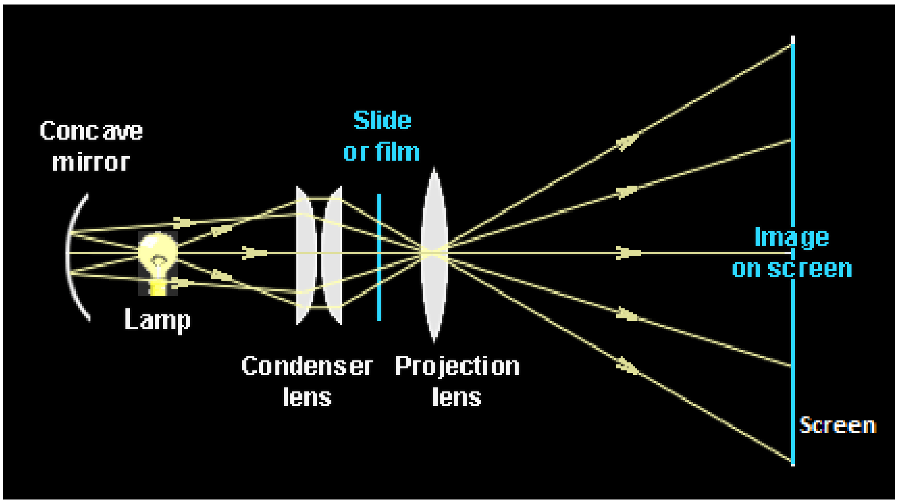


Figure 9.24 the optical projector.

Parts of a projector and their functions

Projector Lens: it is used to focus the image of the object slide onto the screen.
Screen: it is used to reflect (diffuse) the projected image in all directions for the viewers to see.
Curved mirror – it is used to collect all the light rays and reflect them to the object (the slide film).
The light source – it is used to provide bright light in order to illuminate the object.
The condensing lens – it is used to bring together the scattered rays of light and concentrate them on the object.

How the projector works.
The object placed in the projector transparent is usually a kind of a negative of a film with a picture on it.
When the light from the source and the mirror passes through the object it forms an image on the screen with help from the focusing lens.
Usually the pictures are still (stationary) ones.

In a moving picture projector, several closely similar pictures are flashed quickly so that the eye of an observer will see it as if it is moving.

NOTE The image of the projector is usually magnified considering the position of an object i.e. between F and 2F.

Telescope

A telescope is an instrument used to observe distant objects.
Figure 9.25 is a diagram of a telescope.

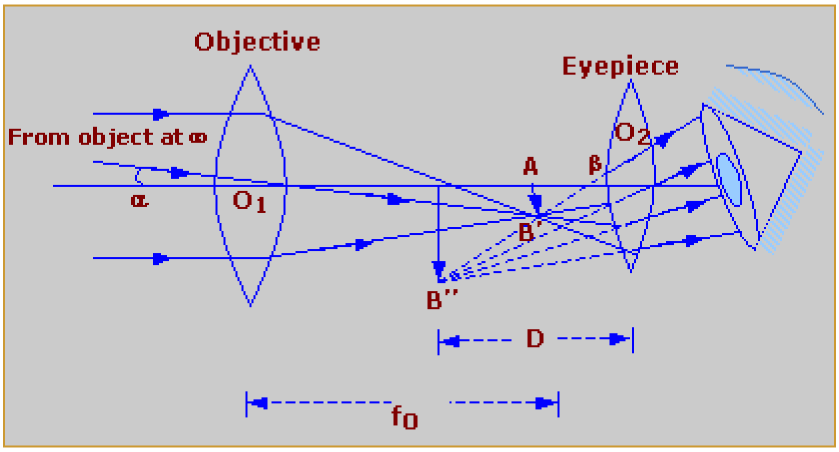


Figure 9.25 a telescope

Parts of a telescope and their functions

Objective lens: It has a long focal length (thin lens).
It is used to produce a real and inverted image of the object.

Eyepiece lens: It has a shorter length (thick lens).
It acts as a magnifying lens.

The final image is a large and inverted image of the distant object. It is also virtual image.

PROJECT

AIM: Making a telescope

MATERIALS: Two converging lenses with different focal lengths e.g. one with a focal length 20 cm and one with focal length 5 cm, a stick of about 30 cm to 40 cm in length, glue and plasticine.

PROCEDURE:

1. Move the lenses in relation to each other until you obtain a magnified image of a distant object.
2. Fix the lenses on the stick using the plasticine.

9.7 Formation of the image in the human eye

The eye is an optical image-forming system.
Many parts of the eye shown in **Figure 9.26** play the important roles in the formation of an image on the retina.

Different parts of the eye and their use

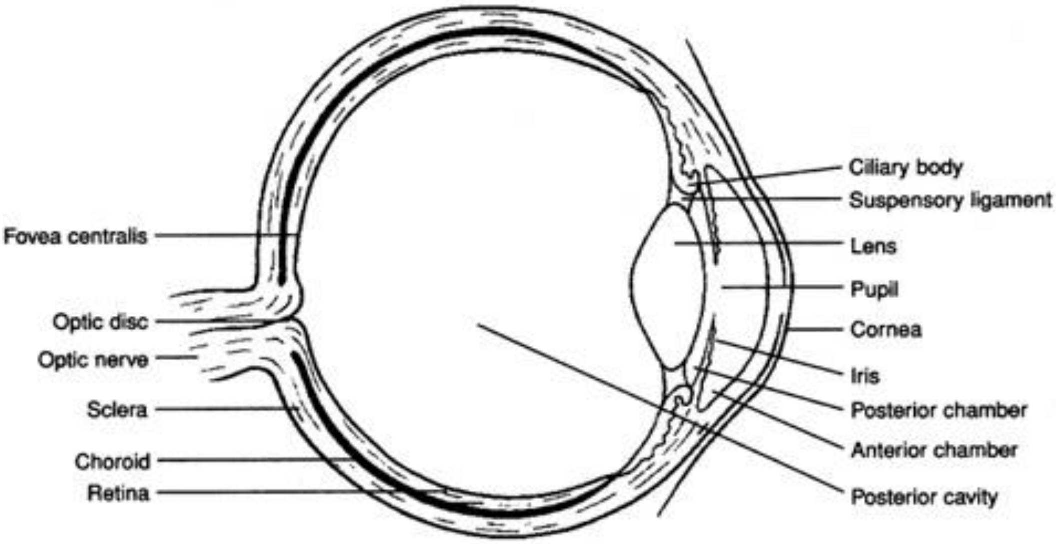


Figure 9.26 the human eye

Iris

- The iris controls the amount of light entering the eye by controlling the size of the pupil.
- It enlarges the pupil in the dark and it closes, causing the pupil to contract in the bright light.

Pupil

- The pupil is a hole through which light enters the eye controlled by the iris.

- It becomes bigger in dim light and becomes smaller in bright light.
- Nocturnal (night) hunting animals such as owls and cats have very big pupil to enter the eye. And these animals can see at night without any problems.
- During the day, these animals' pupils are almost closed in order for them to see. The pupils do not close enough for them to see in the bright sunshine. This is why most of them hide in the shade and dark places such as big shady trees.
- This is why owls are mostly seen more at night than during the day.

Eye lens

- These are used to focus a sharp and inverted image on the screen called the **retina.**
- The special ability of the eye lens is that it can change its shape curvature.

Cornea

- This is the tough, transparent, and protective outer cover to the eye.
- All light entering the eye passes through the cornea.
- It also helps in the refraction of the rays of light.

Retina

- This is a light sensitive part of the eye where images are formed.
- The central pupil looks black. The black that is seen is the retina of the eye inside at the back of the eye.

Optic nerve

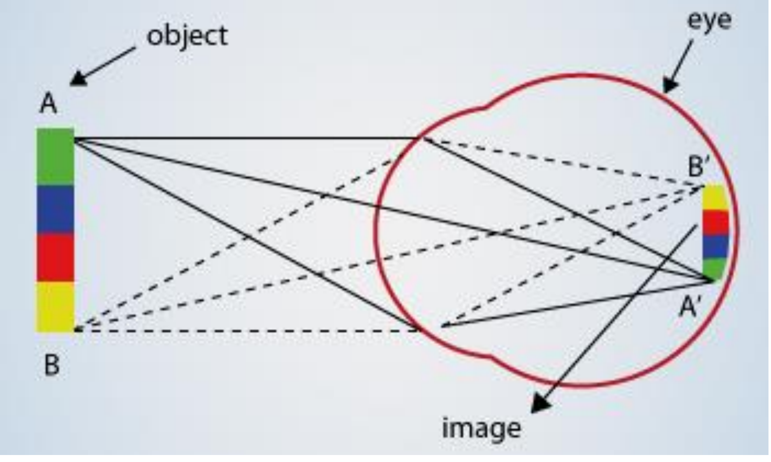
- This is connected to the retina at the back of the eye. The picture formed on the retina is carried to the brain through this nerve (the optic nerve) for interpretation.

Ciliary muscle

- These muscles are connected to the lens.
- They are used to change the curvature (shape) of the lens so that the focal length changes to what the eye would like to see.
- The focal length will be shorter when the lens is shorter and thicker and the focal length will be longer when the lens is longer and thinner.

Formation of the image in a human eye using ray diagrams

A ray diagram can be used to show how light passes from a point on a real object (located somewhere in space outside the eye) to the corresponding position on the image of the object on the retina at the back of the eye.



Accommodation of the eye

This refers to the ability of the eye to focus light from objects placed at different distances into the retina. This is achieved by changing the shape of the eye lens. The shape of the eye lens can be changed by the help of the ciliary muscles.
This emphasizes the point that short fat lens have a stronger bending power of light rays, hence they have a shorter focal point.

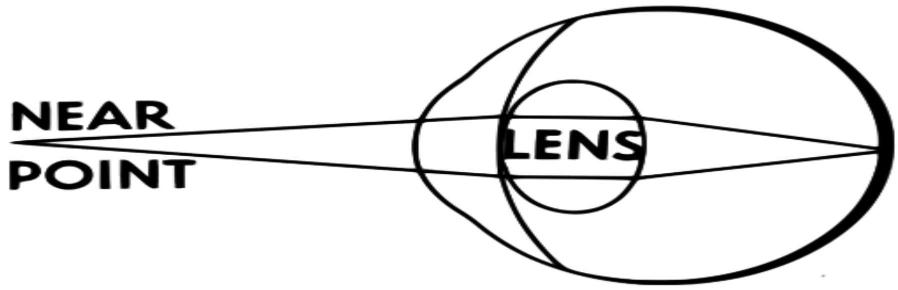


Figure 9.28 (a)

Nearby Objects

- Have a longer image distance.

Shorten the focal length

- Ciliary muscles contract
- Squeeze the lens into a more convex (fat) shape
- Pushes cornea bulge out further: greater curvature

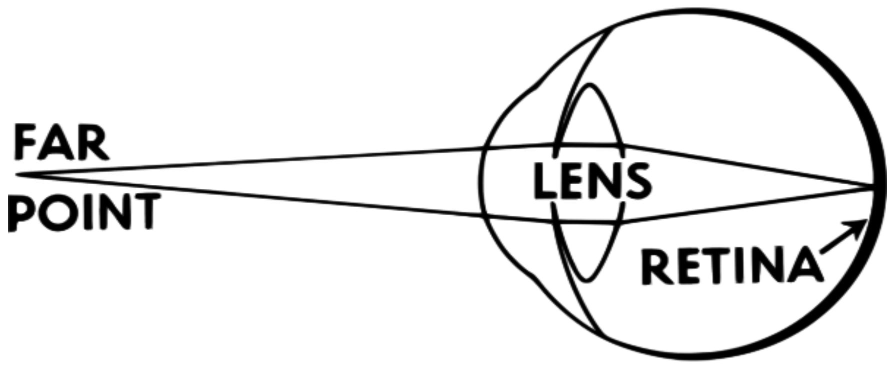


Figure 9.28 (b)

Distant Objects

- Have a shorter image distance.

Lengthen the focal length

- Ciliary muscles relax
- Lens assumes a flatter (thinner) shape
- Cornea is not pushed out = less curvature

Comparing a camera to human eye

Many people have called the eye a living camera because of its similarities with the camera.

Table 9.2 shows similarities between a camera and a human eye

Table 9.2 similarities between a camera and a human eye

The camera	**The eye**
It has a convex lens system which produces a real, inverted image	It has a convex lens system which forms a real, inverted image
There is a light sensitive (film) on which the image is formed.	It has a light sensitive screen (the retina) with about 130 million light sensitive cells on which an image is formed
Light is controlled by diaphragm which increases or decreases the size of aperture in reaction to the amount of light present.	Light is controlled by the iris which increases or decreases the size of the pupil in reaction to the amount of light falling on the eye.
The inside surface is black.	The inside surface is black (the retina is black).

Table 9.3 shows differences between a camera and a human eye.

Table 9.3 differences between a camera and a human eye

Eye	**Camera**
Focal length (f) of the lens changes i.e. the eye lens becomes thicker and shorter or it becomes longer and flatter.	The focal length (f) of lens is just fixed.
The eye is normally open (it does not have specified shutter)	The camera is normally closed (shutter only opens when a picture is taken).
The eye has a fixed image distance (v)	A camera has a changing image distance (v)

Exercise 9.4

In your groups, answer the following questions:

1. Discuss parts of the following optical instruments and their uses:
a. camera **b.** projector **c.** human eye

2. Explain
a. similarities between a camera and a human eye.
b. differences between a camera and a human eye.

9.8 Defects of vision in the human eye and how they can be corrected

Short sightedness (myopia) and its correction

A **short sight** is the situation whereby the eye fails to focus a distant object clearly because the eye ball is too long for the rays from a distant object. In this situation, the light rays converge before reaching the retina.

The problem can be corrected by placing a concave (diverging) lens which can delay the meeting of the light rays.

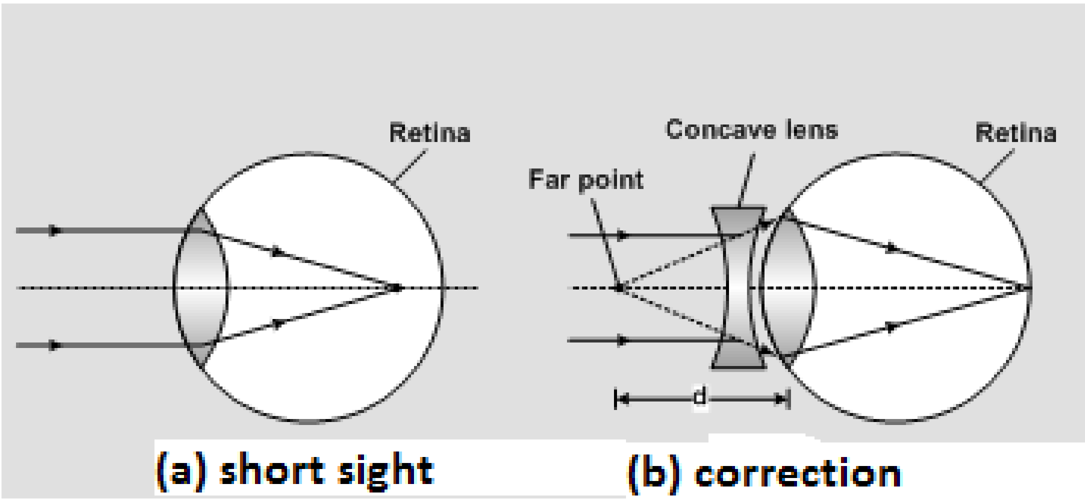


Figure 9.29 short sight and its correction

Long sightedness (hypermetropia) and its correction

A **long sight** is the situation whereby the eye fails to focus a close object clearly because the eye ball is too short for the rays from a close object. In this situation, the light rays converge at a point just beyond the retina.

The problem can be corrected by placing a convex (converging) lens which can cause the rays of light to meet at the retina and form a focused image.

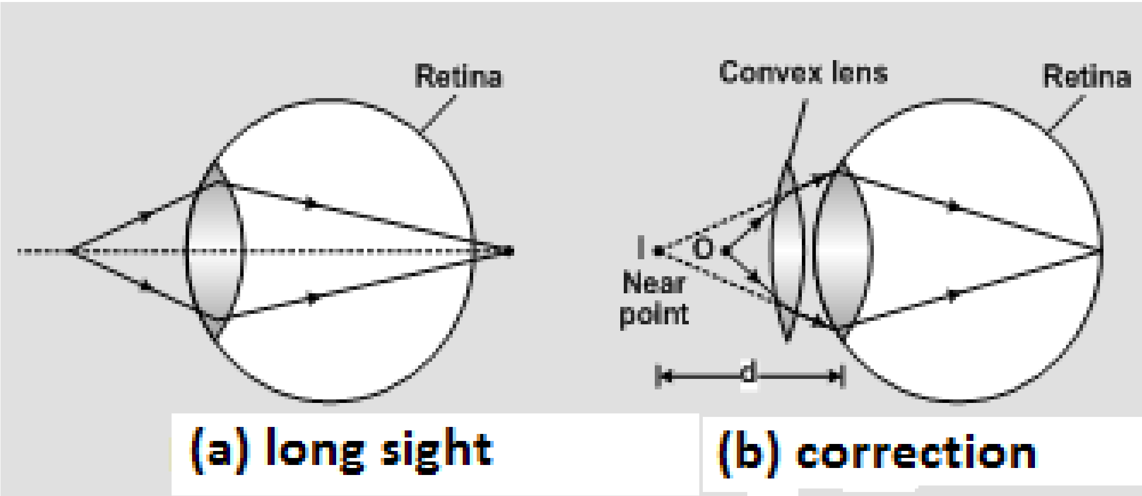


Figure 9.30 long sight and its correction.

Summary

Converging (convex) lenses are those that are thicker in the middle than on the edges while diverging (concave) lenses are lenses that are thinner in the middle than on the edges.

Focal length of a converging lens can be found experimentally using a distant object, mirror method and graphical method.

The position, size, and nature of the image can be corrected using ray diagrams.
The position, size and nature of the image can also be found by calculations using the lens formula.A lens formula is given as:

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

The optical instruments that use the lenses are a camera, projector, telescope, and a human eye.

Student assessment

1. Define
   a. principal axis
   b. focal length
   c. principal focus
   d. focal plane

2. state the difference between each of the following pairs:
   a. object and image
   b. real image and virtual image.

3. A 5cm tall object is placed 10 cm away from a converging lens of focal length 5 cm.
   a. Draw a ray diagram to find the position of an image formed. (use a scale 1cm: 2cm on both axes).
   b. State the nature of the image formed.
   c. Calculate the magnification of the image.

4. An object 2 cm tall placed 8 cm from a converging lens of focal length 10 cm.
   a. Draw a ray diagram to scale to find the size and position of the image formed.
   b. Calculate the magnification in this case.
   c. What would happen to the size of an image if the object were moved gradually.
      i. Away from the lens?
      ii. Toward the lens?

5. An object 3cm high is placed 12 cm away from a diverging lens of focal length 4 cm.
   a. Using lens formula, find the image distance.
   b. find
      i. height.
      ii. magnification.
      iii. nature of the image formed.

6. With the aid of diagrams explain
   a. The structural difference between a convex lens and a diverging lens.
   b. The functional difference between a convex lens and a diverging lens.

7. a. Copy and complete the **Figure 9.31**, to show the position of the image.

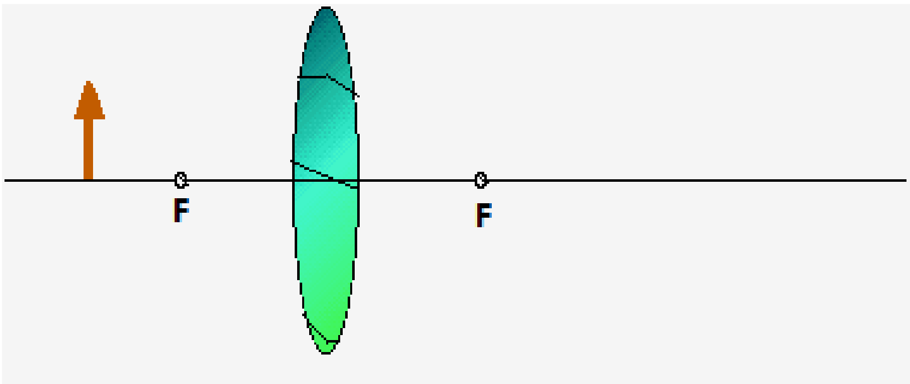


Figure 9.31

b. Calculate the magnification of the image.

8. State the nature of an image which can be formed from an object placed at a distance greater than twice the focal length of the converging lens.

9. An object is placed 20 cm in front of a convex lens of focal length 10 cm.
a. Using the lens formula, calculate the image distance.
b. Calculate the magnification.
c. What is the nature of the image produced?

10. Describe an experiment that you would carry out to find the magnification of the converging lens.

11. With the aid of a well labeled diagram, explain how a converging lens can form a real image of a burning candle on the screen.

12. With the help of labeled diagrams, explain
a. The similarities between a camera and a human eye.
b. The differences between a camera and a human eye.

13. An object 8 cm long is placed 10 cm in front of a converging lens of focal length 15 cm.
a. Use the lens formula to calculate the image distance.
b. Calculate magnification of the image.
c. Calculate the image height.

14. With the aid of a well labelled diagram, explain how an image is formed in a slide film projector.

CHAPTER 10

Nuclear physics

Objectives

At the end of Chapter 10, you must be able to:

- ***Describe the nuclear structure of an atom.***
- ***Describe isotopes.***
- ***Explain radioactivity.***
- ***Describe radioactive emissions.***
- ***Discuss dangers and applications of radioactivity.***

10.1 Nuclear structure of an atom

Atomic structure

An atom has two parts, namely nucleus and electron shells or energy levels.
Figure 10.1 below shows the parts of an atom.

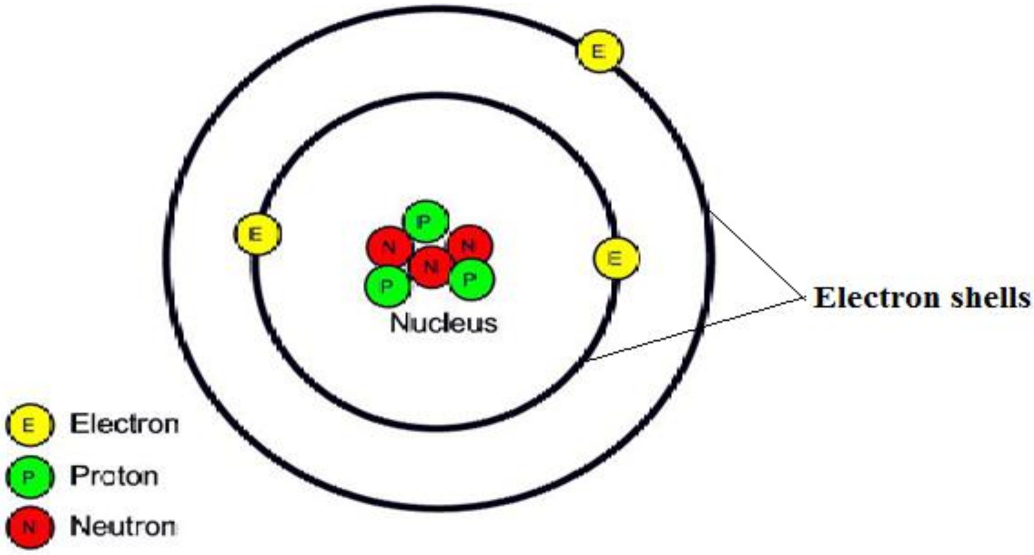


Figure 10.1 structure of an atom

Constituent particles of the nucleus

The nucleus of an atom consists of:

a. Neutrons

These are the particles that have no (zero) charge.
A neutron has mass of 1 atomic mass unit (1amu).

b. Protons

These are positively (+vely) charged particles.
A proton has a mass of 1 atomic mass unit (1amu).

The electron shells or energy levels consist of **electrons.**
These are negatively (-vely) charged particles.
An electron has negligible mass, hence its mass is taken to be 0 (zero).
This can be summarized as shown in **Table 10.1.**

Table 10.1 particles of an atom

Particle	Position in an atom	Charge	Mass(amu)
Neutron	Nucleus	0	1
Proton	Nucleus	+1	1
Electron	Energy levels	-1	0

Nuclear notations

Atomic number and mass number

Atomic number, Z of an element is defined as the number of protons in its nucleus. This is also called **proton number.**
Mass number, A of an element is defined as the total number of protons and neutrons (protons + neutrons) in its nucleus. This is also called **nucleon number.**
All atoms are neutral because they have equal number of protons (+ves) and electrons (-ves). Protons and neutrons are equal but of opposite charges, therefore they cancel out each other.

The nuclear notation of an atom can be presented as follows:

- Mass number (A) is placed on the top left of the symbol of an atom.
- Atomic number (Z) is placed at the bottom left of the symbol of an atom.

For example, if an element is X, its nuclear notation can be presented as shown below:

$${}^{A}_{Z}X$$

Using the atomic number as **Z,** mass number as **A** and number of neutrons as **N**, the equation can be written as follows:

$$\mathbf{A=Z+N}$$

Therefore, the number of Neutrons N=A-Z

c. Worked example

Nuclear notation of Lithium is shown below.

238
U
92

Write down
a. The number of protons
b. Mass number
c. Atomic number
d. The number of neutrons

Solution
a. Number of protons = 92
b. Mass number = 238
c. Atomic number = 92
d. Number neutrons = 238 – 92 = **146**

Exercise 10.1

In your groups, answer the following questions:

1. Discus the nuclear structure of an atom.

2. Radium (Ra) has an atomic number 88 and mass number 226.
a. How many protons and neutrons does the nucleus have?

10.2 Isotopes

All atoms of the same element have the same atomic number but do not always have the same mass number. This is because sometimes the number of neutrons is different although the number of protons is the same. Atoms of the same element with the same atomic number but have different mass numbers are called **Isotopes.**

Characteristics of isotopes

(i) Isotopes of an element have the same number of protons inside their nuclei. Therefore, all the isotopes of an element contain the same number of electrons.

(ii) Different isotopes of an element have different mass numbers.

(iii) Since isotopes of an element have the same number of protons and electrons, all the isotopes of an element show the same chemical properties, same electronic configurations, and the same number of valence electrons.

(iv) Isotopes of an element have different masses. So, the properties which depend upon the atomic mass should be different for different isotopes. Many physical properties e.g., melting point, boiling point, density, etc., depend upon the atomic mass. So, different isotopes of an element show different physical properties.

Examples of isotopes

Isotopes of Lithium
Since Lithium`s proton or atomic number is 3, then this means that the number of neutrons can be either 3 or 4. Hence we have isotopes of Lithium of mass numbers 6 and 7 called **Lithium – 6** and **Lithium – 7** respectively.

$$\mathbf{{}^{6}_{3}Li} \qquad \mathbf{{}^{7}_{3}Li}$$

Lithium- 6 Lithium- 7

Isotopes of carbon

Carbon – 12 Carbon-14

$$\mathbf{{}^{12}_{6}C} \qquad \mathbf{{}^{14}_{6}C}$$

Isotopes of Uranium

Uranium – 235	Uranium – 238
$^{235}_{96}\mathbf{U}$	$^{238}_{96}\mathbf{U}$

10.3 Radioactivity

Radioactive isotopes or radioisotopes

Radioactive isotopes are isotopes that are unstable. These isotopes break up spontaneously or their nuclei **randomly disintegrate** (breakdown). For these radioisotopes to be stable, they release particles or radiation. The process is called **radioactivity**.

Radioactivity is the process of emitting radiation particles by an unstable substance. Substances like uranium and polonium radio activate on their own. These substances are called **radioactive substances or radioactive isotopes.** Radiation is the term used to describe what is emitted by a radioactive element in terms of particles and energy. The radiation emitted by a radioactive material is sometimes called **nuclear radiation** because it comes from the nucleus of an atom.

Types of radioactivity

There are two types of radioactivity:

Natural Radioactivity

Natural radioactivity is the radioactivity that happens on its own naturally from natural nuclides. **For example**, when natural uranium – 238 decays, there is no influence whatsoever from the mass.

Induced Radioactivity

Induced radioactivity is the radioactivity which takes place from artificial nuclides (isotopes are made by reverse of the decay process).
This process happens when a stable atom is made to absorb nuclear particles or gamma rays or protons which become unstable, as a result.

For example, cobalt -59 is bombarded (hit) with neutrons from the reactor. Then cobalt 59 becomes cobalt -60 which is unstable. As a result, Cobalt – 60 emits strong gamma rays.

10.4 Radioactive emissions

Types of nuclear radiation

There are **three** types of nuclear radiation that are emitted during radioactivity. These types of nuclear radiation are Alpha (α), Beta (β) and Gamma (γ) named after the 1st three Greek letters.

Properties of nuclear radiations

The alpha (α) particles

- Alpha particles are Helium atoms because they have 2 protons and 2 neutrons.
- They have a net positive charge.
- They attract electrons from nearby atoms.
- They are least penetrating because they are big. They are stopped or absorbed by a sheet of paper or few centimetres of air.
- They are the most ionising of all the nucleus radiation.
- They are deflected towards the negative charge because they are positively charged since unlike charges attract.
- They are deflected toward the South Pole of the magnetic field.

The beta (β) particles

- These particles are emitted with variable velocities.
- These are electrons.
- They carry a negative charge.
- They are much less ionizing than alpha particles.
- They are more penetrating than the alpha particles. They penetrate a layer of air and a thin sheet of paper because they are lighter. They are stopped by a few millimetres of aluminium.
- They are deflected towards the positive side of an electric field because they are negatively charged. Their size of deflection is greater than in alpha particles because beta particles are lighter than alpha particles.
- They are deflected towards the North pole of magnetic field.

The gamma (γ) rays

- These are electromagnetic waves of very short wavelength.
- They result from energy changes inside atomic nuclear radiation.
- They have no charge and no mass.
- They have no ionization effect because they have no charge.
- They are the most penetrating because they have no mass. They penetrate a layer of air, a sheet of paper and a sheet of aluminium. But they can be absorbed by thick, lead metal.
- They show no deflection in both electric and magnetic fields because they have no charge.

Penetration, deflection in electric and magnetic fields of nuclear radiations can be shown in diagrams below:

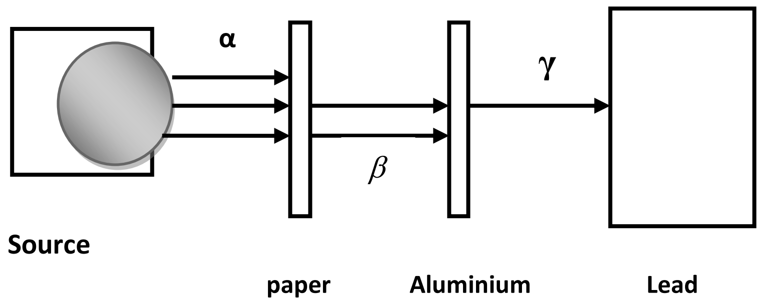


Figure 10.2 penetrations of the radiations

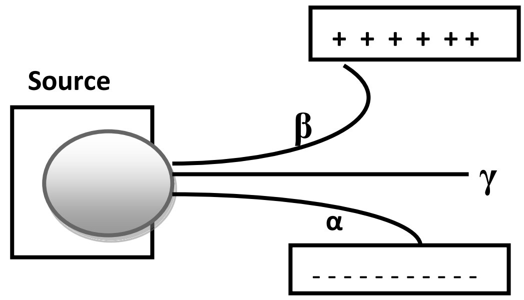


Figure 10.3 deflections in an electric field of the radiations

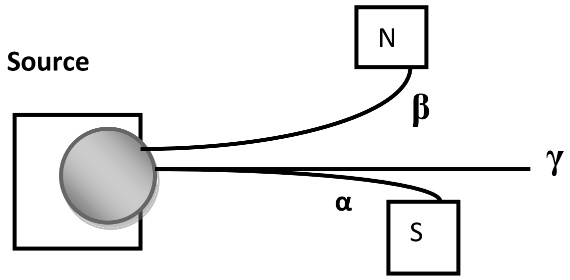


Figure 10.4 deflections in the magnetic field of the radiations

Exercise 10.2

In your groups, answer the following questions:

1. Explain the following:

a. an alpha particle is same as a nucleus of a helium atom.

b. a beta particle is same as an electron.

2. Discuss the difference between the nuclear radiations in terms of:

a. ionization effect.

Radioactive decay

Some isotopes are stable while others are unstable. This is to mean that not all combinations of protons and neutrons are stable. The isotopes that are not stable decay or disintegrate (break off) into more stable form.

Radioactive decay is the spontaneous disintegration of unstable nucleus or radioisotope to become stable. Radioactivity is the spontaneous random emission (release) of particles from within the nucleus of the atom. **Spontaneous random** means that the particles are released in bursts of irregular periods (times). The original atom completely changes its form; it does not remain the same element any longer. Radioactive decay involves the emission of an α–particle and a β- particle.

The nucleus which decays is called the **parent nucleus**. The stable nucleus which results is called the **daughter nucleus.** The combination of the daughter nucleus and the particle emitted is called the **decay products.** A daughter nucleus is always in excited state when it is formed at the stable state of the third particle of radiation called Gamma ray (γ).

Alpha decay

When a nucleus undergoes α decay it loses two protons and two neutrons.
Therefore:

- Its mass number (A) decreases by 4.
- Its atomic number (Z) decreases by 2.

If a nucleus X becomes a nucleus Y as a result of alpha decay, then the nuclear equation is given as:

$$\mathbf{{}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha}$$

Parent daughter alpha particle

For example

226 222 4

$$_{88}Ra \longrightarrow {}_{86}Rn + {}_{2}\alpha$$

Alpha particle is a helium nucleus.
Therefore, the nuclear equation can also be written as

$$^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

Note that the mass number is conserved (226→222+4) and atomic number or charge is also conserved (88→86+2).

Beta Decay (β)

Beta particles are emitted by a nucleus which has many neutrons to be stable.
Unstable nucleus emits an electron while the proton remains in the nucleus. The nucleus effectively loses a neutron and gains a proton because a neutron changes into a proton. This makes the nucleus to increase its atomic number by 1. Therefore, the emitted beta particle is taken as an electron.

When a nucleus undergoes β-decay:

- Its mass number (A) remains unchanged.
- Its atomic number (Z) increases by 1.

The nuclear equation becomes;

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta$$

Parent daughter β-particle

For example:
Carbon-14 decays by β-emission to nitrogen-14. Therefore, its equation is as follows:

$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta$$

Parent daughter β-particle

Beta particle is an electron, therefore the equation can also be written as

$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

Note that the mass number is conserved (14→14+ 0) and atomic number or charge is also conserved (6→7-1).

Gamma emission (γ)
Gamma is emitted in an electromagnetic form when a stable excited nucleus gets settled. A stable nucleus emits a photo of gamma radiation. Usually gamma rays are produced along beta or alpha particle.

- Gamma radiation has no mass or atomic number.
- Gamma rays have very short wavelength.

The nuclear equations for a γ- emission are

$$\mathbf{{}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-1}Y + {}^{4}_{2}\alpha + {}^{0}_{0}\gamma}$$

Parent daughter α particle γ particle

OR

$$\mathbf{{}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta + {}^{0}_{0}\gamma}$$

Parent daughter β particle γ particle

NOTE The energy breaking the nucleus is not coming from any external source. It is from the same nucleus.

Half-life of isotopes

Half-life is time taken for half or the number of original substance to decay and change into a new substance. It can also be defined as the time taken for half the nuclei present to disintegrate. Recall that radioactive decay is a random process. Different radioactive substances decay at different rates.
For example: If you have 48 atoms of radium, then the time taken for 24 atoms to decay is known as half life of radium.

Here are some of the half lives of some elements:

Element	**Half life**
Thorium	10^{10}yrs
Radium	1 620yrs

Bismuth – 210	5 days
Potassium – 218	3 minutes
Polonium – 214	10^{-6} yrs
Sodium	15 hrs
Uranium – 233	7×10^{8}yrs
Carbon 14	5 600yrs

From the information above, it means that the time taken for 48 atoms of uranium to decay and become 24 is 700 000 000 years (7×10^8yrs). Note that the total masses of decayed and undecayed remain the same as the original mass.

Activities and decay curves

Activity in radioactivity is the average number of disintergration per unit time in a radioactive sample. The sample will decrease exponentially with time. The rate of decay of a radioactive substance can be plotted on a graph. Usually the graph of decay of any substance is a curve shape as shown in **Figure 10.5.**

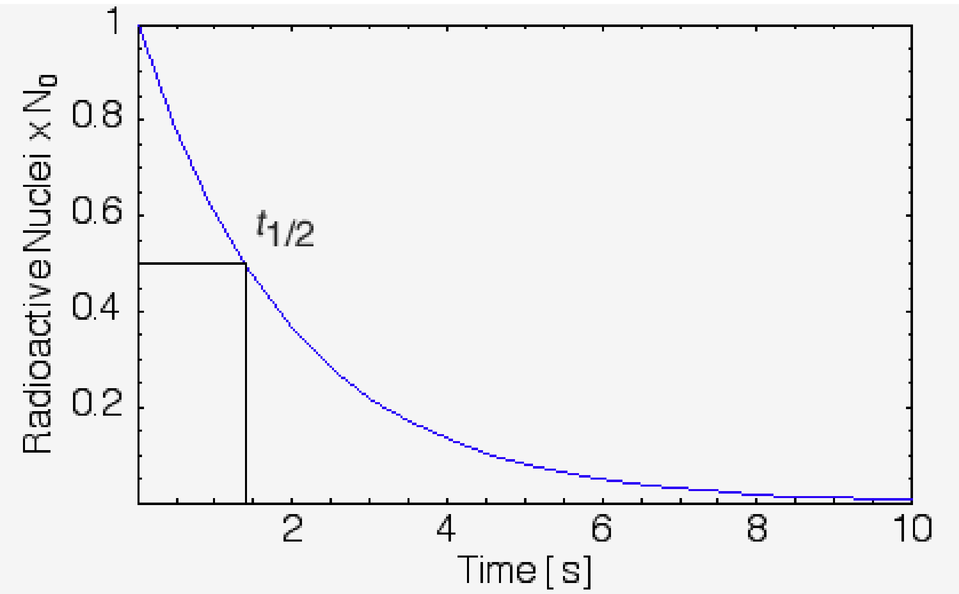


Figure 10.5 radioactive curve

When you start with 1 count/min and the half life of a particle is the time at half of 1. From **Figure 10.5,** the half of 1 is 0.5. Therefore, half-life of a substance is time at 0.5 counts/min, which is **1.4 seconds**.

Measuring half-life of a substance

A half life of a substance can be measured by placing a source in front of a Geiger-Muller tube.

Worked Examples

1. When a source is placed in front of a G-Muller tube and scaler, the initial count rate after the background count has been deducted is 4000. After 20 days, the count rate after deduction of the background count is 125. What is the half life of the source?

Solution

EITHER

Firstly, we should find out how many half lives are there in 20 days.

The count rate halves during each half life. Thus;

1^{st} half life count falls from 4000 to 2000

2^{nd} half life countrate falls from 2000 to 1000

3^{rd} half life countrate falls from 1000 to 500

4^{th} half life countrate falls from 500 to 250

5^{th} half life countrate falls from 250 to 125

Thus, the activity has halved 5 times during 20-day interval.

Therefore, its half-life is 4 days.

OR

Original count rate A_o = 4000

Let the number of half lives be n

Final countrate A_n = 125

$$\frac{A_o}{A_n} = 2^n$$

$$\frac{4000}{125} = 2^n$$

$$32 = 2^n$$

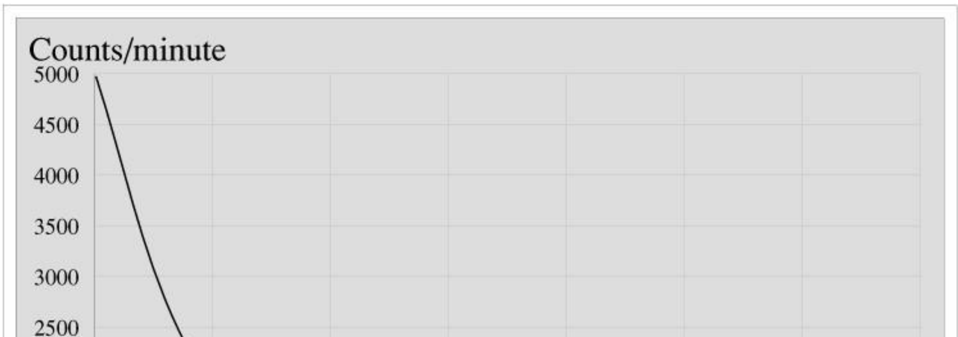
$$2^5 = 2^n$$

$$5 = n$$

Half life of the source = $\frac{20 \text{ days}}{5}$

Half life = **4 days**

2. The graph shows how a sample of an element, a radioactive isotope decays with time.



Use the graph to find the half life of an element.

Solution
Take the time taken for half of 500 count/min beT
T = 7 hours
Therefore, half-life of an element is **7 hours.**

Advantages of using isotopes with short half-lives
If an isotope has short half life it gives a satisfactory decay curve when used in experiments in school laboratories. The curve is simply plotted as activity A against time t and you can read off the half life on the graph.

Remember, the radon-220 is used in school experiments, since it has a half life of about 53 seconds and readings taken over a few minutes will give a satisfactory decay curve.

A radioisotope with short half life is used in agriculture because it does not cause contamination of the soil.

Radioisotopes of short half-life cease to act after their function has been completed. These radioisotopes can be used for a short period in medicines and in agriculture. This prevents the passing of radioisotopes from plants to consumers.

Radioisotopes of short half-life decay into harmless substances.

Ways of detecting radioactive emissions

The following methods are used to detect the radioactive emissions:

a. Photographic plates

Alpha and beta particles produce visible tracks in the plates where they pass.
But these are not good for detecting gamma radiation because gamma radiation has insufficient ionization.

b. Scintillation counters

When beta and alpha particles or gamma rays flow, they produce a flash of light in a crystal: Zinc sulphide and silver crystals for alpha and beta radiation, sodium iodide and tellurium for gamma-rays.

c. Spark counter

If an alpha source is brought up close to the gauze of the spark counter, it will ionize the air. The ionization of air causes sparks between the gauze and wire. If a beta source is used insufficient ions are produced for sparkling to take place. The spark counter can also be used to show the track of a particle as a line of sparks.

d. Cloud chamber

A cloud chamber is mainly used to show the tracks of radioactive particles. The tracks of α-particles are straight and thick. The tracks of β-particle are thin and straight. The γ-rays do not produce tracks but they simply collide with electrons and give out enough. These electrons enable the beta to cause ionization and produce its own shot tracks.
When a radioactive particle passes through air which is supersaturated with the vapour of a liquid, it produces ions that act as a centre on which the liquid can condense. A line of liquid droplets is formed along the track of the particle.

e. Geiger Muller tube

The Geiger – Muller is a tube which contains argon gas at low pressure. The end is sealed by thin mica window to allow alpha particles to pass through the argon gas.
When the particles enter the chamber, the argon gas is ionised by these particles. Then the argon becomes a good conductor of current after being ionized.
The scalar will show the current on its screen.

f. Ionization detector(chamber)

Ionization chamber is a can with coaxial wire electrode. When beta or alpha particles flow in it, they give a current of about 10^{-9} μA.

g. Electroscope

When beta and alpha particles pass the metal cap of the electroscope, the leaf falls because the radiation particles ionize the air around the electroscope. This detection is not good for gamma radiation.

Nuclear fission and fusion

Nuclear fission

Nuclear fission is the splitting of an unstable radioactive particle or nucleus into two or more smaller particles (nuclei). During nuclear fission, a heavy unstable nucleus disintegrates into two or more lighter stable nuclei. The nucleon reaction releases energy in the process.

Natural uranium is one of the dense (heavy) radioactive substance which easily undergoes fission. If one of the high-speed neutrons hits the nucleus of a neighbouring uranium-235 atom, the neutron is not repelled by the nucleus but uranium captures the neutron. This may cause formation of unstable uranium-236 which undergoes fission. Uranium-236 splits into two heavy radioactive nuclei, often of Barium and Krypton, with the production of three more neutrons.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{236}_{92}U \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \text{Energy}$$

If the new neutrons find some unsplit uranium atoms they also hit the other atoms which also release neutrons in turn. So, a chain of nuclear fission may continue, if there are still uranium atoms available the energy released is great.

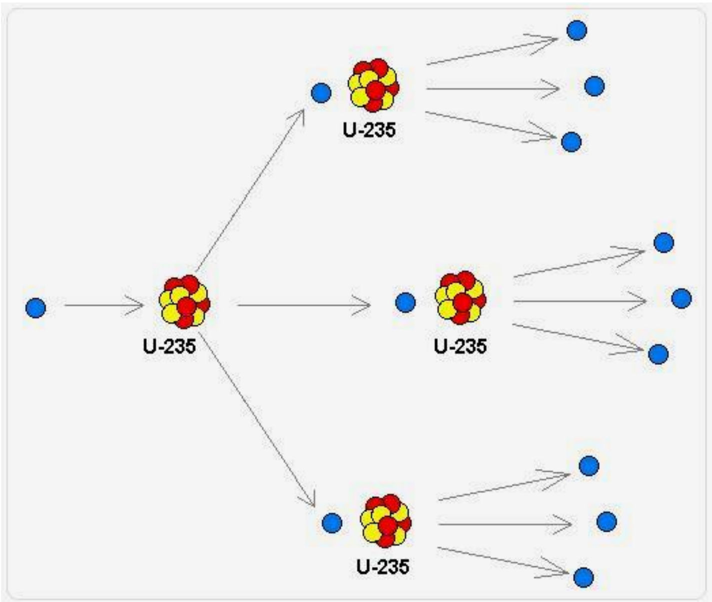


Figure 10.7 nuclear fission

Any isotope with atomic number (Z) greater than 83 is unstable.

Nuclear fusion

Nuclear fusion is the coming together of smaller nuclei to form one bigger nucleus. In nuclear fusion, two light nuclei to produce a heavier nucleus. **For example,** two isotopes of hydrogen fuse to form a nucleus of helium and a neutron.

$$^{2}_{1}H + ^{3}_{1}H \qquad ^{4}_{2}He + ^{1}_{0}n + \text{Energy}$$

In nuclear fusion great energy is also released just like in nuclear fission.

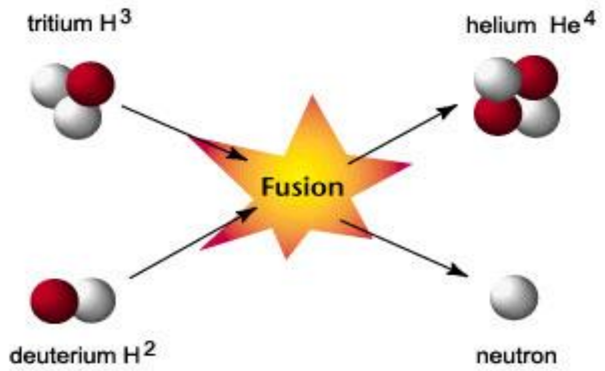


Figure 10.8 nuclear fusion

Exercise 10.3

In your groups, answer the following questions:

1. Discuss the properties of alpha particle, gamma ray, and beta particle.

2. Explain the detection of alpha and beta particles by using;
a. photographic plates
b. spark counter
c. Geiger Muller

3. Explain why ionization detector is not used to detect gamma rays.

4. Draw a labeled diagram to show the deflection of the radiation particles in magnetic poles.

10.5 Dangers and applications of radioactivity

Danger of radioactivity substances to human beings

Radioactivity is very dangerous to human beings. The first and probably the only time atomic bombs were used in World War II, 1945 on Hiroshima and Nagasaki in Japan. Terrible results were seen there but up to this time the effects of the bombs are still experienced by the Japanese people.

When a human being is exposed to radioactive products, the following are some of the effects:

- Burns
- Leukemia
- Some children being born with serious abnormalities
- Sterility (inability to produce children)
- Cell mutation (changes which may be passed to future generations).

Precautionary measures when handling radioactive substance

- The resource should only be handled by the forceps or tongs provided and showed never touched by above hand.
- Never point radioactive substances towards a person.
- Food should never be taken near these substances because it may be easily contaminated.
- Never smoke near a radioactive source.
- Users of radioactive substances should always wear rubber gloves which should be washed after the substances have been safely put away.
- Put on special clothing when in places of radioactive sources.
- Use thick-walled lead containers to transport radioactive samples.

Uses of radioactivity

The following are some of the uses of radioactivity:

Carbon -14 dating

The radioactivity of carbon-14 can be used to date archaeological samples. This uses the half–life of carbon-14. The activity of carbon-14 taken from an ancient piece of a human bone can be compared with that of an equal mass of carbon-14 from a bone of living human. From this comparison, it is possible to estimate the time that has passed since the bone was part of the human being.

Example
Suppose an archaeological sample has an activity of 5 disintegrations per minute and that of an equal mass of carbon from a living plant has an activity of 10 disintegrations per minute. The activity of the sample is one half that of the present–day level. Therefore, its age is equal to the half life of carbon-14. The sample is 5730 years old.

NOTE
It is not possible to detect samples of matter that has been dead for more than 12000 years because their carbon-14 content is too low to give an accurate reading.
This method of dating can be used with success to determine not only the ages of animal remains but also those of wood, paper, cloth, and other organic material.

Locating positions
The exact position of an underground pipe can be located if a small quantity of radioactive liquid is added to the liquid being carried by the pipe. This also allows leakage to be detected since the soil close to the leak becomes radioactive.

In this process, you are advised to use a short-lived radioisotope because it will not cause permanent contamination to the soil.

In Agriculture
Radioactive phosphorus is used to assess the different abilities of plants to take up phosphorous from different types of phosphate fertilizers.

Industry
In industries, radioactivity is used to monitor the thickness of a metal.
The thickness of a metal sheet can be monitored during manufacture by passing it between a gamma ray source and a stable detector. The thicker the sheet, the greater the absorption of gamma rays.

Medicine (Radiotherapy)
Gamma rays from strong cobalt radioisotopes are used in the treatment of cancer. Cancer cells are destroyed by gamma radiation from a high activity of cobalt 60. It is also used in hospitals for x-rays types of photography especially for x-raying the inner parts of patients. This treatment is called **radiotherapy.**

Power generator
Radioactivity of an element like uranium–235 in a nuclear power station generates power called **Nuclear Power.**

Sterilization
Gamma rays are used to sterilize medical instruments and dressings because gamma rays kill bacteria.

Summary

The nucleus of an atom consists of protons and neutrons. The electrons are found around the electron shells. Protons are positively charged, neutrons have no charge, and electrons are negatively charged.

An atomic number is the number of protons found in the nucleus of an atom. Mass number is the total number of protons and neutrons found in the nucleus of an atom.

Isotopes have the same number of protons but different number of neutrons.

Radioactivity is the process of emitting radiation particles by an unstable substance.

Natural radioactivity is the radioactivity that happens on its own from natural nuclides while **Induced radioactivity** is the radioactivity which takes place from artificial nuclides (isotopes are made by reversing the decay process).
Half-life is time taken for half of the number of original substance to decay and change into a new substance.

Nuclear fission is the splitting of an unstable radioactive particle or nucleus into two or more smaller particles (nuclei) while **Nuclear fusion** is the coming together of smaller nuclei to form one bigger nucleus.
The types of nuclear radiations are alpha, beta and gamma.

Large exposure to radioactive emissions can cause radiation sickness and death.

The dangers of radioactive emissions can be minimized by following the safety measures.

The applications of radioactivity are in:

- Archaeology
- Nuclear power generation
- Agriculture
- Tracers
- Industrial
- Medicine (radiotherapy)
- Sterilization

Student assessment

1. Define the following;

a. Isotopes
b. Proton number
c. Radioactivity
d. Half-life

2. Write down **two c**haracteristics of isotopes.

3. Explain the difference between

a. Nuclear fission and nuclear fusion

b. Natural radioactivity and induced radioactivity

4. State **five** instruments that can be used to detect radioactive emissions.

5. Discuss methods of how radioactive materials are safely handled and stored.

6. Describe the following:

a. Alpha particles.
b. Beta particles
c. Gamma rays.

7. Copy and complete the diagram in **Figure 10.9** to indicate how the radiations may be absorbed.

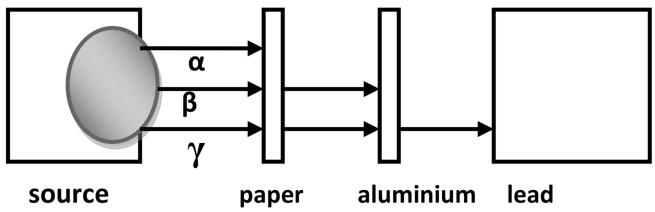


Figure 10.9

Explain why each radiation particle behaves the way it has been shown above.

8. **Figure 10.10** shows the deflection of radiations in an electric field.

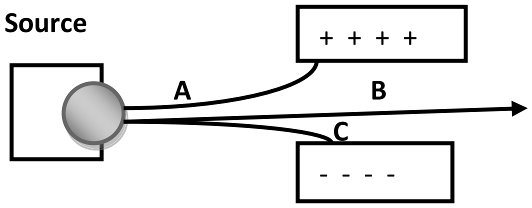


Figure 10.10

a. Name the radiations A, B, and C.
b. Explain why B is not deflected.

9. The nuclear notation of nitrogen is shown below.

$$^{23}_{11}\mathrm{Na}$$

Write down its

a. Atomic number

b. Mass number

c. Number of neutrons

10. Explain why ionization detector is not used to detect gamma rays.

11. Draw a labeled diagram to show the deflection of the radiation particles in magnetic poles.

12. An isotope of magnesium (Mg) contains 12 protons and 12 neutrons.

a. Find

(i) its mass number

(ii) its atomic number

(iii) its number of electrons.

b. Complete the nuclide of Mg

$$^{\square}_{\square}\mathbf{Mg}$$

13. List **three** sources of radiation.

14. Write down **five** safety precautions that should be taken when handling radioactive substances.

15. The doctor wants to check the fracture of the bone in the leg.

a. What type of radioactive material should be used?

b. Give a reason for your answer.

16. State **three** dangers of radioactive substances.

17. List **five** uses of radioactive substances.

18. Explain why gamma rays are used in sterilizing medical equipment.

19. When the nucleus of sodium-24 emits a beta particle it decays to magnesium according to the following equation:

$$^{24}_{11}\mathrm{Na} \rightarrow \ ^{24}_{12}\mathrm{Mg} + \ ^{0}_{-1}\mathrm{e}$$

a. Besides magnesium, what other particle is produced when sodium-24 decays?

b. Name the beta particle in this equation.

c. How does the mass of the of the parent nucleus compare with the masses of the products?

20. **a.** Define half-life.

b. A bone in a living animal contains 100 g of carbon -14 and an identical skeleton found in an ancient burial ground contains 12.5 g of carbon -14. Calculate the age of the skeleton. (Half-life of carbon 5600 years). Show your working.

21. What changes in the mass number and atomic number of the parent nucleus take place if it emits a beta particle?

Glossary

Alternating current the current whose direction in a circuit changes at regular interval.
Amplifier a device that magnifies the input signal.
Analogue circuits produce a continuous varying signal.
angular displacement the directional displacement represented as an arc length s.
angular velocity the rate of change of angular displacement.
Atomic number the number of protons in its nucleus.

Band theory a theory which explains why conductors, semiconductors and insulators are different in conduction.

Calibrating a spring putting a scale on the spring so that it may be used to find the weight of some given masses.
Centre of gravity the point through which the earth's gravitational force acts on the object.
Centre of mass the point on the object where all the mass is said to be focused.
Centripetal force the force which acts on an object towards the centre of the circle to make an object move in a circle.
Coefficient sliding friction the ratio of sliding force F to the force pressing the surfaces together.
Coefficients of static friction ratio of static force F to the force pressing the surfaces together.
Contraction decrease in volume of a substance without gaining any matter.
Convex lenses are lenses that are thicker in the middle than on the edges.
Digital circuits produce two numbers, 1's and 0's.
Doping the process of adding impurities to a semiconductor to improve its conductivity.
Elastic material the material that when it is deformed, it springs back to its original shape when the force has been removed.
Elasticity the ability of an object to return to its original shape when the force has been removed after it has been stretched, compressed, bent, or twisted.
Electric motor a device that converts electrical energy to kinetic energy (energy of movement).

Electromagnetic induction	the process by which emf is induced in a conductor by means of magnetic field.
Expansion	increase in volume of a substance without gaining any matter.
Extension	the difference between its stretched and unstretched lengths.
Free fall	falling in a vacuum without experiencing frictional force or resistance.
Frictional force	the force which acts to oppose the motion.
Half-life	the time taken for half or the number of original substance to decay and change into a new substance.
Heat	the measure of the total internal energy contained in a body.
Image	a picture of a real thing.
Induced magnetism	the magnetism which is introduced in magnetic materials for example in steel and iron metals.
Induced radioactivity	the radioactivity which takes place from artificial nuclides.
Inductor	a passive electronic component that stores energy in the form of a magnetic field.
Inelastic collision	a collision in which some kinetic energy is lost.
Inertia	the resistance an object has to a change in its state of motion.
Isotopes	atoms of the same element with the same atomic number but have different mass numbers.
Lamina	a three-dimensional shape that is so thin, that it can be considered two dimensional.
Lever	any device that can turn about a pivot.
Linear momentum	the product of its mass and its velocity.
Long sight	the situation whereby the eye fails to focus on a close object.
Magnetisation	the process of making a magnetic material magnet.
Mass number	the total number of protons and neutrons in the nucleus of an atom.
Moment of a force	the turning effect of a force from the pivot or fulcrum.
Mutual inductance	the induction of an electromotive force in a coil of wire by changing the current in a different coil.
Natural radioactivity	the radioactivity that happens on its own naturally from natural nuclides.
Nuclear fission	the splitting of an unstable radioactive particle or nucleus into two or more smaller particles (nuclei).
Nuclear fusion	the coming together of smaller unstable nuclei to form one bigger stable nucleus.
Object	a real thing.
Perfect elastic collision	a collision in which there is no loss of kinetic energy (kinetic energy is conserved).
Radioactive decay	the spontaneous disintegration of unstable nucleus or radioisotope to become stable.
Radioactivity	the process of emitting radiation particles by an unstable substance.
Semiconductors	materials whose electrical conductivities are higher than those of insulators but lower than those of conductors.
Short sight	the situation whereby the eye fails to focus a distant object clearly,
Sliding or **dynamic frictional force**	the value of frictional force when one surface is sliding over another at a constant speed.
Static or **limiting frictional force**	the maximum value of the frictional force between two surfaces.
Step down transformer	a transformer that transforms high voltage to low voltage or steps down voltage.

Step up transfer	a transformer that transforms low voltage to high voltage or steps up voltage.
Temperature	the measure of the hotness or coldness of a substance or an object.
Terminal velocity	the maximum, constant velocity reached by an object falling through a vacuum and fluids (gas or liquid).
T**hermistor**	a resistor whose resistance depends on temperature. It is a temperature-dependent resistor.
Torque	the turning moment of a force.
Transistor	a three-terminal device that conducts current in both directions.
Unbalanced forces	two unequal forces are acting on an object in opposite directions.
Uniform circular motion	the motion of an object in a circle at constant speed.

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