

Topic1: PROPERTIES OF MATTER

The Kinetic theory of matter

Matter is anything that occupies (takes up) space and has mass. Soil, water, gases, metals, are some of examples of matter. Matter is made up of very small particles called atoms which are held together by forces. According to the kinetic theory of matter, the particles of matter possess kinetic energy and so they are always moving. When a substance is heated the particles gain more kinetic energy move faster. On cooling down, they lose the kinetic energy and begin to move slowly. The kinetic theory of matter can be used to explain how the particles behave in solid, liquid or gas states.

Properties of the three states of matter according to the kinetic theory of matter

Solids

In solids the particles are held together by very strong forces and are in fixed positions. Figure 1.1 below shows a regular arrangement of particles in a solid state.

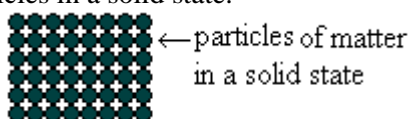


Figure 1.1

According to the kinetic theory of matter, the particles in the solid state are always vibrating from side to side in their fixed positions.

When a solid is heated, the forces between the particles become weak as they gain more kinetic energy and thus increasing their vibrations. This causes the particles to push each other further apart and makes the solid to expand. If more heat is applied, a point is reached whereby the particles are knocked off from their fixed positions. At this point the solid turns into a liquid. The solid is said to be melting. The temperature at which this happens is called the melting point of the substance.

Liquids

In liquids, the forces between the particles are very weak. These weak forces enable the particles to move from one point to another by sliding over each other, in addition to vibrating from side to side. The particles are not regularly arranged and take the shape of a container as shown figure 1.2 below.



Figure 1.2

When a liquid gains more heat, the kinetic energy of its particles increases. This results in increasing the speed of movement of the particles until they begin to jump and escape from the liquid. This process is called boiling and the temperature at which this happens is called the boiling point.

Gases

There are no forces to hold together the particles in the gas state. Therefore the particles in the gas state are always moving randomly at high speeds and in the process they always collide with each other and with anything that is on their way. They change direction after each collision.

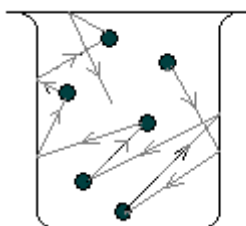


Figure 1.3

The random movement of the particles is called the Brownian movement.

When a gas is heated the particles gain more kinetic energy and move faster than before. This makes them to collide with each other and with the wall of their containers more often and with much greater forces.

Molecular motion and gas pressure

Consider a balloon fitted to a mouth of an empty conical flask and heated in a bath of hot water as follows;

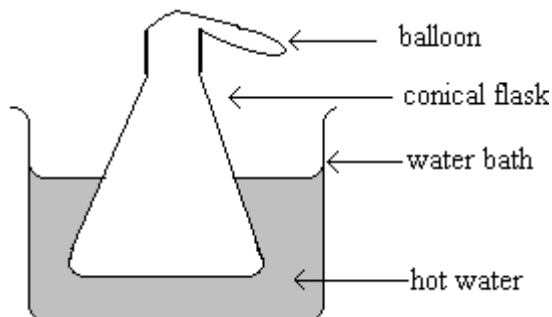


Figure 1.4

As time goes, the balloon expands, even though no more air particles are added to it. Why does this happen? When the air or gas particles inside the balloon are heated they gain more kinetic energy and so they move faster. When they move faster, they strike the walls of the balloon (or container) more often and with greater forces. Thus the pressure exerted by the particles on the walls of the balloon from inside. The balloon expands consequently.

Effect of temperature on molecular speed

When water is heated, its temperature increased and its particles moved about in the container with more energy and higher speed. This shows that when the temperature of a substance increases, the speed of motion of its particles (molecules) increases as well. This happens because when a substance is heated, its particles gain more kinetic energy and so move faster and the temperature increases.

Absolute Temperature

As the temperature of a substance is decreased the motion of its particles decreases as well. This happens because the particles of the substance lose their kinetic energy in the form of heat, so hence move slowly. If the substance continues losing heat, both the temperature of the substance and the kinetic energy of the particles decrease. This implies that the temperature of a substance is related to the kinetic of its particles. Temperature is, therefore the measure of the average kinetic energy of the particles of a substance. The temperature measured in terms of the kinetic energy of the particles of a substance is known as the absolute temperature.

The absolute temperature is measured in kelvins (K) on a kelvin scale of temperature. The kelvin scale is also known as the absolute scale of temperature. On the absolute scale of temperature, zero kelvin (0K) is called the absolute zero. There is no temperature that can be measured below the zero kelvin temperature. At zero kelvin all the particles of any kind of matter have zero kinetic energy, which is the lowest kinetic energy of the particles and so, they do not move at all.

Temperatures scales

Temperature can be measured in various scales. Some of the common ones are as follows;

Scale	Symbol
degree Fahrenheit	F
degree Celsius	°C
Kelvin	K

It is necessary to know how to convert temperature from one scale to another. For instance to convert temperature from degrees Celsius to kelvins you are supposed to add 273 to the temperature given in degrees Celsius.

Examples

$$23^{\circ}\text{C} = 23 + 273 = 293\text{K} \quad \text{and}$$

$$200^{\circ}\text{C} = 200 + 273 = 473\text{K}$$

To change the temperature given Kelvins the temperature in degree Celsius ($^{\circ}\text{C}$) you must subtract 273 from the temperature in degrees Celsius.

Examples

$$298\text{K} = 298 - 273 = 25^{\circ}\text{C}$$

$$273\text{K} = 273 - 273 = 0^{\circ}\text{C}$$

Exercise

1. Convert the following Kelvin temperatures to degrees Celsius temperatures

(a) 175 K (b) 295 K (c) 0K

2. Convert the following degree Celsius temperatures to Kelvin temperatures:

(a) 37°C (b) -73°C (c) 273°C

Evidence of molecular motion

Consider a crystal of potassium permanganate which is carefully dropped into a beaker of water. The colour of the water in the beaker changes from colourless to purple. This shows that the particles of potassium permanganate, which are purple in colour, spread out and mix with the particles of water. The spreading out and mixing of particles is known as diffusion. Diffusion shows that the particles substances are always moving. Diffusion mainly takes place in liquids and gases because the particles in these states can move from one place to another.

The gas laws

The behaviour of any gas depends on its pressure, volume and temperature. A change in any of these factors always produces a change in at least one of the other two factors. The behaviours of the gases are described in the following gas laws; the Boyle's law, the Charles' law and the pressure law.

The Boyle's law

The relationship between the pressure and the volume of a fixed mass of a gas at a constant temperature is known as the Boyle's law. The law states that at constant temperature, the pressure of a fixed mass of a gas is inversely proportional to its volume or simply $p \propto 1/V$. If we introduce a constant k, we get $p = k/V$. Provided the mass of the gas is constant, we can also say that $P_1V_1 = P_2V_2$, where subscripts 1 and 2 refer to two pressure and volume readings for the same mass of gas at different conditions, ie P_1 = initial pressure, V_1 = initial volume, P_2 = final pressure and V_2 = final volume.

Exercise

A gas of volume 1.5 m^3 exerts a pressure of 2000 N/m^2 . If the volume is increased to 3.0 m^3 , what will be the pressure of this gas?

Answer is 1000 N/m^2

The Charles' law

If a certain mass of gas is enclosed in a syringe whose piston can move freely, the piston moves out when the syringe is placed in a hot water bath and moves in when the syringe is placed in a cold water bath. The movement of the piston is in response to the changes in the kinetic energy of the particles of the gas in the syringe so that the pressure is kept constant. The relationship between volume and temperature of a fixed mass of a gas at a constant pressure is known as the Charles' law. It states that at constant pressure, the volume of a given mass of a gas varies directly as its temperature increases or mathematically $V \propto T$. Introducing a constant, k we get $V = kT$. This implies that $V_1/T_1 = V_2/T_2$.

The Pressure law

Consider a syringe set at the 10 ml mark and the opening closed tightly. It is easier to push the piston with a thumb until the volume of the air inside the syringe is reduced to 2 ml while the temperature is low. But it is difficult to reduce the volume of the same mass of air to 2 ml if the temperature is high. These observations suggest that, at a constant volume, the pressure of a fixed mass of a gas increases as its temperature increases. This relationship is called the pressure law. Mathematically, $P \propto T$, which implies that $P = kT$ and $P_1/T_1 = P_2/T_2$.

According to the kinetic theory of matter the kinetic energy of the particles increases when their temperature increases. When this happens, the particles move faster and strike the walls of the container more often and harder thereby increasing the pressure.

A mnemonic might be useful here! Of the three variables; temperature, pressure or the volume, the variable which is kept constant in each of the three laws, might be remembered using the following expression; *From Blantyre, Bt, to Chitipa, Cp, by a Passenger vehicle, Pv*. Where Bt means in Boyle's law temperature is kept constant, Cp means in Charles' law pressure, is kept constant and Pv means in the pressure law, volume is kept constant.

Exercise

The pressure of a gas at 300K is 2000 Pa. Find the pressure of the gas at 500K. answer 1200Pa

The general gas equation

All the three gas laws we have looked at so far rely on the fact that at least one variable (T, P or V) is constant. But this is not the case all the times, it is, therefore, useful to combine the laws into one equation. These laws are as follows; Boyle's law; $P \propto 1/V$ and the pressure law; $P \propto T$. Combining these laws we have P varies inversely as V and directly as T or in short $P \propto T/V$. Introducing a constant k we get $P = kT/V$ and after rearranging we get $PV/T = k$.

If we have a fixed mass of a gas then we can say $P_1V_1/T_1 = P_2V_2/T_2$, where subscripts 1 and 2 refer to two pressure, volume and temperature readings for the same mass of gas at two different conditions, ie P_1 = initial pressure, V_1 = initial volume and T_1 = initial temperature and P_2 = final pressure, V_2 = final volume and T_2 = final temperature.

Important note! In all the calculations involving the gas laws, the temperature must be in kelvins, K.

Example

1. A gas occupies a volume of 600cm³ at a pressure of 760mmHg and a temperature of 25°C. What volume would it occupy at pressure of 780mmHg and a temperature of 50°C?

Working out

$$(P_1V_1)/T_1 = (P_2V_2)/T_2$$

$$P_1 = 760\text{mmHg}, V_1 = 600\text{cm}^3, T_1 = 25 + 273 = 298\text{K}, P_2 = 780\text{mmHg}, T_2 = 50 + 273 = 323\text{K}.$$

$$\text{Therefore; } (760\text{mmHg} \times 600\text{cm}^3) / 298\text{K} = (780\text{mmHg} \times V_2) / 323\text{K}$$

$$\Rightarrow (760\text{mmHg} \times 600\text{cm}^3 \times 323\text{K}) / (298\text{K} \times 780\text{mmHg}) = V_2$$

$$\therefore V_2 = 633.7\text{ cm}^3.$$

Exercise

(1) 20 x 10⁻³m³ of gas at 25°C exert a pressure of 4000Pa. Find the pressure exerted by this at 47°C in a container of volume 40 x 10⁻³m³.

Liquid pressure

Liquids exert pressure on the sides of the container as well as anything within the liquid itself. This pressure is transmitted in all directions and increases with depth. So what is the formula for the pressure of a column of a liquid? Consider the liquid in the container shown in figure 1.6 below;

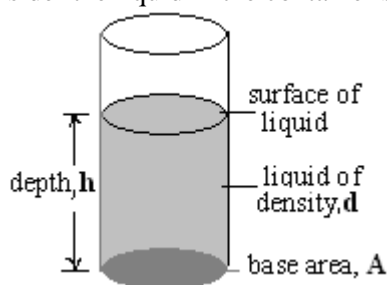


Figure 1.20

Calculating pressure exerted by the liquid at the bottom of the container.

Pressure = (force)/(area) or pressure = f/A

But **force** = weight of the liquid and

weight = mass \times gravitational field strength (**mg**)

\Rightarrow pressure = $(mg)/A$

But mass = volume \times density (**vd**)

\Rightarrow pressure = $(vdg)/A$

volume = Base area \times height of the liquid column (**Ah**)

\Rightarrow pressure = $(Ahdg)/A$

\therefore pressure = hdg

The unit of pressure

Consider the following example;

A liquid of density 1000kg/m^3 fills a container up to a height of 2m. What is the pressure exerted by this liquid at the bottom of the container if the gravitational field strength is 10 N / kg ?

Working out

Liquid pressure = $h d g$

$h = 2\text{m}$

$d = 1000\text{kg/m}^3$

$g = 10\text{ N / kg}$

\therefore pressure of the liquid = $(2\text{m} \times 1000\text{kg} \times 10\text{ N}) / (\text{m}^3 \text{ kg})$
 $= 20\,000\text{ N/m}^2$

The unit of pressure is, therefore, N/m^2 . The unit N/m^2 is called pascal (Pa) in honour of sir Blaise Pascal, the man who investigated and contributed a lot to the understanding of air pressure. Pa is the SI unit of pressure. Other units that are used to measure pressure are; millimetres of mercury, (mmHg), atmospheres, (atm). The gravitation field strength, **g** in the formula liquid pressure = $h d g$ is constant; its value is always approximately equal to **10N/kg** on the earth's surface. Therefore, the pressure exerted by a liquid at the bottom of a container depends only on its density, **d**, and height, **h**.

Exercise

1. If density of paraffin is 800 kg/m^3 , what is the pressure due to the paraffin at the bottom of a tank 2m deep?

2. A pressure of $50\,000\text{ Pa}$ is exerted by a column of water at the base of a container. Calculate the height of the water column. (Density of water = 1000 kg/m^3 ; $g = 10\text{ m/s}^2$)

3. A dam is 100m high, what is the pressure at the bottom?

Uses / applications of liquid pressure

Liquids display a number of properties. Some of the properties are as follows; liquids flow, take the shape of the container, and, if placed in a sealed container, a liquid distributes applied pressure evenly to every surface in the container, and liquids do not compress significantly. The pressure exerted by liquids increases with depth. Liquids do not compress significantly, except under extremely high pressures. The pressure in liquids at rest is independent of the shape (area or slope) of the container. These properties of liquids enable a number of applications of liquid pressure in everyday life. Some of the applications of the liquid pressure include hydraulic machines, dams, domestic water supply and manometers.

Hydraulic machines

Figure 1.21 below shows the basic principle of hydraulic machines:

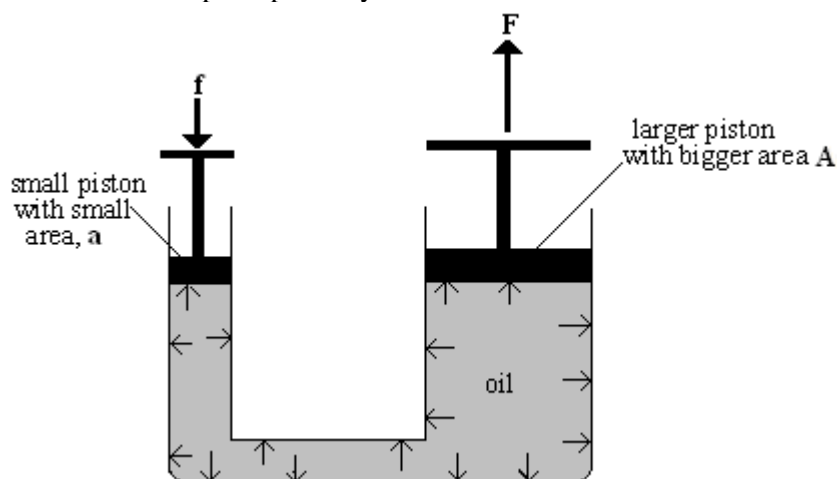


Figure1.21

If a downward force, f , acts on a piston of a small area, a . The pressure transmitted throughout the liquid is given by f / a .

$$\Rightarrow \text{pressure} = f / a$$

This pressure acts on a second piston of a larger area, A , producing a larger upward force, F ;

$$F = \text{pressure} \times \text{area}, A$$

$$\Rightarrow \text{pressure} = F / A$$

On the smaller piston; pressure = f / a

On the larger piston; pressure = F / A .

Since pressure is the same throughout the liquid;

$$\Rightarrow F / A = f / a$$

$$\therefore F = (f A) / a$$

Example

A force of 1N is exerted on a piston of area $1/100\text{m}^2$ of a hydraulic machine. Calculate the force that acts on the other piston if it has a larger area of $\frac{1}{2}\text{m}^2$.

Working out

$$F = (f A) / a$$

$$\therefore F = (1\text{N} \times \frac{1}{2}\text{m}^2) / (1/100)\text{m}^2 \\ = 50\text{N}$$

This means a force of 1N could lift a load of 50N. The hydraulic machine has multiplied the smaller force 50 times.

Examples of Hydraulic machines

- i. Hydraulic car jack.
- ii. Hydraulic car brakes
- iii. Hydraulic fork lifts.

Dams

A dam is thicker at the bottom than at the top since pressure at bottom is the greatest.

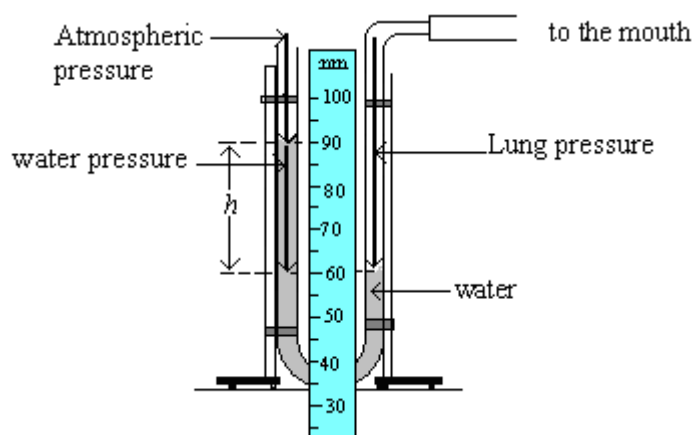
Large dams are built at for hydroelectric generation. The high pressure on the deep side of the dam causes water to flow through the holes at great speed turning the turbines in the holes and generate electricity.

Domestic water supply

The main water comes from a reservoir, but in order to maintain a constant high pressure to a consumer it is pumped to a top of a water tower located at a high ground.

Manometer

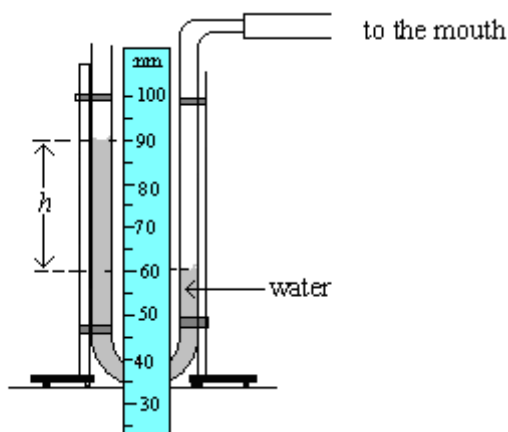
A manometer is an instrument used to measure the pressure of a gas from a supply such as lungs. Consider air blown from the lungs into a manometer shown below;



The pressure of the air from the lungs changed the levels of the water in the manometer. The open end of the tube is acted upon by the atmospheric pressure. This means that the pressure of the air supplied by the lungs is balanced by the atmospheric pressure plus the pressure by the water column given by the differences in the water levels. Therefore the lung pressure = water pressure in column h + atmospheric pressure.

Example

What is the pressure supplied by the lungs in the figure below, if the atmospheric pressure is 100 000 Pa, density of water is 1000kg/m^3 and gravitational field strength is 10N/kg ?



Working out

The height difference = 30 mm.

$$\Rightarrow h = 30 \text{ mm} \times (1\text{m})/(1000\text{mm}) = 0.03\text{m}$$

$$d = 1000\text{kg/m}^3$$

$$g = 10\text{N/kg}$$

$$\therefore \text{the pressure by the 30mm column of water} = 0.03\text{m} \times 1000\text{kg/m}^3 \times 10\text{N/kg} \\ = 300\text{Pa}$$

The pressure supplied by the lungs = pressure of the 30mm of water + 100 000 Pa of the atmospheric pressure.

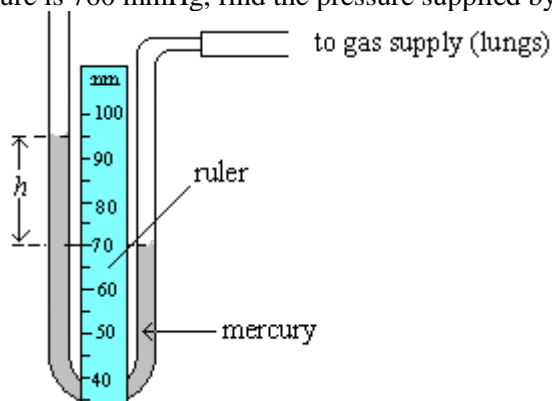
$$\text{Hence the pressure supplied by the lungs} = 300\text{Pa} + 100\,000\text{Pa} \\ = 100\,300\text{Pa}$$

Normally the pressure of a gas supply is measured in millimetres of mercury (mmHg). In this case the liquid used in the manometer is mercury and the pressure supplied by the gas supply is found as follows;

1. working out the difference in the levels of mercury in the manometer in millimetres (mm)
2. add the pressure of the column of the mercury in the units of mmHg to the atmospheric pressure also in mmHg.

Example

The diagram in figure below shows a manometer with which a student used to measure the pressure of her lungs. If the atmospheric pressure is 760 mmHg, find the pressure supplied by the lungs.



Working out

$$\text{From the diagram, } h = 95\text{mmHg} - 55\text{mmHg} \\ = 40\text{mmHg}$$

$$\therefore \text{the pressure supplied by the lungs} = 40\text{ mmHg} + 760\text{ mmHg} \\ = 100\text{mmHg}$$

Thermal expansion of matter

Generally, matter expands when heated and contracts when cooled. According to kinetic theory of matter the molecules solids and liquids vibrate faster and push each other further apart when are heated. When cooled the molecules vibrate slowly and move closer to each other. This is contracting. If these changes are resisted, large forces are created. Some of the uses of expansion and contraction of solids are separating stuck glass tumblers and removing tightly screwed bottle covers.

Practical applications of matter

The forces created because of expansion or contraction can have many practical uses such as; shrink fitting and riveting metal plates.

Shrink fitting

This is used to produce a tight fit between two pieces of metal, such as an axle and a wheel;

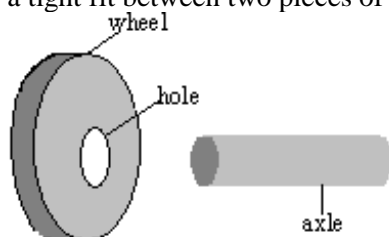


Figure1.23

The axle, which is slightly larger than the hole on the wheel, is dipped in cold, liquid nitrogen, which is at about -200°C .

The axle contracts when it cools and fits exactly into the wheel. Upon regaining the normal temperature, it expands and produces a tight fit.

Riveting Metal Plates

This is the process of fixing two metal plates together using rivets. To rivet metal plates together a hot rivet is placed in a rivet hole and the end is hammered flat. On cooling, the rivet contracts and pulls the plates together tightly (Figure 1.24).

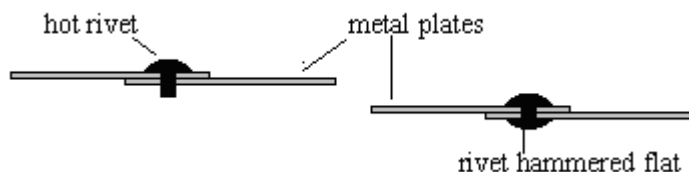


Figure1.24

Review questions

1. Mention two uses of each of the following in everyday life;
 - a. liquid pressure
 - b. thermal expansion of matter.
2. Explain why the base of a dam is made thicker at the bottom.
3. Two identical jars were filled with liquid mercury (density 13.6g/cm^3) and water (density 1g/cm^3) respectively. Explain the difference in pressure at the base of the two jars.
4. If density of water is 1000 kg/m^3 , calculate the pressure due to the water at the bottom of a swimming pool 2m deep.
5. Explain why gas pressure increases with increase in temperature of the gas.
- 6
 - a. Define diffusion.
 - b. In which state doesn't diffusion take place? Give a reason.
7. The pressure in a vertical water pipe in the ground floor of a building is $4 \times 10^5\text{ Pa}$, but three floors up the pressure is $2 \times 10^5\text{ Pa}$. What is the height of the building between the ground floor and the third floor? (*Density of water = $1 \times 10^3\text{ kg/m}^3$*)
8. A bicycle pump contains 50cm^3 of air at 17°C and a pressure of 1.0 atm. Find the pressure when the air is compressed to 10cm^3 and its temperature rises to 27°C
9. The volume of a gas in a container is 6m^3 and has pressure of 4 atm when the temperature is 27°C . Calculate its pressure when the volume is reduced to 3m^3 and its temperature is raised to 177°C .
10. Derive a formula to show that the pressure of a liquid depends on its density and depth.
11. At atmospheric pressure a mercury barometer reads 0.76m. If one atmosphere is equal to 101 000 Pa, calculate the density of mercury.

12. A gas of volume 2m^3 at 27°C is cooled to -137°C at constant pressure. What is its new volume?
13. A container holds a gas at 0°C . To what temperature must it be heated for its pressure to double at constant volume?
14. A mass of gas occupies volume of 200 cm^3 at temperature of 27°C and a pressure of 1 atm. Calculate the volume when;
- (a) the pressure is doubled at constant pressure.
 - (b) the temperature is doubled at constant pressure.
 - (c) the pressure is $1\frac{1}{2}$ atm and the temperature is 127°C .
15. (a) State two factors on which the pressure exerted by a liquid depends.
(b) The atmospheric pressure on a particular day was measured as 750mmHg. What is this pressure when it is measured in Pascals, Pa (N/m^2) ? (Density of mercury is $13\,600\text{kg / m}^3$ and the gravitation field strength is 10 N/ kg)
16. In a hydraulic machine, a force of 20N is applied to a piston of area 0.2m^2 . The area of the other piston 2.0 m^2 . What is;
- (a) the pressure transmitted through the liquid?
 - (b) the force on the other piston?
- 17 (a) Why must a liquid and not a gas be used as the fluid in a hydraulic machine?
(b) On what other property of a liquid do hydraulic machine depend?

TOPIC 2:

ELEMENTS AND CHEMICAL BONDING

The Structure of the Atom

An atom is the smallest particle of any type of matter. It is made up of three sub-atomic particles namely protons, neutrons and electrons. Protons are positively charged particles and each proton has a charge of +1. Electrons are negatively charged and each electron has a charge of -1. Neutrons are not charged. Each neutron has a charge of zero. They are said to be neutral. Table 2.1 below is the summary of the characteristics of the sub-atomic particles.

Sub-atomic particle	Symbol	Mass (amu)	Charge
Proton	p	1	Positive, +
Neutron	n	1	None
Electron	e	0	Negative, -

Table 2.1

In any atom, the number of protons is equal to the number of the electrons. For example Carbon has 6 protons therefore, it also has 6 electrons. So it has $[6 \times (+1)] = +6$ positive charges and $[6 \times (-1)] = -6$ negative charges. The overall charge of the atom is $[6 \times (+1)] + [6 \times (-1)] = 0$. All atoms are therefore, electrically neutral.

The arrangement of the sub-atomic particles in the atoms

Protons and neutrons are contained in a region at centre of the atom known as nucleus. The protons and the neutrons are fixed in their positions.

Electrons are found outside the nucleus in regions called shells or orbits. They are always moving at high speed in their orbits circulating the nucleus.

Electron configuration

The term electron configuration refers to the way electrons are arranged in an atom of an element. It is also called *the electron structure*. Each orbit holds a fixed number of electrons. The first orbit, which is the lowest energy level holds a maximum of electrons 2 because it is small, the second and the third energy levels hold a maximum of 8 electrons, as shown figure 2.1 below. The shells are at different energy levels, with the one closest to the nucleus being the lowest energy level.

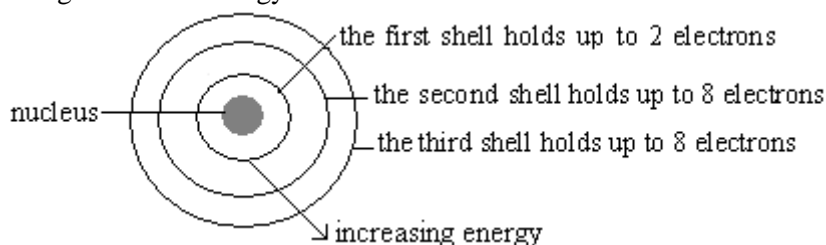


Figure 2.1

To write electronic configuration we write as n.n.n....where the first n stands for the first shell, second stands for the second shell and so on. For instance, magnesium has 12 electrons and so has an electron configuration of 2.8.2

The electrons in the outermost shell are called valence electrons. Magnesium has two valence electrons. Figure 2.2 below shows the structure of the magnesium;

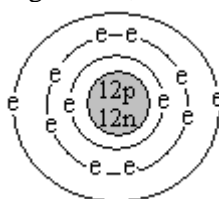


Figure 2.1

Atomic Number and Mass Number

An atomic number is the number of protons of an element (or atom). It is represented by the symbol **Z**. The atomic number of an element its identity. i.e. Each element has got its own atomic number and there are no two or more elements with the same atomic number.

The number of protons plus the number of neutrons of an atom is referred to as the mass number. It is also known as the nucleon number because it refers to the number of particles in the nucleus. The mass number is represented by the symbol **A**. The atomic mass is related to the atomic mass and the number of neutrons (**N**) by the following equation: $A = Z + N$.

The mass number (**A**) and the atomic number (**Z**) and the chemical symbol of the element (**X**) are represented using the following short hand;



Table 2.1 below shows the Atomic numbers and the mass numbers of the first 20 elements.

Element	Symbol	Atomic number (Z)	Number of electrons	Number of neutrons (N)	Mass number(A)
Hydrogen	H	1	1	0	1
Helium	He	2	2	2	4
Lithium	Li	3	3	4	7
Beryllium	Be	4	4	5	9
Boron	B	5	5	6	11
Carbon	C	6	6	6	12
Nitrogen	N	7	7	7	14
Oxygen	O	8	8	8	16
Fluorine	F	9	9	10	19
Neon	Ne	10	10	10	20
Sodium	Na	11	11	12	23
Magnesium	Mg	12	12	12	24
Aluminium	Al	13	13	14	27
Silicon	Si	14	14	14	28
Phosphorus	P	15	15	16	31
Sulphur	S	16	16	16	32
Chlorine	Cl	17	17	18	35
Argon	Ar	18	18	22	40
Potassium	K	19	19	20	39
Calcium	Ca	20	20	20	40

Table 2.1

Electron Configuration and the Periodic Table

When the first twenty elements are arranged according to the number of electrons in their outer shells and according to the number of shells each element has, a table with vertical columns and horizontal rows is arrived at. This table is referred to as a periodic table because as we follow the list of the elements in the order of increasing atomic numbers from an atomic number of one to twenty, the numbers of the electrons in the outer shells and the properties of the elements are repeated periodically. Table 2.3 below shows how the first twenty elements are arranged in a periodic table.

	I							0
1	H (1)							He (2)
2	Li (2,1)	Be (2,2)	B (2,3)	C (2,4)	N (2,5)	O (2,6)	F (2,7)	Ne (2,8)
3	Na (2,8,1)	Mg (2,8,2)	Al (2,8,3)	Si (2,8,4)	P (2,8,5)	S (2,8,6)	Cl (2,8,7)	Ar (2,8,8)
4	K (2,8,8,1)	Ca (2,8,8,2)						

Table 2.3: the periodic table of the first 20 elements

Groups / families

The vertical columns in the periodic table are known as groups. They are also called families. The groups are numbered in roman numerals from left to right up to group seven. The last group is called group O. The number of electrons in the outer shell of an element corresponds to the group number in the periodic table to which the element is found, except for elements in group O. All the elements in group O, have their outer shells completely filled. Completely filled outer shell means that the element has 2 electrons if it has one shell or 8 electrons in the outer shell if the element has more than one electron shell.

Periods/ Series

Periods are the horizontal rows in the periodic table. Periods are also called series. The periods are numbered in Arabic numerals from the top going down wards.

Periodicity in the periodic table

Periodicity means periodic repetition. All the elements in the same group;

- have same number of electrons in the outer shells.
- have similar properties. However the properties may change slightly as we go down the group due to changes in sizes of the atoms.

Predicting the Group and the Period of an Element Given the Atomic Number

To predict the group and the period of an element

- first write down its electron configuration.
- the number of electrons in the outer shell of an atom of an element is equal to the group number.
- the number of shells of an element is equal to its *period* in the periodic table.

Example

What is the group, the period and the name of the following element; ${}_{14}^{28}\text{X}$.

Working out

The element has 14 protons; therefore it has also 14 electrons.

So its electron configuration is 2. 8. 4.

Therefore, the element belongs to group 4 and period 3.

Its name is sulphur, S.

Exercise

Identify the following elements in the periodic table; (a) ${}_{17}^{35}\text{X}$ (b) ${}_{18}^{40}\text{X}$.

Stable Electron Configuration

An electron configuration with a completely filled outer shell is a stable electron configuration. Atoms with completely filled outer shells stable and do not normally react with other atoms. Therefore, all the atoms of the elements in group O are stable. These elements are called noble gases because of their stability.

All atoms with incompletely filled outer shells are not stable. In order to attain stability the atoms with incompletely filled outer shells react and combine with other atoms. During the reaction, they attain the stable electron configuration by losing / gaining electrons or by sharing the outer shell electrons. After gaining/ losing or sharing the electrons, chemical bonds are formed between the atoms.

Chemical bonds

A chemical bond is the force that holds two atoms together to form ions or molecules. Chemical bonds form when electrons of one atom are attracted to the nucleus of another atom. The electrons that participate in chemical bonds are valence electrons, which are the electrons in the valence (outer) shell. The electrons that are used to form the chemical bonds are either completely lost by one of the atoms and gained by the other atom or are shared between the two atoms depending on the electronegativities of the atoms involved. Electronegativity is the measure of the attraction of an atom involved in a bond for shared electrons in a chemical bond. Non-metal elements have high electronegativities since they have high attraction for any shared electrons. Metal have low electronegativities because they have weak attraction for shared electrons.

The number of chemical bonds a given atom can form or has formed with one or more other atoms is called valency. The valency of an element depends on the number of the valence electrons that may be involved in forming the bonds. An atom with a valency of one can form one bond and that with two can form two bonds and so on. Valency is like strings with which the atom can be attached to other atoms. For example, a magnesium atom loses two valence electrons in order to achieve a stable electron configuration therefore, its valency is 2. We can visualise this as two strings with which the magnesium atom can attach to other atoms as follows;

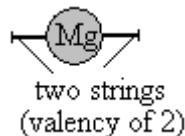


Figure 2.4

The strings are free to move to any side of the atom. The combining powers of other atoms such as sodium, aluminium, chlorine, oxygen and carbon may be represented as follows;

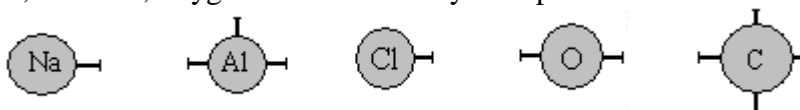


Figure 2.5

With the strings the atoms can attach to each other to form compounds or elements as follows;

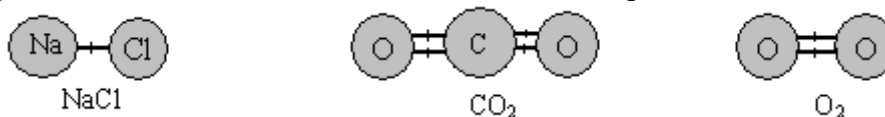


Figure 2.6

The group number of an element in the periodic table can be used to determine its valency as follows;

- (a) In groups, I, II, III and IV valency of each elements is equal to its the group number.
- (b) In groups V, VI and VII valency is equal to 8 minus the group number.
- (c) Elements in group O have a valency of zero.

Covalent bonds

When two atoms of non-metal elements with equal or approximately equal electronegativities react together, none of them is ready to lose its electrons because both have high electronegativities. So, in order to achieve a stable electron configuration, they share their valence electrons.

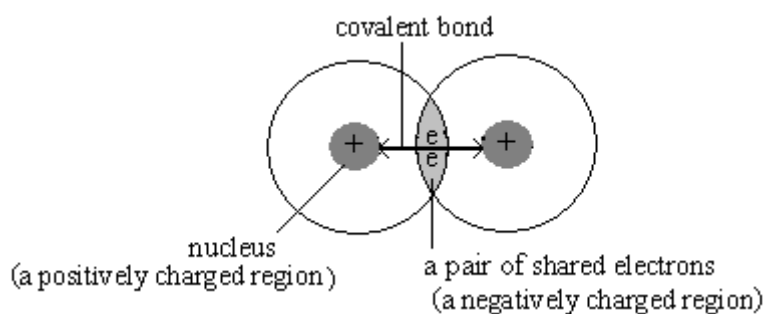


Figure 2.6

The shared electrons experience a force of attraction from both nuclei. This positive-negative-positive attraction holds the two atoms together. This attraction is what is called a chemical bond and it is very strong. One pair of electrons constitutes one bond. In a normal covalent bond, eg in H_2 , O_2 or HCl , each atom donates one electron to the bond. A group of atoms that are joined together by a covalent bond is called a molecule. The molecules then join together to form a substance, using weak intermolecular forces such as hydrogen bonds, dipole-dipole moments or the van der Waals forces. In molecular substances there

are, therefore, two types of bonds; the covalent bonds which are the bonds between the atoms, inter atomic forces, and the bonds between the molecules, the inter-molecular forces. If the covalent bond is formed by one of the atoms donating both electrons to the bond then it is called dative (or coordinating) bond. The best example of this is one of the bonds in ammonium ion, NH_4^+ .

Figure 2.19 below depicts the forces that exist in a water molecule.

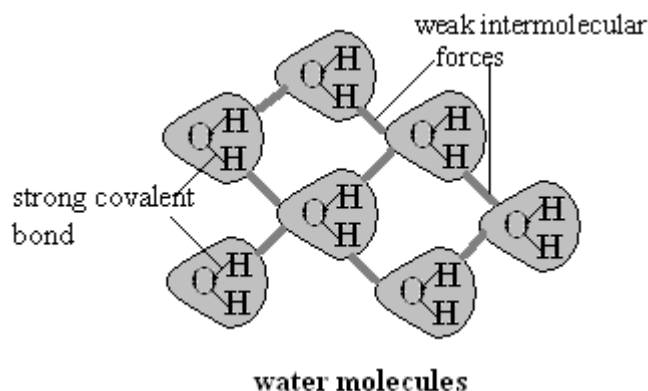


Figure 2.19

Properties of molecular (or covalent) substances

1. Most molecular substances have low melting and boiling points. This is because the inter-molecular forces are weak. Therefore a lower amount of energy is needed to break them and separate the molecules.
2. They do not readily dissolve in water. If they do, their solutions do not conduct electricity. This is because ions are needed to conduct electricity in an aqueous solution. However, molecular substances dissolve into molecules rather than dissociate into ions.

Dot and cross diagrams representing covalent bonds

To draw a dot and cross diagram to represent a covalent bond, all the valence electrons are represented. Dots are used to represent valence electrons of one atom and crosses to represent the valence electrons of the other electrons as follows;

a) Hydrogen molecule

A hydrogen atom has only one electron. But it can become stable if its shell can hold two electrons.

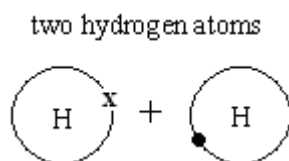


Figure 2.12

When two hydrogen atoms get close enough, their shells overlap and then they can share electrons. A single bond is then formed between them. The dot and cross diagram representing the oxygen molecule is as shown in figure 2.13 below.

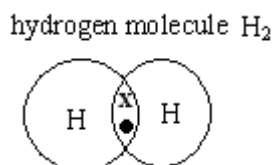


Figure 2.13

Each atom, then has two electrons in its shell, hence they are stable. The two electrons shared between the two atoms constitute one covalent bond between the two atoms.

b. Oxygen molecule

The formula for oxygen is O_2 , so each molecule must contain two atoms. Each oxygen atom has 6 outer electrons; it needs a share in two more electrons to reach a full shell.

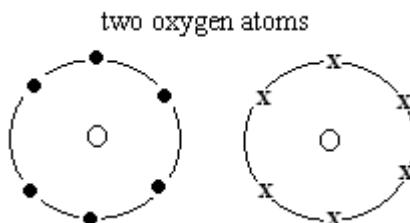


Figure 2.14

When the two atoms get close together, their outer shells overlap and share four electrons, two from each atom as shown in figure 2.5 below.

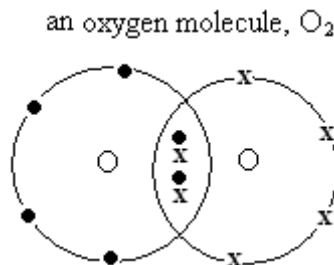


Figure 2.15

A double bond is then formed between the two oxygen atoms.

c. Nitrogen molecule

The formula for nitrogen is N_2 . Each nitrogen atom has 5 electrons in the outer shell, so it needs a share in three more electrons to reach full outer shell.

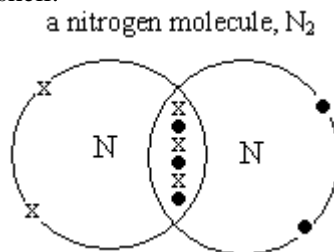


Figure 2.16 (a)

The three pairs of the shared electrons result in three bonds being formed between the two nitrogen atoms.

d. Water molecule

The formula of water is H_2O . In each water molecule, an oxygen atom shares electrons with two hydrogen atoms to reach full shells. The dot and cross diagram representing a water molecule is as follows;

a water molecule

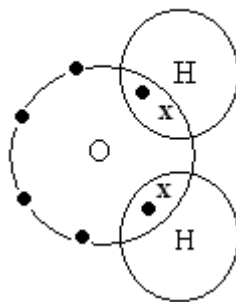


Figure 2.18

When a dash is used to represent a bond, it represents a pair of electrons. In the following representations each dash is representing two electrons;

- a) hydrogen molecule; $\text{H}-\text{H}$.
- b) oxygen molecule; $\text{O}=\text{O}$.
- c) Nitrogen molecule; $\text{N}\equiv\text{N}$.
- d) water molecule;

Ionic bonds

When an atom loses or gains electrons it becomes an ion. An ion contains an unequal number of protons and electrons. An ion is therefore, a charged atom. When an atom loses electrons, it becomes a positively charged ion which is known as a cation. Normally it is metal atoms which lose one electron to become a cation. For example a sodium atom loses one electron to become a cation as follows; $\text{Na} \rightarrow \text{Na}^+ + \text{e}^-$.

Other examples of cations are; K^+ , Mg^{2+} , Al^{3+} .

When an atom gains electrons, it becomes a negatively charged ion. The negatively charged ions are called anions. Non metal atoms normally gain electrons to become anions. A chlorine atom gains an electron and become an anion as follows; $\text{Cl} + \text{e}^- \rightarrow \text{Cl}^-$. The examples anions are Br^- , O^{2-} .

The size of the charge on the ion is equal to the valency of the element. For example the following atoms have a valency of 1; K, Na, Cl and Br, while Mg, and O both have a valency of 2.

Just as with the opposite poles of a magnet, when a positive and a negative ions approach one another, a very strong force of attraction is formed. This is called an ionic bond (or an electrovalent bond). The transfer of the electrons from one atom to another to achieve a stable electron configuration is referred to as ionic bonding. During ionic bonding, metal atoms lose electrons and become cations while the non-metals gain electrons to become anions.

The ionic bond results in the formation of an ionic compound. An ionic compound is formed when massive numbers of positive and negative ions gather and arrange in a systematic fashion to form a solid. In the ionic compound, positive ions are surrounded by negative ions, and negative ions are surrounded by positive ions as shown in figure 2.12 below.



a systematic arrangement of ions in an ionic compound

Figure 2.12

This systematic arrangement of ions is known as a crystal lattice.

Properties of ionic compounds

1) Ionic compounds have high melting and boiling points.

High temperatures are required to break the strong ionic bonds in the ionic compounds. Therefore, a lot of energy is required to melt ionic compounds or cause them to boil.

2) Ionic compounds conduct electricity when they are dissolved in water.

This is because when ionic compounds are dissolved in water the dissociated ions are free to conduct electricity through the solution. Molten ionic compounds also conduct electricity.

3) Ionic solids are good insulators.

Although they conduct in molten form or in aqueous solutions, ionic solids do not conduct electricity very well because the ions are bound so tightly to each other.

4) Ionic compounds are hard and brittle.

Ionic compounds are hard because the positive and the negative ions are strongly attracted to each other; therefore they are difficult to separate. However, when pressure is applied to an ionic crystal then ions of like charges may be forced closer to each other. The electrostatic repulsive forces can be strong enough to split the crystal. This is why ionic solids also are brittle.

Dot and cross diagrams of ionic compounds

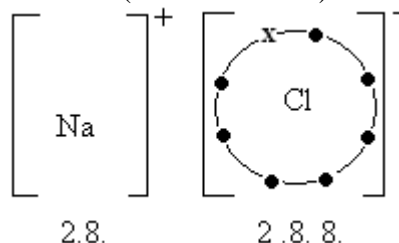
When using dot and cross diagrams, only the valence (outer) shells of the atoms are shown. When drawing the dot and cross diagrams of ionic compounds, the ions must not touch. So, to isolate each ion in space, they are supposed to be enclosed in square brackets.

a) Sodium chloride

The valence shell of a sodium atom has one electron while the valence shell of a chlorine atom has seven.

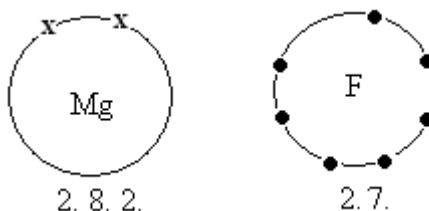


When the two elements react together to form an ionic compound, the sodium atom donates its valence electron to the chlorine atom. The seven valence electrons of chlorine now become eight, a full third shell, and the sodium atom also has a full outer shell (the second shell).

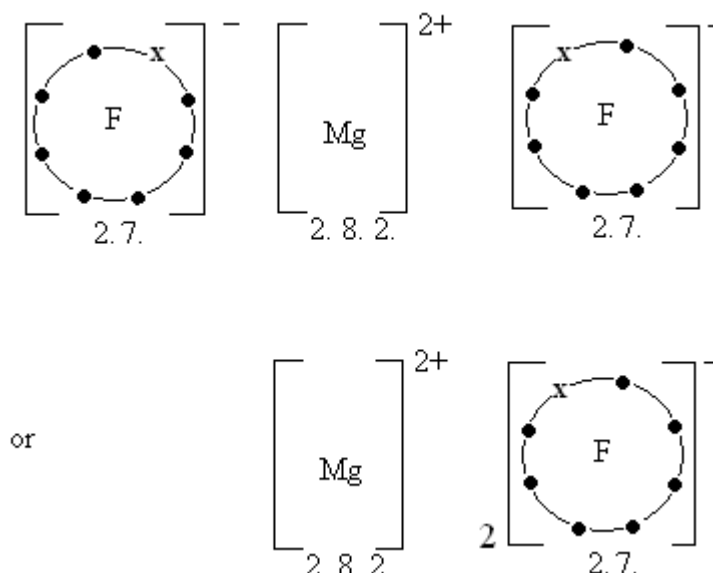


b) Magnesium and Fluorine

The valence shell of a magnesium atom has two electrons while the valence shell of each fluorine atom has seven.



When the two elements react together to form an ionic compound, the magnesium atom donates its two valence electrons and since each fluorine atom requires only one electron to have its outer shell completely filled, then two fluorine atoms are required to take the two electrons from the magnesium atom. The seven valence electrons of fluorine now become eight, a full third shell, and the magnesium atom also has a full valence shell (the second shell).



Working out formulae of compounds given valencies

All compounds are electrically neutral and their formulae must show this neutrality by balancing the valencies (or the charges). In working out the formulae we can consider all compounds (ionic or covalent) as being made up of ions and then use the charges on the ions to come up with the formula. The valency of the element gives the size of the charge while group of the element in the periodic table can be used to determine the sign of charge (whether positive or negative). Elements in groups I to III have positive charges and those in groups V to VII have negative charges. The charge of those in group IV can be positive if bonded to a more electronegative element and negative if bonded to a less electronegative element.

Example

Work out the formula for aluminium oxide. (Valencies; Al=3, O=2).

Working out

Ions present;	Al ³⁺	O ²⁻
	Al ³⁺	O ²⁻
		O ²⁻
Total charge	6+	6-

∴ the formula for aluminium oxide is Al₂O₃.

Note that the number of the atoms of each element is written as a subscript after the chemical symbol of the element in the formula. Also note that the metal ion is written first. Polyionic ions should be placed in brackets e.g. Fe (NO₃)₂.

Some metal elements can have multiple valencies. For example, copper can form two different compounds with chlorine; CuCl and CuCl₂. For all elements with multiple valencies, the valence that has been used in the particular compound is indicated in Roman numerals in brackets inside the name of the compound immediately after the name of the metal ion. **E.g.** Copper (II) chloride or Iron (III) iodide.

Exercise

Write down the formulae of the following compounds.

- a) copper (I) oxide b) aluminium sulphide c) methane (made up of carbon and hydrogen atoms)
(valencies; Cu=1, O=2, Al=3, sulphur=2, C=4, H=1)

Polar and Non-polar molecules

Both the sulphuric acid and the sugar are held together by covalent bonds. However a solution of sugar does not conduct electricity while the solution of sulphuric acid does conduct electricity. Why does it happen this way? This happens because molecules of sugar are not polar while the molecules sulphuric acid are polar. A polar molecule is a molecule which is partially charged by having a small positive charge at one end and a small negative charge on the other end (figure 2.31 a). Non polar molecules do not have charges at their opposite ends (figure 2.31 b).

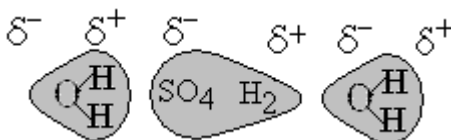


Figure 2.31 (a)



Figure 2.31 (b)

When dissolved in water, the sulphuric acid dissociates into H_3O^+ and SO_4^{2-} . It is these ions which conduct the electricity through the solution. This happens because when dissolved in water, the water molecules which are also polar, surround the molecules of sulphuric acid with ends with opposite partial charges facing each other.



The water molecules pull the sulphuric acid apart. The end result is that the molecule of sulphuric acid is split into a positive ion and a negative ion as shown below;



The sugar molecule is not split by water molecules when dissolved in the water because sugar molecules are not polar.

Now the question is why are some molecules polar while others are not polar? For a molecule to be polar or non polar, it depends on whether the pair of the bonding electrons is shared equally or not, between the two atoms.

Non polar covalent bonds

When two atoms bonded by covalent bond have the same electronegativity the bonding electrons are shared equally. For instance the bonding electrons are shared equally between two chlorine atoms.

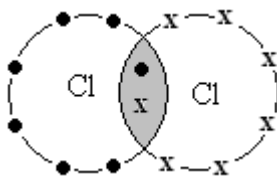


Figure 2.38

A covalent bond in which the pair of bonding electrons is shared equally is called a non polar covalent bond or a pure covalent bond. It is only atoms of the same element that can have the same electronegativity; therefore, a pure covalent bond only exists between two atoms of the same element. This implies that pure covalent bonds are formed only in elements such as chlorine, oxygen, hydrogen e.t.c.

All molecules made up of pure covalent bonds are non polar. So, chlorine, oxygen, hydrogen molecules are non polar molecules.

Bond polarity

In most covalent compounds the pair of bonding electrons is not shared equally between the atoms. The atom with the higher electronegativity takes a greater share of the electrons as shown in a hydrogen chloride below;

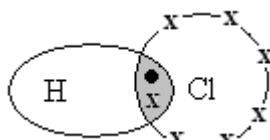
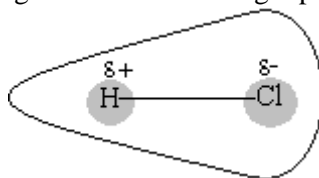


Figure 2.31

This makes the bond to be polar, with the more electronegative atom having a slight negative charge (designated as δ^-) while the less electronegative atom has a slight positive charge (designated as δ^+).

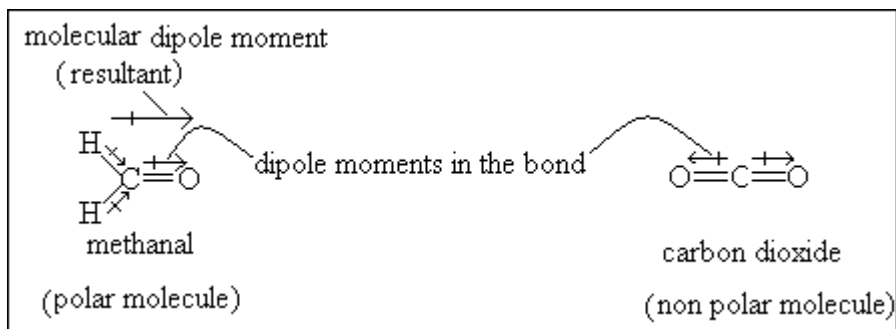


The polarisation of charge in HCl bond is due to different electronegativities of chlorine and hydrogen. The separation of charge is referred to as polarity.

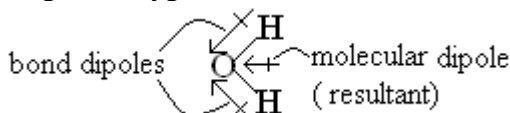
Thus a polar covalent bond is a covalent bond with unequal electron sharing due to difference in electronegativities of the atoms involved in the bond. The separation of charge at the bond is called dipole (which means two poles). The separation of the charge in the molecule can be represented by an arrow indicating a dipole (i.e. two charges separated by a distance). The tip of the arrow points towards the more electronegative atom $\text{H} \overset{+}{\text{---}} \overset{-}{\text{Cl}}$.

Polarity of molecules

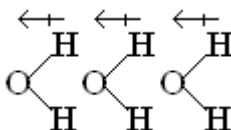
Bond polarity is measured by its dipole moment. This is a force created in the bond due to the existence of the two opposite charges. Polarity of the molecule is the sum of all the bond polarities in the molecule. Since dipole moment is a vector quantity (with both magnitude and direction), molecular dipole moment is the vector sum of the individual dipole moments. Consider the molecular dipole moments of methanal (an aldehyde) and carbon dioxide. Both contain a polar carbonyl ($\text{C}=\text{O}$) group. However, we find that methanal is highly polar while carbon dioxide is non polar. This is so because carbon dioxide is a linear molecule and so, the individual dipoles cancel each other, whereas in methanal the individual dipole moments add to give a resultant.



Water is a bent molecule with polar O–H bonds. The bond dipole moments add to give a resultant dipole directed towards the more electronegative oxygen as shown below;

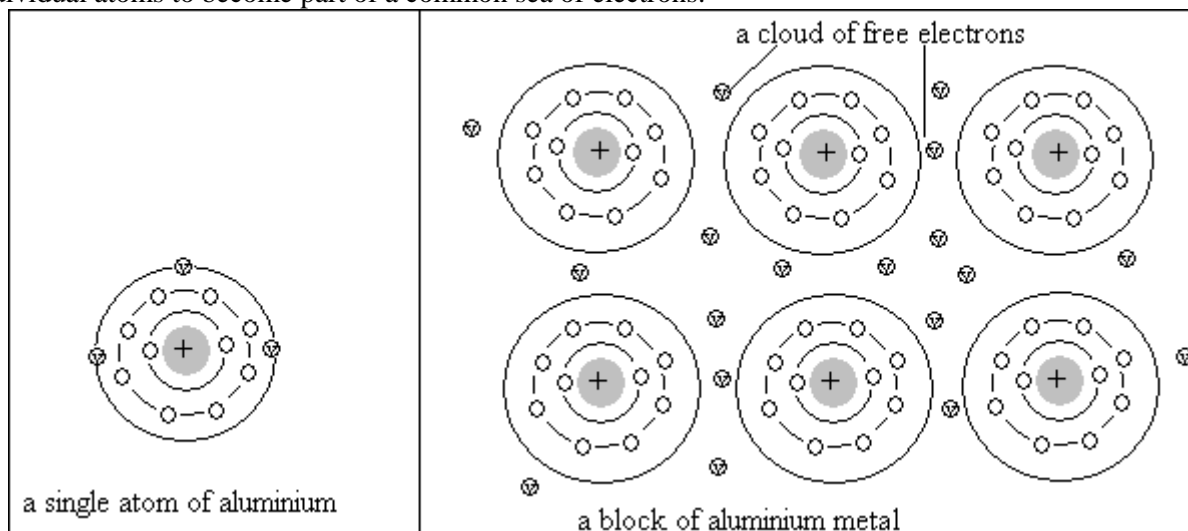


Polar molecules have permanent dipole moments. Since opposite charges attract, when polar molecules approach each other, they orient themselves in a head-to-tail manner.



Metallic Bonding

Metals contain only one to three electrons in the outer shell. When an element has only one to three electrons in the outer shell, the bond between these electrons and the nucleus is relatively weak. So, for example when aluminium atoms are grouped together in a block of a metal, the outer electrons leave the individual atoms to become part of a common sea of electrons.



In this arrangement, the valence electrons are able to move freely throughout the block and are able to conduct heat and electricity easily. Thus the electrons are said to be delocalised, hence the bond is also delocalised.

These electrons form a sea of electrons around the positive ions (cations). Metallic bond is the force of attraction between the cations and the sea of the free electrons.

It should be noted that in a metallic bond, the bonding electrons are shared by all the atoms in the metal block, unlike the covalent substance where the bonding electrons are shared between two atoms.

Properties and uses of Metals

Property	Use
Metals conduct electricity. This is because metals have a sea of free electrons.	They are used in electrical wiring
Metals are good conductors of heat. This is because they have free electrons.	They are used to make cooking pots.
They are malleable and ductile. This is because the atoms can slide over each other when the metal is deformed due to the delocalised nature of the bond.	They are drawn into wires and are used to make sheets

Table 2.6

The Halogens

Halogens are elements in group 7 of the periodic table. They include elements such as fluorine, Chlorine, Bromine and iodine.

The halogens are electronegative non-metals. They exist as diatomic molecules as follows F_2 (F-F), Cl_2 (Cl-Cl), etc.

(i) Physical properties of the halogens

a. Halogens are coloured elements.

Fluorine ----pale yellow
 Chlorine-----greenish yellow
 Bromine----- reddish brown
 Iodine-----purple black

b. The melting points and the boiling points increase as we go down the group. This is because as we go down the group the sizes of the molecules increase and therefore the sizes of the intermolecular forces increase as we go down the group.



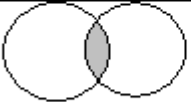
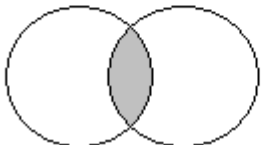
Element	molecule	Melting point	Boiling point
F ₂		-220	-188
Cl ₂		-101	-34
Br ₂		-7	59
I ₂		114	184

Table 2.7

The stronger in intermolecular forces mean that more heat is needed to separate the molecules, hence the increase in the melting and the boiling points as we go down the group.

Exercise

1. a. Using the data given in the table below, plot a graph of boiling point against relative molecular masses of the halogens.

Element	Relative molecular mass	Melting Point (°C)	Boiling Point (°C)
F ₂	36	-220	-188
Cl ₂	70	-101	- 34
Br ₂	100	-7	59
I ₂	132	114	184

Table 2.8

b. From your graph, what is the relationship between the relative molecular masses and the boiling points of the halogens?

c. Explain the shape of the graph.

2. Chemical properties of halogens

a. The reactivity of the halogens decreases as we go down the group. This is because

(i) The atomic radius increases as we go down the group. Atomic radius is the distance between the nucleus and the outermost shell as shown below;

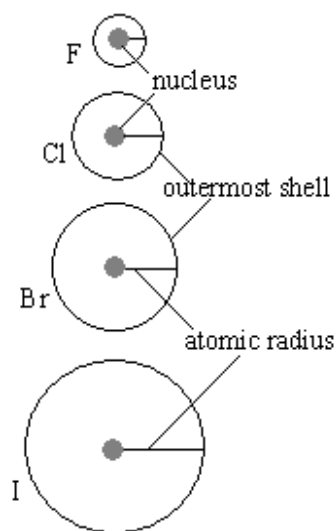
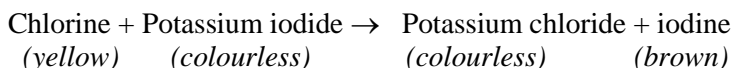


Figure 2.41

(ii) The effective nuclear charge decreases as we go down the group. Effective nuclear charge is the force of attraction from the nucleus of the atom which is felt by the electrons in the outer shells. When more shells are added to the atom, the electrons in the outer most shells are shielded from the nuclear charge by the electrons in the inner shells. Therefore, it becomes difficult for the nucleus to attract electrons from other elements.

b. Halogens undergo displacement reactions. This is the reaction where a more reactive halogen displaces a less reactive one from its compound. For example when chlorine water was added to Potassium chloride solution no colour change is observed. This shows that no reaction takes place. But when chlorine water is added to the solution of potassium iodide, the colour of the solution changes from colourless to brown. This shows that a chemical reaction has taken place. Chlorine has displaced potassium from the compound of potassium iodide. The reaction is as follows;



Chlorine can displace both bromine and iodine from their compounds. Bromine can displace iodine only from its compound while iodine can displace neither chlorine nor the bromine from their compounds. Therefore the halogens up in the group are more reactive and can displace the ones that are lower in the group.

Uses of the halogens

Fluorine

1. It is added to drinking water to prevent tooth decay.
2. It is used in toothpaste because it hardens the enamel.
3. It is used to make poly tetra-fluoroethane (PTFE), which is used to make non stick frying pans and soles of iron.

Chlorine

1. to make PVC pipes
2. to sterilize drinking water
3. to make household bleaches such as *javel*.
4. to make DDT (dichloro diphenyl trichloroethane)

Bromine

1. to make disinfectants

2. to coat photographic films as silver bromine (AgBr_2)

Iodine

1. to treat wounds
2. to make photographic chemicals such as silver iodide (AgI_2)
3. to make dyes and printing inks
4. to make antiseptics
5. It is added to salt to be used in the body to prevent goitre.

Sulphur

Sources of sulphur

1. Volcanic regions
2. Crude oil such as organic sulphur compounds and natural gases such as hydrogen sulphide.
3. Metal ores, such as Iron sulphide (FeS_2), Lead sulphide (PbS), Zinc sulphide (ZnS).
4. Tissues of living plants. For example the substance that makes people cry when slicing onion is a sulphur compound. And the smells of garlic, mustard, cabbage are due to sulphur compounds.

Physical properties of sulphur

1. It is a brittle yellow substance
2. It is made up of crown shaped molecules, each with eight atoms, S_8 as shown figure 2.42.

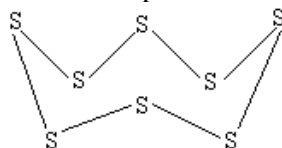


Figure2.42

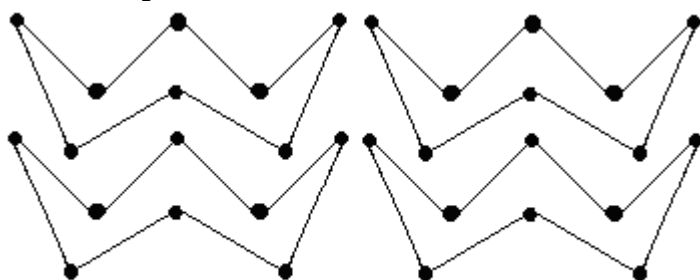
3. It Sulphur has a low melting point
4. It is insoluble in water
5. It does not conduct electricity
6. It has two allotropes; rhombic sulphur and monoclinic sulphur. Rhombic sulphur exists at room temperature while monoclinic sulphur exists at temperatures above 94.5°C .

Allotropes are different forms in which an element can exist in the same physical state.

Of the two allotropes of sulphur, rhombic ***sulphur is more stable*** than the monoclinic sulphur.

This is because of the interlocking arrangement of the sulphur molecules in rhombic sulphur is more stable than the staked arrangement of the molecules in monoclinic sulphur as shown in following diagrams:

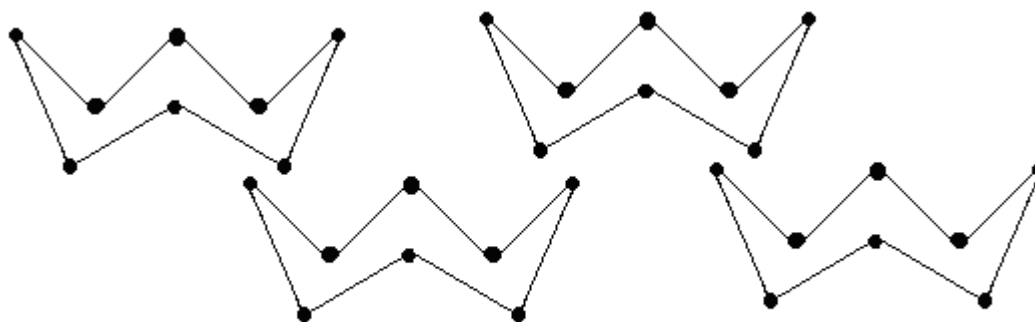
Rhombic sulphur



The molecules are interlocked in rhombic sulphur

Figure2.43

Monoclinic sulphur



the molecules are stacked in monoclinic sulphur

Figure 2.44

If the sample of monoclinic sulphur is left at room temperature, it will change to its more stable form, the rhombic sulphur.

Chemical Properties of Sulphur

a) Sulphur reacts with metals to form sulphides.

Sulphur reacts with magnesium to form magnesium sulphide; $\text{Mg} + \text{S} \rightarrow \text{MgS}$. It also reacts with Iron to form Iron Sulphide; $\text{Fe} + \text{S} \rightarrow \text{FeS}$.

b) It burns in oxygen to produce Sulphur dioxide; $\text{S} + \text{O}_2 \rightarrow \text{SO}_2$

Uses of Sulphur

Sulphur has a number of importance uses in our lives as follows;

- 1) to produce sulphuric acid.
- 2) to vulcanise rubber. Vulcanisation means adding sulphur to rubber in order to toughen it.
- 3) to make matches, pesticides, drugs and paper.
- 4) to make sulphur concrete.
- 5) to manufacture gun powder.
- 6) to manufacture plastic flowers.

Sulphuric acid (H_2SO_4)

The major use of sulphur is the production of Sulphuric acid. The sulphuric acid is produced by a process known the contact process. The process has the following steps.

(a) Sulphur is burnt in oxygen to produce sulphur dioxide; $\text{S}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{SO}_2(\text{g})$

(b) Sulphur dioxide is reacted with oxygen to produce sulphur trioxide $2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3$.

(c) There are two routes that can be used to produce the acid;

i. The sulphur trioxide is mixed with water to produce sulphuric acid; $2\text{SO}_3 + \text{H}_2\text{O} \rightarrow 2\text{H}_2\text{SO}_4$

However this route has some disadvantages;

- the reaction is very violent so that it is very dangerous.
- the acid produced is very thick and too concentrated.

ii. To produce a good sulphuric acid with required concentration, a different the following route can be followed;

1) Sulphur trioxide is mixed with concentrated sulphuric acid to produce a substance known as oleum ($\text{H}_2\text{S}_2\text{O}_7$)

2) The oleum is then added to water to produce sulphuric acid of the required concentration;

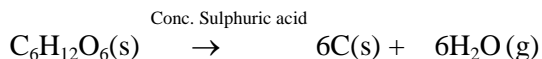


Uses of Sulphuric Acid

Sulphuric acid is important because it is used in the following ways, such as;

- 1) to manufacture fertilisers e.g. sulphate fertilisers
- 2) to make paint and dye stuff
- 3) to make fibres; eg in the manufacture of nylon.

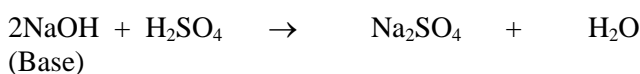
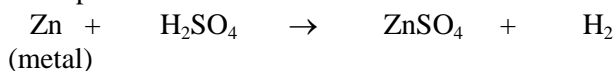
- 4) as acid in car batteries
- 5) to make detergents and soaps.
- 6) as a dehydrating agent. When sulphuric acid is added to sugar a reaction, which gives out a lot of heat, takes place and the sugar turns into a black staff. In this reaction the concentrated sulphuric acid removes water from the sugar molecules ($C_6H_{12}O_{6(s)}$) leaving behind the black mass of carbon. The removal of water from a substance is called dehydration. Dehydration reaction gives out a lot of heat, which causes the water to boil off. The equation for the reaction is as follows;



Sulphates

Sulphates are salts formed by the reaction of sulphuric acid with metals, bases or carbonates.

Examples



Uses of Sulphates

1. to manufacture fertilisers, e.g. ammonium sulphate fertiliser $(\text{NH}_4)_2\text{SO}_4$.
2. in diagnostic medical X-ray studies, e.g. barium sulphate.
3. to make Plaster of Paris (P. O. P), e.g. calcium sulphate
4. as a laxative in medicine, e.g. magnesium sulphate.

Review questions

1. a. The atomic numbers for each of the following seven elements are as follows: aluminium, Al = 13, carbon, C = 6 ; Boron, B = 5 ; oxygen, O = 8; nitrogen, N = 7; phosphorus, P = 15; and sulphur, S =16 .

For each of these elements write down:

- i. The periodic table to which it belongs
 - ii. its group number in the periodic table.
 - iii. the number of electrons in the atom.
 - iv. its electron configuration
 - v. The number of outer – shell electrons in one atom.
- b. Which of the above elements would you expect to have similar properties? Why?

c. For the reaction between aluminium, Al and oxygen, O;

- i. Draw the atomic structures of the elements.
- ii. Draw the structure of each ion formed.
- iii. Draw a dot and cross diagram for the compound formed.
- iv. Write a chemical formula for the ionic compound formed.
- v. Write the name of the compound.

(RAM; Al = 27, O = 16)

3. a. Why are noble gases chemically unreactive?
- b. Which electrons in an atom are involved in chemical bonding?
- c. What is considered a stable electron configuration?

4. Define the following; a. Covalent bonding. b. Metallic bonding c. Intermolecular forces. g. Intramolecular forces.

5. Oxygen molecules, O_2 have double covalent bonds between the atoms, and the bonds are very strong. Why does oxygen have very low melting and boiling points?

7. Calcium chloride is made up of charged ions. Why does it not conduct electricity when in solid state?

8. Draw dot and cross diagrams of each of the following compounds;

- a. Lithium oxide, Li_2O
- b. Magnesium iodide, MgI_2

9. Atoms of elements X, Y and Z have 8, 9 and 12 electrons respectively.

a. Determine the formulae of the compounds formed by the combination of the elements;

- i. X and Y. ii. Y and Z iii. X with itself.

b. In each of the cases shown in a. (i) – (iii) above name the type of chemical bond formed.

c. Give the properties you would expect to be shown by the compounds formed in;

- a. (ii). a. (iii) and a.(iv)

10. a. Why does the reactivity of the halogens decrease as the group descends?

b. Predict what would happen in the following reactions;

- i. Fluorine + Potassium chloride $\longrightarrow ? + ?$
- ii. Bromine + Sodium chloride $\longrightarrow ? + ?$
- iii. Bromine + Potassium iodide $\longrightarrow ? + ?$

11. a. Name three sources of sulphur in the Earth' crust?

b. Sulphur burns in air to produce sulphur dioxide. Write an equation for the reaction.

(Valences; S = 2, O = 2)

c. Explain what happens when rhombic sulphur is heated to about 95°C .

3. CHEMICAL REACTIONS I

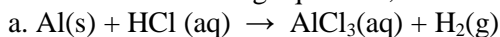
Chemical reactions

A chemical reaction is the rearrangement of atoms to form new substances. For example, when a piece of aluminium metal is thrown into a beaker with hydrochloric acid, the aluminium metal disappears and a gas comes out from the beaker. This shows that a chemical reaction has taken place because both the aluminium metal and the acid disappear and new substances form. The reaction can be represented by the following chemical equation; $\text{Al(s)} + \text{HCl(aq)} \rightarrow \text{AlCl}_3\text{(aq)} + \text{H}_2\text{(g)}$.

However, the equation is only telling us that aluminium reacted with hydrochloric acid and produced aluminium chloride (AlCl_3) and hydrogen gas (H_2). It is not telling us the exact quantities of the substances that reacted together, and the products. To find the exact quantities we need to balance the equation. Chemical equations can be balanced by trial and error or by a systematic method.

Examples

Balance the following equations;



Working out

Since to balance an equation we need to whole numbers (coefficients) in front of the chemical symbols so that the numbers of the atoms of each kind are the same on both sides of the equation;

-let the balanced equation be $\mathbf{aAl(s)} + \mathbf{bHCl(aq)} \rightarrow \mathbf{cAlCl_3(aq)} + \mathbf{dH_2(g)}$.

-then we have to make equations using the numbers of the atoms of each kind on both sides of the equation.

Using the number of the Al atoms on both sides of the equation , we have;

$$\mathbf{a = c} \dots\dots\text{(i)}$$

Using the numbers of the H atoms, on both sides, we have;

$$\mathbf{b = 2d} \dots\dots\text{(ii)}$$

Using the numbers of the Cl atoms on both sides, we have;

$$\mathbf{b = 3c} \dots\dots\text{(iii)}$$

let $\mathbf{a = 1}$, then substituting 1 for c in (i) we have;

$$\mathbf{c = 1}$$

substituting 1 for c in (iii) we have,

$$\mathbf{b = 3 \times 1}$$

$$\mathbf{b = 3}$$

substituting 3 for b in (ii) we have;

$$\mathbf{2d = 3}$$

$$\mathbf{d = 3/2}$$

Therefore, the balanced chemical equation is $\mathbf{1Al(s) + 3HCl(aq) \rightarrow 1AlCl_3(aq) + 3/2H_2(g)}$.

However, all the coefficients must be whole numbers, therefore, the whole equation must be multiplied by 2 to make 3/2 to remove the denominator, 2 as follows; $\mathbf{2[1Al(s) + 3HCl(aq) \rightarrow 1AlCl_3(aq) + 3/2H_2(g)]}$.

Therefore, the correct equation is; $\mathbf{2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)}$

Exercise

Balance the following



The mole

Different objects are counted in different units such as shown in table 3.1;

unit	Number of objects in one unit	Example of objects
dozen	12	batteries
gross	144	pencils
ream	500	sheets of paper
mole	602 000 000 000 000 000 000 000 (or in standard form; 6.02×10^{23})	atoms, molecules or ions

Table 3.2

The counting units represent a number consistent with their use and the size of the objects. For example, a wholesale shop owner sells a dozen of batteries because 12 is a practical number for that purpose. On the other hand, we buy a ream of paper which is 500 sheets of paper. But a ream of batteries is not a practical amount to buy because 500 batteries is too big a number of batteries for practical purposes. Similarly counting atoms, molecules or ions in dozens or reams would not be practical because the sizes of these particles are very small. It is therefore practical to count these particles in moles. One mole = 602 000 000 000 000 000 000 000 particles, (i.e. 6.02×10^{23} particles). A mole means an amount of substance containing 6.02×10^{23} particles. The unit of a mole is **mol**. One mole of oxygen atoms contains 6.02×10^{23} oxygen atoms, '**O**' and one mole of oxygen molecules contains 6.02×10^{23} oxygen molecules, '**O₂**'. The number 6.02×10^{23} is called Avogadro's number, L.

Relationship between number of moles of different substances and their masses

The relationship between the number of moles of the particles of any substance and the mass is as follows; the mass of one mole of the particles of any substance is equal to the sum of the relative atomic masses (RAM) of the atoms in the molecule of the substance in grams. For example, the relative atomic mass of oxygen atoms is 16. Therefore one mole of oxygen atoms is 16g, while the mass of one mole of oxygen gas (O₂) is 32g.

Molar mass

Molar mass is the mass of one mole of any substance. It is the relative formula mass (RFM) or the relative atomic mass (RAM) expressed in grams. The molecular mass of any substance is found as follows;

- Writing the chemical symbol or formula of the substance.
- Finding the RAM or the RFM of the substance.
- Expressing the mass in grams.

Example

What is the mass of each of the following?
(RAMs: H = 1, S = 32, O = 16)

Working out

(The RFM of a sulphuric acid molecule (H₂SO₄)
= $2 \times 1 + 1 \times 32 + 4 \times 16 =$
= 100

Therefore, the molar mass of H₂SO₄ is 100g

Exercise

1. Calculate the molar masses of each of the following;

- CO₂
- NaCl

2. What is the mass of each of the following

- 0.2 moles of HCl
- 3 moles of NaOH
- 0.6 moles of calcium carbonate (CaCO₃)

(RAMS: C = 12, O = 16, Na = 23, H = 1, Cl = 35.5)

Mole calculations

Sometimes we need to convert the mass of a substance to the number of moles of the substance and vice versa. In order to do this we can use cross multiplication.

Examples

- How many moles of sodium Na, are there in 46 g of sodium, Na? (RAM; Na = 23)

Working out

Let x be the number of moles of Na in 46 g Na

Since 23g Na = 1 mol

\Rightarrow 46 g Na = x mol

Cross multiplying, we have;

$$23 \text{ Na} \times x \text{ mole} = 46 \text{ g Na} \times 1 \text{ mole}$$

Making x the subject;

$$x = (46 \text{ g Na} \times 1 \text{ mole}) / (23 \text{ Na} \times \text{mole}) \\ = 2$$

\therefore there are moles of Na in 46g Na.

2. Calculate the mass of 2 moles of Iron. (RAM of Iron = 56)

Working out

Let x be the mass of 2 mol Fe

Since 1mol Fe = 56g

\Rightarrow 2 moles Fe = x g

Cross multiplying;

$$1 \text{ mol Fe} \times x \text{ g} = 2 \text{ moles} \times 56 \text{ g}$$

Making x the subject;

$$x = (2 \text{ moles} \times 56 \text{ g}) / (1 \text{ mole Fe} \times 1 \text{ g}) \\ = 112$$

\therefore the mass of 2 moles of Fe is 112g

Exercise

1. How many moles are in 12g Mg?

2. Calculate the number of moles in 20g N

3. What is the mass of 2.5 moles of carbon, C?

(RAMs: Mg = 24, N = 14, C = 12)

Empirical Formula

Empirical formula is the formula that shows the simplest ratio in which atoms combine in a compound. The empirical formulae of compounds are determined experimentally.

Example

An experiment shows that 2.4g magnesium combines with 1.6g oxygen to form magnesium oxide. What is the empirical formula of magnesium oxide.

	magnesium	oxygen
mass	2.4g	1.6g
Moles	$2.4 \times (1 \text{ mole}) / 24 \text{ g} = 0.1 \text{ mol}$	$1.6 \times (1 \text{ mole}) / 16 \text{ g} = 0.1 \text{ mol}$
Divide each result above by the smallest result	$(0.1 \text{ mol}) / (0.1 \text{ mol}) = 1$	$(0.1 \text{ mol}) / (0.1 \text{ mol}) = 1$

\Rightarrow the atoms combine in the ratio 1:1 to form the compound.

\therefore the empirical formula of the magnesium oxide is Mg_1O_1 or simply MgO .

Exercise

1. An experiment shows that 32g of Sulphur combine with 32g of Oxygen to form the compound Sulphur dioxide. What is the empirical formula of the compound Sulphur dioxide? (RAMs; S = 32, O = 16)

2. A hydrocarbon has a percentage composition by mass of 85.7% of carbon and 14.3% of hydrogen. Calculate the empirical of the hydrocarbon. (RAM; C = 12, H = 1)

4. Molecular formula

Molecular formula is the formula that shows the actual numbers of atoms that combine the molecule.

Molecular formula differs from the empirical formula in that the empirical formula shows only the simplest ratio of the atoms in the molecule while the molecular formula shows the actual numbers of the atoms. It is worked out as follows;

1. Work out the empirical formula.
2. Calculate the empirical formula mass.
3. Identify the actual (molecular) mass.
4. Find the ratio: (actual formula mass)/(empirical formula mass)
5. Multiply the subscripts in the empirical formula by the result you find in step (iv) above to find the molecular formula.

Example

An alkane has percentage composition is 84.2 % carbon and 15.8% hydrogen. Its formula mass is 114g. What is its molecular formula?

(RAM; C = 12, H = 1)

Working out

	Carbon	Hydrogen
Mass	84.2g	15.8g
Moles	$84.2\text{g} \times (1 \text{ mole}/12\text{g}) = 7.02\text{moles}$	$15.8\text{g} \times (1 \text{ mole}/1\text{g}) = 15.8\text{moles}$
<i>Divide each result above by the lowest result;</i>	$(7.02 \text{ moles})/(7.02) = 1$	$(15.8 \text{ moles})/(7.02) = 2.25$
<i>Multiply each result by 4 to make 2.25 a whole number</i>	$1 \times 4 = 4$	$2.25 \times 4 = 9$

This implies that 4 carbon atoms combine with 9 hydrogen atoms. Therefore the empirical formula is C_4H_9
Empirical formula mass = $(12\text{g} \times 4) + (1\text{g} \times 9)$

$$= 57\text{g}$$

$$\text{Actual formula mass} = 114\text{g}$$

$$\text{Actual formula mass} = 114\text{g} = 2$$

$$\text{Empirical formula mass} = 57\text{g}$$

$$\begin{aligned}\text{The molecular formula} &= \text{C}_{4 \times 2}\text{H}_{9 \times 2} \\ &= \text{C}_8\text{H}_{18}.\end{aligned}$$

Exercise

1.2g of magnesium combines with 3.55 g of chlorine. If the formula mass is 94g, work out the molecular formula of the compound.

(RAM; Mg = 24, Cl = 35.5).

Concentration

Concentration of a solution means the amount of solute dissolved in a given volume of solution.

$$\text{Concentration} = (\text{amount of solute})/\text{volume}$$

Ways of expressing concentration

(i) moles per unit volume

e.g concentration = (number of moles)/ volume of solution

When the concentration is expressed as moles volume its units can be mol/cm^3 , mol/litre or mol/dm^3 .

Molarity

The concentration expressed as number of moles per cubic decimetre, mol/dm^3 or mole/litre is referred to as molarity. The unit of molarity is molar, and is abbreviated M. For example, if a solution contains 3 moles of solute per cubic decimetre of solution, its molarity is 3 mol/dm^3 or 3 M.

Calculating number of moles given concentration of a solution

Number of moles (n) = concentration x volume.

Example

How many moles of NaOH are there in 0.5 dm^3 of NaOH of concentration 2M?

Working out

$n = \text{concentration} \times \text{volume}$.

$$= \frac{2 \text{ mol}}{\text{dm}^3} \times 0.5 \text{ dm}^3$$

$$= 1 \text{ mole.}$$

NB; $1 \text{ dm}^3 = 1 \text{ litre}$
 $= 1000 \text{ cm}^3$
 $= 1000 \text{ ml}$

Examples

(1). What is the molarity of H_2SO_4 in a solution made by dissolving 49g of H_2SO_4 in 250 ml of solution?
 (RAM; H=1, S=32, O=16)

Working out

Molarity (m) = $\frac{\text{number of moles (n)}}{\text{volume (v) in } \text{dm}^3}$

number of moles = $\frac{\text{mass} \times 1 \text{ mole}}{\text{molar mass}}$

mass of H_2SO_4 given = 49g

molar mass of $\text{H}_2\text{SO}_4 = (1 \times 2) + (32 \times 1) + (16 \times 4)$
 $= 98 \text{ gmole}$

so, number of moles = $49 \text{ g} \times \frac{1 \text{ mole}}{98 \text{ g}}$

volume in $\text{dm}^3 = 250 \text{ ml} \times \frac{\text{dm}^3}{1000 \text{ ml}}$

$$\begin{aligned} \text{Therefore, molarity of } \text{H}_2\text{SO}_4 &= 49 \text{ g} \times \frac{1 \text{ mole}}{98 \text{ g}} \div \frac{250 \text{ ml} \times \text{dm}^3}{1000 \text{ ml}} \\ &= 49 \text{ g} \times \frac{1 \text{ mole}}{98 \text{ g}} \times \frac{1}{250 \text{ ml}} \times \frac{1000 \text{ ml}}{\text{dm}^3} \quad \backslash \\ &= 2 \text{ mol/dm}^3 \text{ (or 2M)} \end{aligned}$$

Exercise

1. What is the concentration of a solution containing 4 moles of NaOH in 2 dm^3 of solution?
2. What is the concentration of sodium carbonate solution containing 53g of the salt (Na_2CO_3) per dm^3 ?
 (RAM; Na = 23, C = 12, O = 16, H = 1)

(ii) Mass concentration

Mass concentration means mass (g) of solute present in a given volume of solution in cubic decimetres (dm^3).

Mass concentration = $\frac{\text{mass (g) of solute}}{\text{Volume (dm}^3\text{)}}$

For example, the concentration of NaOH made by dissolving 40g of NaOH in 2 dm^3 of water = $40 \text{ g}/2 \text{ dm}^3$
 $= 20 \text{ g/dm}^3$

Exercise

1. What is the mass concentration of a solution containing 4 moles of NaCl in 2dm^3 of solution?

Standard Solutions

A standard solution is a solution whose concentration is known. Standard solutions are used for volumetric analysis (i.e. in titrations to standardize other solutions). Standard solutions can be prepared in the following ways;

- Dissolution of solid solutes
- Dilution of stock solutions

(a) Dissolution of solutes (i.e. dissolving Solutes)

This is a process whereby a solid solute of a measured mass is dissolved into a solution of known volume. To prepare a standard solution by solute dissolution we need to know the concentration and the volume of the solution to be prepared. The following steps are then followed;

- Calculate the required mass of the solute as follows:
 - if the concentration is given as mole concentration (or molarity), convert it to mass concentration by multiplying it with molar mass / mole.
 - convert the mass concentration to mass;
 - mass = mass concentration \times volume (of solution to be prepared)
- Weigh out the calculated mass of the solute using a beam balance.
- Dissolve the solute completely in a beaker.
- Transfer quantitatively into a volumetric flask of the required volume of the solution to be prepared. Quantitatively means nothing must be left in the beaker. The beaker must be rinsed thoroughly.
- Fill the flask with more distilled water up to the mark, put the stopper and shake to mix thoroughly.

Example

Describe how you can prepare 250ml of 2M Potassium carbonate (K_2CO_3) solution.
(RAM; K = 39, C = 12, O = 16)

Working out

- Calculate the required mass of K_2CO_3 as follows;
 - mole concentration = $2\text{moles} / \text{dm}^3$.
 - mass concentration = $(2\text{mol}/\text{dm}^3) \times 138\text{g}/1\text{mol} = 276\text{g}/\text{dm}^3$
 - mass of the K_2CO_3 required = $276\text{g}/\text{dm}^3 \times 0.25\text{dm}^3 = 69\text{g}$
- Weigh out 69g of K_2CO_3 and place it into a 250ml volumetric flask.
- Add just enough distilled water into the beaker to dissolve the pellets.
- Transfer the solution into the volumetric flask quantitatively.
- Rinse the beaker with distilled water three times adding into the volumetric flask.
- Add distilled water up to the 250ml mark
- Mix thoroughly.

Exercise

Describe how you can prepare 200ml of 0.2M Na Cl solution.

(b) Dilution of stock solutions

Some standard solutions are kept so that other standard solutions can be prepared from them by dilution. These standard solutions are highly concentrated and are known as *stock solutions*. Dilution means making less concentrated a highly concentrated solution. In order to make a standard solution from a more concentrated solution, we need the following information; the volume of the solution to be prepared, the concentration of the diluted standard solution to be prepared and the concentration of the stock solution. The following dilution formula is used when preparing standard solutions from stock solutions.

$$c_1 v_1 = c_2 v_2$$

Where c_1 = concentration of the stock solution

v_1 = volume to be transferred from the stock solution (ml or dm^3)

c_2 = concentration of the dilute solution to be prepared
 v_2 = volume of the dilute solution to be prepared (ml or dm^3)

Steps to be followed;

- 1) calculate the volume, v_1 to be transferred from the stock solution.
$$v_1 = (c_2 v_2) / c_1$$
- 2) measure the calculated volume of the stock solution using a measuring cylinder.
- 3) transfer it into an appropriate volumetric flask.
- 4) rinse the measuring cylinder with some distilled water and transfer the water into the volumetric flask.
- 5) add more distilled water to the volumetric flask up to the mark, put the stopper and shake.

Example

Describe how you can prepare 250 cm^3 of 0.2 M hydrochloric acid from 2M hydrochloric acid solution.

Working out

- (i) Calculate the volume (v_1) of the 2M hydrochloric solution to be taken as follows:

$$c_1 v_1 = c_2 v_2$$

$$c_1 = 2\text{M}, \quad v_1 = ?$$

$$c_2 = 0.2\text{M}, \quad v_2 = 250\text{cm}^3$$

$$2\text{M} \times v_1 = 0.2\text{M} \times 250\text{ml}$$

$$\therefore v_1 = (0.2\text{M} \times 250\text{cm}^3) / 2\text{M}$$
$$= 25\text{cm}^3$$

- (ii) Pour out 25cm^3 of the 2M hydrochloric acid and transfer it into a 250cm^3 volumetric flask.
(iii) Add distilled water up to the 250cm^3 mark and shake to mix.

Exercise

Describe how you can prepare 500ml of 0.555M HCl from 11.3M HCl.

Finding Concentration of a Substance in Solution

The process of finding the concentration of a solution is referred to as standardization. One way of standardizing solutions is by titration.

Titration

Titration is a process of adding a solution of one reactant drop by drop from a burette or syringe to a solution of another reactant in a conical flask or beaker until reaction is just complete.

The concentration of a solution of the unknown concentration can be worked out using the following steps;

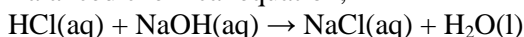
- a) Find the volume of the standard solution (in dm^3).
- b) Find number of moles (n) of the standard solution using the given concentration and the volume.
Use the formula $n = c v$.
- c) Find the reaction ratios from the balanced chemical equation for the reaction.
- d) Find number of moles of the standard solution using the reaction ratios.
- e) Find the concentration of the standard solution using the number of moles and the given volume.

Example

25.0 cm^3 of 0.1M of sodium hydroxide (NaOH) solution required 23.5cm^3 of dilute hydrochloric acid(HCl) for neutralisation. Calculate the concentration of the HCl.

Working out

Balanced chemical equation;



The experiment used 25.0 of 0.1M NaOH solution,

$$n = cv$$

$$c(\text{NaOH}) = 0.1\text{M or } 0.1 \text{ mol/dm}^3$$

$$v(\text{NaOH}) = 25.0 \text{ cm}^3 \text{ or } 0.025\text{dm}^3$$

Therefore number of moles of NaOH, $n(\text{NaOH}) = 0.1 \text{ mol/dm}^3 \times 0.025 \text{ dm}^3$

Reaction ratios = 1:1

$n(\text{NaOH}) / n(\text{HCl}) = 1/1$

$n(\text{HCl}) = 0.1 \text{ mol/dm}^3 \times 0.025 \text{ dm}^3$

$v(\text{HCl}) = 23.5 \text{ cm}^3 = 0.0235 \text{ dm}^3$

Hence $c(\text{HCl}) = (0.1 \text{ mol/dm}^3 \times 0.025 \text{ dm}^3) / 0.0235 \text{ dm}^3$
 $= 0.106 \text{ mol/dm}^3$ or 0.106 M

Facts about practical titration

- During titration there are two different solutions; a titrant and the analyte.
- Titrant is a standard solution whereas the analyte is the solution whose concentration is to be known.
- During titration a titrant is added slowly from the burette in small volumes to the analyte until the amount of the solutions have just reacted to completion. The concentration of the analyte can be worked out by measuring the volume of the titrant that is needed to react with the analyte.

Titration procedure

- 1) Arrange the apparatus as shown figure 3.3 below;
- 2) Put a measured volume of the analyte into a conical flask.
- 3) Adding a few drops of indicator into the flask (the function of the indicator is to indicate the point when the reaction is complete).
- 4) Pour the titrant into the burette.
- 5) Drip the titrant from the burette into the conical flask slowly, while swirling the flask continuously.
- 6) Stop when there is a colour change of the indicator. This is the end point.
- 7) Record the new level of the solution in the burette.
- 8) Find the volume of the solution used. (Volume used = final volume – initial volume),
- 9) Calculate the concentration of the solution whose concentration is not known.

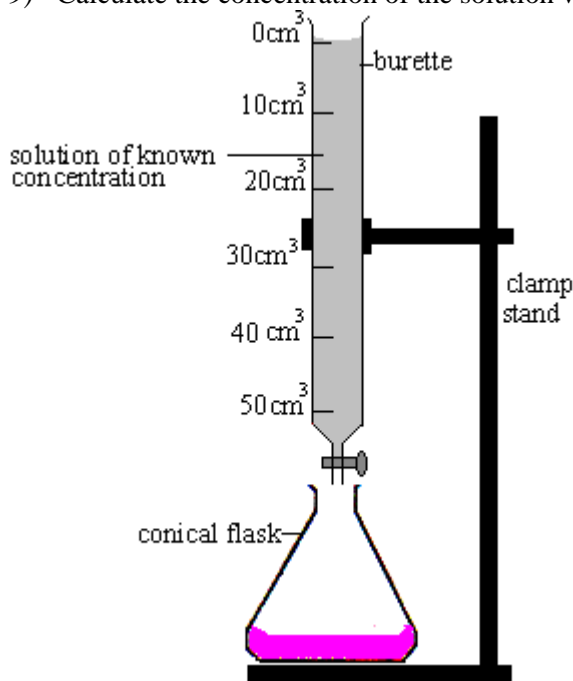


Figure 3.3

NB: A syringe can also be used instead of the burette. In this case the volume used = initial volume – final volume.

Possible sources of errors when carrying out titrations

- Inaccurate readings of the volumes of the solution.
- overshooting. This means adding more than enough solution from the burette.

Example

Describe how you can determine the concentration of sodium hydroxide (NaOH) using a 0.2M hydrochloric acid (HCl).

Working out

- 1) Pour the acid into a burette and note the level.
- 2) Pipette 25cm^3 of the sodium hydroxide solution into a conical flask.
- 3) Add a few drops of indicator into the conical flask (the colourless solution changes to pink, if the indicator used is phenolphthalein).
- 4) Drip the acid drop by drop slowly into conical flask, swirling continuously.
- 5) Stop adding the solution when there is colour change on the indicator.
- 6) Calculate the volume of the acid used; volume of acid used = final volume – initial volume
- 7) Calculate the concentration of the NaOH used as follows;
 - i. calculate the number of moles of HCl used;
number of moles = molarity \times volume (dm^3)
 - ii. Write down the balanced chemical equation for the reaction between HCl and NaOH ie. $\text{NaOH} + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O}$.
 - iii. From the balanced chemical equation, write down the ratio of number of moles;
number of moles of NaOH : number of moles of HCl = 1:1
 - iv. Use the ratio of the number of moles and the number of moles of HCl used to find the number of moles of NaOH used.
 - v. Concentration of NaOH = (moles of NaOH)/(volume(dm^3) of NaOH used).

Exercise

Describe how the concentration of 20cm^3 of sodium solution can be determined by evaporation method.

Molar gas volume

Molar volume is the volume of one mole of a gas. The volume of any type of gas depends on its pressure and temperature. At room temperature and pressure (rtp) one mole of a gas occupies a volume of 24 dm^3 (or 24 l). Room temperature and pressure is 20°C and 1 atm respectively.

At standard temperature and pressure, stp, one mole of a gas occupies a volume of 22.4 dm^3 . Standard temperature and pressure is 0°C and 1 atm respectively.

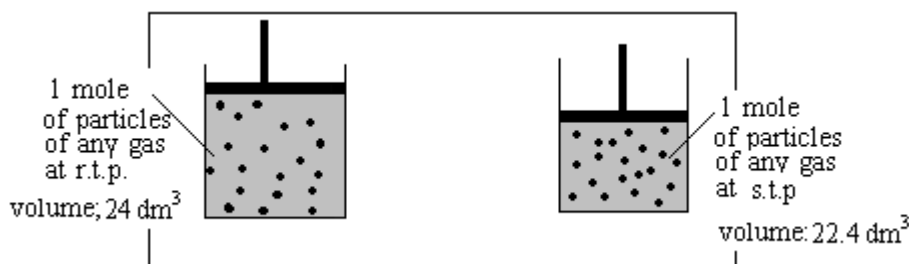


Figure 3.4

Example

How many moles of CO_2 gas are there in 60 litres of CO_2 gas at rtp?

working out

Let the number of moles be x .

At rtp; 24 dm^3 of a gas = 1 mol

60 dm^3 of a gas = $x\text{ mol}$

Cross multiplying; $24\text{ dm}^3 \times x\text{ mol} = 60\text{ dm}^3 \times 1\text{ mol}$

Making x the subject; $x = (60\text{ dm}^3 \times 1\text{ mol}) / 24\text{ dm}^3\text{ mol}$

$$x = 2.5\text{ moles}$$

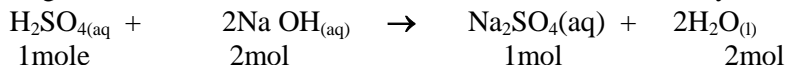
\therefore there are 2.5 moles of CO_2 in 60 dm^3 of CO_2 gas.

Exercise

1. A reaction produces 100 cm^3 of hydrogen gas at rtp. How many moles of H_2 is this?
2. What volume does 48g of an oxygen gas, O_2 occupy at (a) rtp (b) stp?
3. What is the mass of 56 dm^3 of hydrogen gas at stp?

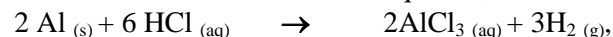
Molar Volume and Reacting Masses

In many chemical reactions, gases are produced or used up. The numbers of moles or the masses of substances react in ratios related by balanced equations. When volumes of gases react or are produced during the chemical reactions, these volumes are also related by balanced equations;



Examples

1. Given the balanced chemical equation;



what mass of Al is needed to produce 50 dm^3 of H_2 at stp? (RAM: Al = 27)

Working out

Let the mass of Al needed be y

From the balanced equation given;

2mol Al produces 3 mol H_2 gas

Mass of 2mol Al;

Let the mass be $x\text{g}$

1mol Al = 27g

2mol Al = $x\text{g}$

Cross multiplying: $(1\text{mol Al}) \times (x\text{g}) = (2\text{mol Al}) \times (27\text{g})$

Making x the subject; $x = (2\text{mol Al} \times 27\text{g}) / (1\text{mol Al g})$
 $= 54$

\Rightarrow The mass of 2 mol Al = 54g

Volume of 3mol H_2 gas at stp;

Let the volume be v

1mol of gas at stp = 22.4 dm^3 .

3mol of gas at stp = $v \text{ dm}^3$

Cross multiplying; $1\text{mol of gas at stp} \times v \text{ dm}^3 = 3\text{mol of gas at stp} \times 22.4 \text{ dm}^3$

Making v the subject; $v = (3\text{mol of gas at stp} \times 22.4 \text{ dm}^3) / (1\text{mol dm}^3)$
 $v = 67.2$

\Rightarrow The volume of 3 mol H_2 gas at stp = 67.2 dm^3

$\therefore 54\text{g Al} = 67.2 \text{ dm}^3 \text{ H}_2 \text{ gas}$

$y\text{g} = 50 \text{ dm}^3 \text{ H}_2 \text{ gas}$

Cross multiplying;

$(y\text{g}) \times (67.2 \text{ dm}^3 \text{ H}_2 \text{ gas}) = (54\text{g Al}) \times (50 \text{ dm}^3 \text{ H}_2 \text{ gas})$

Making y the subject;

$y = (54\text{g Al}) \times (50 \text{ dm}^3 \text{ H}_2 \text{ gas}) / (67.2 \text{ dm}^3 \text{ H}_2 \text{ gas})\text{g}$

$y = 40.18$

Hence the mass of Al needed to produce 50 dm^3 of H_2 at stp is 40.18g

Exercise

Given the balanced chemical equation,

$4\text{NH}_{3(\text{g})} + 5\text{O}_{2(\text{g})} \rightarrow 4\text{NO}_{(\text{g})} + 6\text{H}_2\text{O}_{(\text{l})}$, what volume of NO gas measured at rtp will be produced from 19.5g of O_2 ? (RAM; N = 14, H = 1, O = 16)

Heats of Reactions

During reactions chemical bonds between the particles in the substances that are mixed together are broken and new bonds are formed when new substances are formed. For example, when aluminium metal and hydrochloric acid are mixed aluminium chloride and hydrogen gas are formed. The chemical equation for the reaction is $2\text{Al (s)} + 6\text{HCl (aq)} \rightarrow 2\text{AlCl}_3\text{ (aq)} + 3\text{H}_2\text{ (g)}$. For this reaction to take place the chemical bonds between the particles in the aluminium metal and in the hydrochloric acid must break. When these bonds are broken, new bonds between the particles in aluminium chloride (AlCl_3) and between the particles in hydrogen gas (H_2) are formed.

Energy, in the form of heat is used to break chemical bonds. This energy is taken from the surroundings, such the solution in which the reaction is taking place, containers like beakers or test tubes where the reaction is taking place and/or the surrounding air.

When the new chemical bonds are formed between the particles in the new substances, energy, in the form of heat is given out to the surroundings. Bond breaking and bond formation take place simultaneously. So when heat is taken in from the surroundings to break the bonds, heat is also given out to the surroundings immediately.

In most reactions the amount of heat energy taken in from the surroundings to break bonds is not the same as the amount of heat energy given out to the surroundings when new bonds are formed. The difference between the heat energy taken in to break the existing bonds and the heat energy given out when the new bonds are formed during chemical reactions is called heat of reaction. Heat of reaction is found by subtracting heat given out from the heat taken in. The symbol for the heat of reaction is ΔH , mathematically, $\Delta H = \text{heat energy taken in} - \text{heat energy given out}$.

Exothermic and endothermic reactions

There are two types of reactions depending on how the amount of the heat energy taken in to break the bonds compares with the amount of the heat energy given out when the new bonds are formed. The reaction in which the amount of the heat energy given out is greater than the amount of heat energy taken in is known as an exothermic reaction. This is because the overall result of the reaction is that heat energy is given out to the surroundings. The prefix 'exo-' means out, so the reaction gives out heat.

Since $\Delta H = \text{heat energy taken in} - \text{heat energy given out}$, the value of the heat of reaction for an exothermic reaction has a negative sign. Experimentally, an exothermic reaction is identified by a rise in the temperature of the solution and the container in which the reaction is taking place. This means that the solution and the container in which the reaction is taking place feels warmer or even hotter like in burning.

The reaction in which the amount of the heat energy given out is less than the amount of heat energy taken in is called an endothermic reaction. This is because the overall result of the reaction is that heat energy is taken in from the surroundings. The prefix endo- means in, so the reaction removes heat from the solution and the container in which the reaction is taking place. The value of the heat of reaction for an endothermic reaction has a positive sign. An endothermic reaction is identified by a decrease in the temperature of the solution and the container in which the reaction is taking place. The container feels colder.

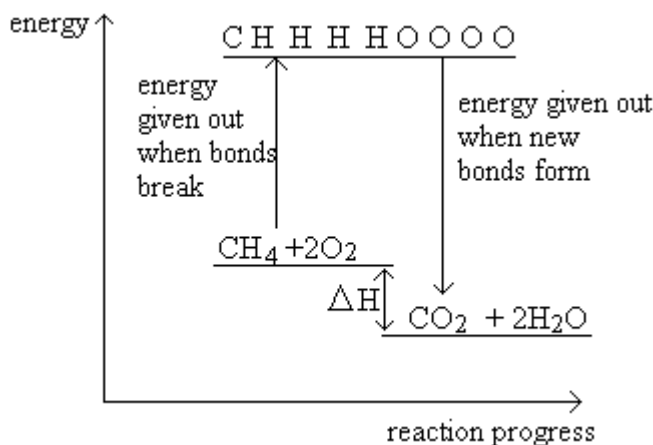
Energy Diagrams

When the bonds are broken during chemical reaction, the particles are temporarily separated from each other. The separate particles are said to be in ionic or gas state. In the gas state, the particles possess the greatest amount of energy. The particles use some of the energy they form new bonds. The graphical depiction of the energy changes that take place during chemical reactions is called an energy diagram.

Consider the reaction represented by the following thermo chemical equation;

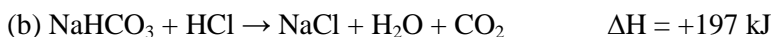
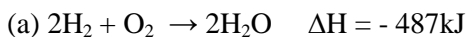


A thermo chemical equation is the one that includes the value of the heat of reaction, ΔH . The negative sign of the heat of reaction at the end of the equation is telling us that the reaction is exothermic, and so less amount of heat energy was taken in when breaking the bonds in the reactants and more heat energy was given out to the surroundings when new bonds were formed in the products. The energy diagram for the reaction is, therefore, as follows



Exercise

1. State whether the reactions represented by each of the following thermo chemical equations are exothermic or endothermic. Explain your answer in each case.



2. Draw an energy level diagram for each of the thermo chemical equations in questions 1 above.

Review questions

1.
 - a. How many particles are contained in one mole of particles? Give the answer in Scientific form.
 - b. The relative atomic mass of aluminium, Al is 27, how many moles of Al are contained in 54g of Al?
 - c. What is meant by molar mass?
2. The equation for the reaction between ethanol and oxygen is as follows;

$$\text{C}_2\text{H}_5\text{OH}(\text{l}) + \text{O}_2(\text{g}) \longrightarrow \text{CO}_2(\text{l}) + \text{H}_2\text{O}(\text{l}) \quad \Delta H = -1371\text{kJ/mol}$$
 - i. Balance the equation.
 - ii. What does $\Delta H = -1371\text{kJ/mol}$ mean?
 - iii. Is the reaction exothermic or endothermic? Give a reason.
 - iv. Draw an energy level diagram for the reaction.
 - v. What volume of CO_2 can be produced from 69g of $\text{C}_2\text{H}_5\text{OH}$ measured at rtp?
(RAM: C = 12, H = 1, O = 16)
3. Explain the following;
 - i. bond making is exothermic
 - ii. bond breaking is endothermic
 - iii. ΔH for exothermic reactions has a negative sign.
4. An organic acid has a percentage composition by mass of C = 40%, H = 6.6 % and O = 53.4%. Its relative molecular mass is 60. Calculate;
 - i. empirical formula of the organic acid.
 - ii. the molecular formula of the organic acid.
(RAMs ; C = 12, H = 1, O = 16)
5. Calculate the empirical formulae of the following ionic compounds from the data given below;
 - i. 1.2g of magnesium combines with 3.55 g of chlorine.
 - ii. 7.67g of sodium combines with 11. 83g of chlorine.

iii. Lead combines with oxygen in the percentage composition by mass of 92.8% lead and 7.2% oxygen.

(RAM; H = 1, O = 16, Mg = 24, Cl = 35.5 Na = 23, Pb = 207).

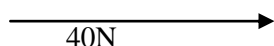
6. What is the mass of HCl present in 155ml of a 0.54M solution?
7. What is the concentration of potassium hydroxide solution used in the following neutralisation reaction? 20cm^3 of 0.2M solution of hydrochloric acid just neutralised 15cm^3 of potassium hydroxide solution.
8.
 - a. Calculate the mass of (a) 3moles and (b) 0.2moles of carbon dioxide gas, CO_2 .
(RAM; C = 12, O = 16)
 - b. Calculate the number of moles of magnesium oxide, MgO in (a) 80g (b) 10g of the compound.
(RAM; O = 16 Mg = 24)
9.
 - a. Calculate the number of moles of ammonia gas, NH_3 in a volume of 72dm^3 of the gas measured at (a) rtp (b) stp.
 - b. Calculate the volume of carbon dioxide gas, CO_2 occupied by
(i) 5moles (ii) 0.5 moles of the gas at (1) rtp (2) stp.

4. FORCES AND MOTION

Scalar and vector quantities

Scalars are quantities that are described by sizes (or magnitudes) only. Examples of scalar quantities are mass, speed, distance, volume etc. Scalars can be added or subtracted by ordinary arithmetic. Example; $2\text{kg} + 4\text{kg} = 6\text{kg}$.

Vectors are quantities that are described by both their magnitude and direction. Examples are forces, displacements, velocity, acceleration etc. Vectors are represented by a straight line, drawn to scale, with an arrow. The length of the line represents the magnitude of the vector while the arrow indicates the direction of the vector. For example a force of 40N eastwards can be represented by a line 4cm long (where the scale is $1\text{cm} : 1\text{N}$), with an arrow pointing to the east as shown below;



Differences between Vectors and Scalars

Scalar	Vector
Described by size only	Described by both size and direction
Added by ordinary arithmetic	Added geometrically

Table 4.1

Properties of Vectors

(i) Vectors can be shifted from one place to another provided their sizes and directions are maintained. This is because vectors which have the same sizes and directions are equal. For example, the following vectors are equal

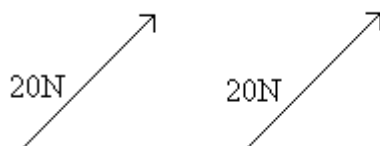


Figure 4.2

(ii) Each vector has its negative.

A negative of a vector is a vector which has the same size as the given vector but is opposite in direction. For example the following vectors are negative to each other.

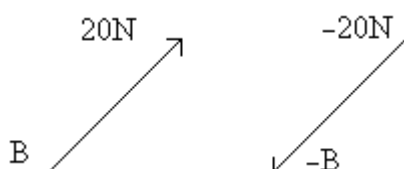


Figure 4.3

(iii) Every vector has multiple vectors to it.

A multiple of a vector is a vector which has the same direction as the given vector but may have a different magnitude. For example the vectors in **figure 4.4** are multiples of each other because vector $F = 2 \times E$.

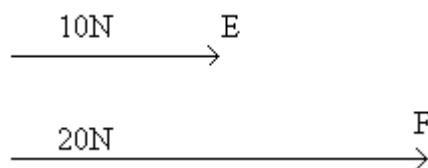
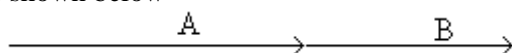


Figure 4.4

Vector Addition (combining vectors)

Two or more vectors can be added together to give a single vector. The combination of two or more vectors is called a resultant vector. To find the resultant of vectors, the vectors must always be drawn head-to-tail as shown below



(i) Adding vectors acting in the same direction along the same line of action

Two vectors acting in the same direction along the same line of action are already head-to-tail. Therefore, their resultant is found adding the magnitudes while maintaining their direction.

Example

A boy is cycling due east with a velocity of 21 km/h and wind also blows due east with a velocity of 25km/h. What is the resultant vector?

Working out

The resultant of the two velocities is found by drawing the two vectors to scale (e.g. 1cm: 1N) and adding them head-to-tail as follows;

$$\begin{array}{c} \xrightarrow{\hspace{2cm}} \\ 21\text{km/h due east} \end{array} + \begin{array}{c} \xrightarrow{\hspace{2cm}} \\ 25\text{km/h due east} \end{array} = \begin{array}{c} \xrightarrow{\hspace{4cm}} \\ 46\text{km/h due east} \end{array}$$

The resultant velocity is 46km/hr due east and has the same direction as the component velocities.

(ii) Adding vectors acting along the same line of action but in opposite directions

If two vectors are acting along the same line of action but in opposite directions their resultant is found by reversing one of them so that they are head-to-tail.

Example

A girl is pushing a box with a force 20N due east. Another girl is pushing the same box in the opposite direction with a force of 15N. Find the magnitude and direction of resultant force.

Working out

The two vectors can be represented as follows

$$\begin{array}{c} \xrightarrow{\hspace{2cm}} \\ 20\text{N} \end{array} + \begin{array}{c} \xleftarrow{\hspace{2cm}} \\ -15\text{N} \end{array}$$

Figure 4.7

The resultant of the two velocities is found by drawing the two vectors to scale and adding them head-to-tail (by reversing one of the vectors) as shown in figure 4.5.

$$\begin{array}{c} \xrightarrow{\hspace{2cm}} \\ 20\text{N} \end{array} + \begin{array}{c} \xleftarrow{\hspace{2cm}} \\ -15\text{N} \end{array} = \begin{array}{c} \xrightarrow{\hspace{1cm}} \\ 5\text{N} \end{array}$$

Figure 4.8

The resultant vector is then found by adding the magnitudes of the two vectors ($20\text{N} + (-15\text{N}) = 5\text{N}$). The sign of the resultant gives its direction. It is the same as the direction the vector with the larger magnitude.

(ii) Adding two vectors acting at an angle to each other

Two vectors acting at angle to each other, as shown below, can be added using rules such as the triangle rule or the parallelogram rule.

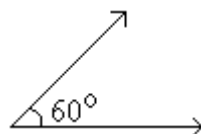


Figure 4.8

1. The triangle rule

The triangle rule for adding vectors says that if two vectors acting at angle to each other are drawn 'head-to-tail' with each other with their magnitudes represented by lengths of straight lines drawn to scale, then the vector that closes the triangle is the resultant of the two vectors. Consider the vectors in figure 4.9 below

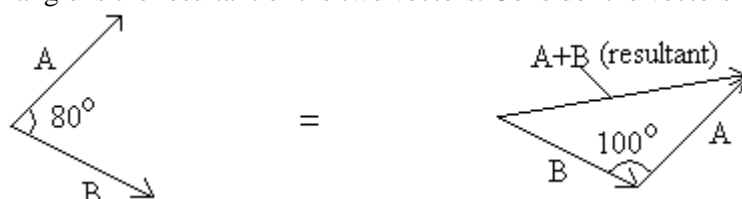


Figure 4.9

The resultant vector is always tail-to-tail with the vector that was not shifted and head - to - head with the vector that was shifted.

2. The parallelogram rule

The parallelogram rule say that if two vectors acting at a point are represented, both in magnitude and direction, by the adjacent sides of a parallelogram, then the diagonal of the parallelogram passing through the point of intersection of the vectors is equal to the resultant of the two vectors both in magnitude and direction. Consider the vectors in figure 4.50:

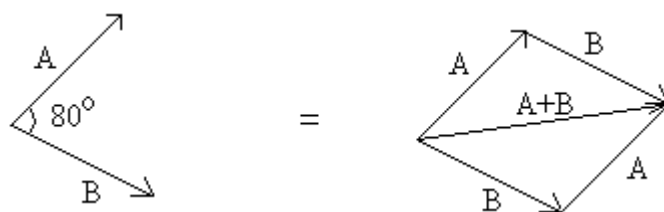


Figure 4.10

Vector subtraction

To subtract a vector means to add a negative of a vector. For example, $A - B = A + (-B)$

a. The Triangle Rule for Vector Subtraction

To subtract a vector using the triangle rule, the vector to be subtracted is reversed so that the two vectors are head - to - tail. The resultant is the vector that closes the triangle. It is tail to tail with the vector that was reversed.

Example

Given two vectors, $A = 10\text{N}$ and $B = 15\text{N}$, acting at an angle of 80° to each other, find the resultant $A - B$.

Working out

To find the resultant vector,

- 1) draw vectors using an appropriate scale e.g 1cm: 5N at an angle of 80° to each other.
- 2) then reverse vector B to get vector $-B$.
- 3) close the triangle
- 4) measure the length of the line that closes the triangle. The length of this line represents the magnitude of the vector $A - B$. Vector $A - B$ is head-to-head with vector A.
- 5) use the scale to find the magnitude of resultant vector $A - B$.

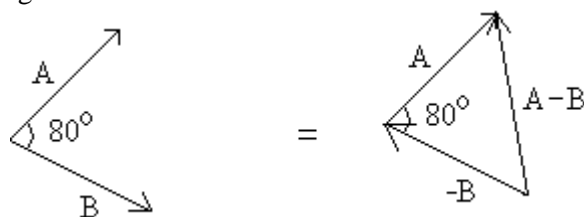


Figure 4.51

b. The Parallelogram rule for the vector subtraction

When subtracting vectors using the parallelogram rule, the vectors are represented by the adjacent sides of parallelogram with the vector to be subtracted reversed in direction.

The diagonal of the parallelogram that passes from the 'tails' to the 'heads' of the vectors is the resultant of the vectors.

Example:

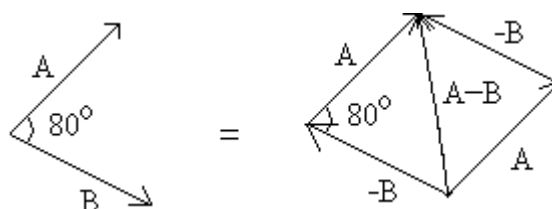


Figure 4.51

Exercise

1. Two girls are dragging a crate eastward along a level ground by pulling a rope held horizontally with forces 160N and 170N respectively. If the friction force opposing the motion is 20N, what is the resultant force on the crate?
2. The velocity of an aeroplane is 250km/hr and its course is due north. It is carried off course by wind blowing from the west at 80km/hr. Find its ground velocity.
3. A pilot in an Air Malawi aeroplane travelling north at 500km/hr sees a South African Airways aeroplane directly in front of him travelling south at 400km/hr. What is the velocity of the South African Airways aeroplane relative to the pilot in the Air Malawi aeroplane?
- 4 Two boys are pulling a bag of cement along a level ground by means of two ropes held horizontally, at an angle of 20° from each other. If the boys are pulling with force 90N and 80N calculate the resultant force on the on the bag.

Components of vectors

A single vector, represented F, can be split into two vectors which are perpendicular to each other. The two vectors are called components of the vector. The component parallel to the vertical is known as *a vertical component*, V and the component parallel to the horizontal is called *a horizontal component*, H. For example, in the figure below, the single vector, F has two components, V and H.

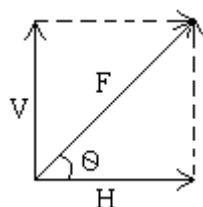


Figure 4.52

When the two components V and H are taken together, they have exactly the same effect as the single vector, F. The process of splitting a vector into its components is called **vector resolution**.

How to work out magnitudes of the components

The magnitudes of the components of a vector can be calculated using either trigonometry or scale drawing

Using the trigonometric ratios

The trigonometry ratios used are the sine ratio and the cosine ratio. The sine ratio is used to calculate the vertical component as follows; $V/F = \sin \theta$, implying that $V = F \sin \theta$. The horizontal component is calculated using the cosine ratio; $H = F \cos \theta$.

Examples

1. Work out the magnitudes of the components of vector below;

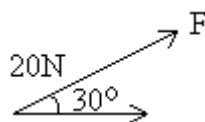


Figure 4.53

Working out

$$V = F \sin \theta$$

Where, $F = 20\text{N}$, and $\theta = 30^\circ$

$$\begin{aligned}\therefore V &= 20\text{N} \times \sin 30^\circ \\ &= 10\text{N}\end{aligned}$$

$$H = F \cos \theta$$

$$\begin{aligned}\therefore H &= 20\text{N} \times \cos 30^\circ \\ &= 17.32\text{N}\end{aligned}$$

2. A person pushes a wheelbarrow along a road with the handle at an angle of 30° to the horizontal, exerting a push of 120N . Calculate the force with which the wheelbarrow is being pushed along the road.

Working out

The force along the road is the horizontal component force, $F \times \cos \theta$.

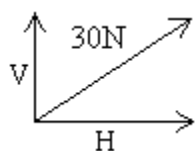
$$\begin{aligned}F \times \cos 30^\circ &= 120\text{ N} \times 0.886 \\ &= 104\text{ N}\end{aligned}$$

b. Scale drawing

The magnitudes of the components of a vector can be found by measuring the lengths of the components and multiplying the lengths with the scale. The scale can be worked out using the length and the magnitude of the vector given. For example, if the magnitude of the vector is 40N and after measuring we find that its length is 4cm , then a scale of $1\text{cm} : 10\text{N}$ can be used.

Example

Find the magnitude of the vertical component of the vector given in the figure below;



Working out

Choose a scale; let it be 1cm: 10N.

Let's assume that after measuring we find that the length of V is 1.5cm

Then we multiply the length by the scale; $1.5\text{cm} \times 10\text{N/cm} = 15\text{N}$

Therefore, the magnitude of the vertical component is 15N.

Exercise

1. Find the magnitudes of the components in the following figure.

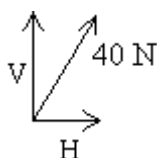


Figure 4.55

2. A box is being pulled along the floor by means of a rope making an angle of 30° with the horizontal. If the pull on the rope is 80N, calculate;

(i) the effective part of the force pulling the box.

(ii) the force tending to lift the box off the ground.

3. A person is walking along a street in a direction 30° north of east. If the person walks 250m, what is the easterly component of the person's displacement?

Distance and displacement

Consider figure 4.56 below. Suppose a person wants to travel from point A to point D by road. Because of the lake between point A and D the road passes through B and C before reaching D. The total length of the road the person has to travel from A to D will be 43 km ($10\text{km} + 8\text{km} + 25\text{km}$). However, upon reaching point D, she will be 24km north of A.

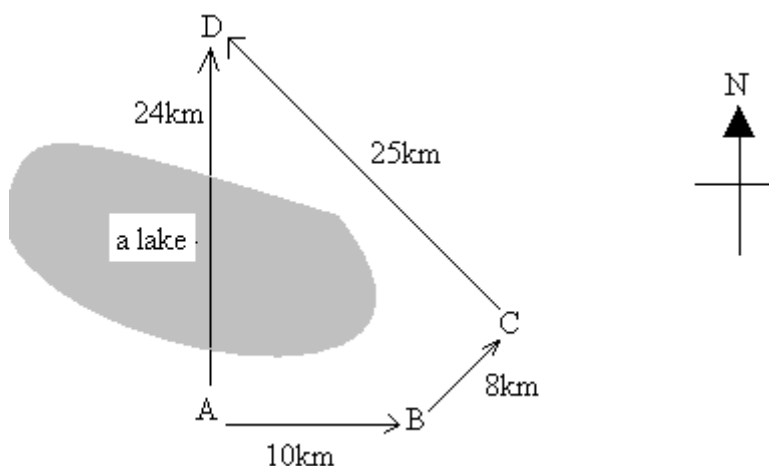



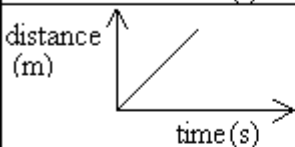
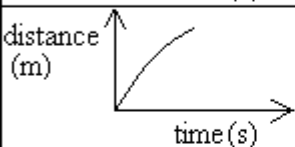
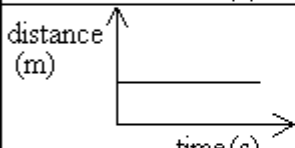
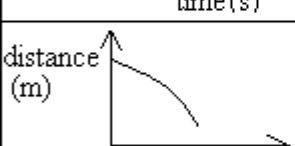
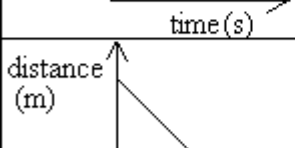
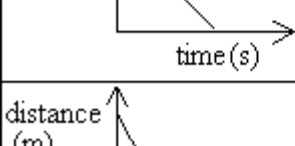
Figure 4.55

The total length of a specified path followed by an object in motion is called distance. Distance is a scalar quantity; for example, we can say that the distance between Limbe and Zomba is 50 km.

Displacement describes how far and in which direction one point is from another. Displacement is distance in a specified direction. The letter s is used to represent displacement. Since displacement is described by distance and direction, it is a vector quantity. Displacement can therefore, be positive or negative. As a vector, displacement can be represented by a straight line with an arrow. For example, 5km due north may be represented as $\xrightarrow{+5\text{km}}$ and 5km due south may be represented as $\xleftarrow{-5\text{km}}$.

Distance – time Graphs

A distance-time graph describes how the distance covered by an object in motion changes as time goes. It is important to know how to interpret the distance-time graphs. The table below gives meanings of some shapes of these graphs.

shape of graph	interpretation	meaning
	change in distance per given time is increasing	the object is moving forward with increasing speed
	change in distance per given time is constant	the object is going forward with constant speed
	change in distance per given time is decreasing (brake are applied)	the object is moving forward with decreasing speed
	change in distance per given time is zero	the object is not moving (it is stationary)
	change in distance is increasing per given time	the object is coming back with increasing speed
	change in distance per given time is constant	the object is coming back at a constant speed
	change in distance per given time is decreasing (brake are applied)	the object is coming back with decreasing speed

Example

Figure 4.55 below shows a distance – time graph representing the motion of a cyclist. Describe the motion of the cyclist represented by each section of the graph.

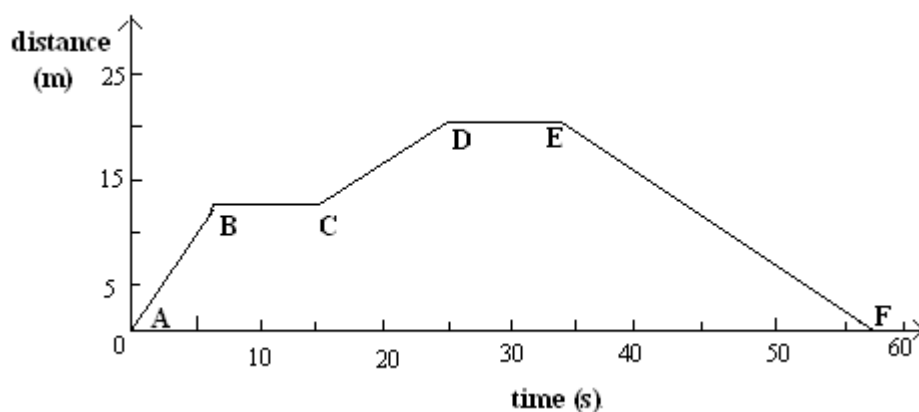


Figure 4.55

Working out

On section AB: Change in distance covered per given time is constant. Therefore, the cyclist is moving with constant speed..

On section BC: Change in distance covered per given time is zero. Therefore, the cyclist is moving with zero speed. In other words, the cyclist is not moving.

On section CD: Change in distance covered per given time is constant. Therefore, the cyclist is moving with constant speed. However the cyclist is moving with less speed than on

On section DE: The cyclist is stationary.

On section EF: Change in distance covered per given time is constant. Therefore, the cyclist is moving with constant speed.. However, she is returning.

The gradient (or slope) of the Distance – Time Graph

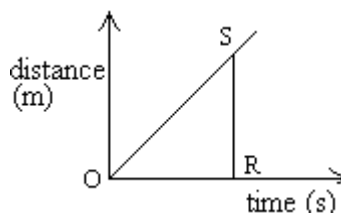


Figure 4.56

$$\begin{aligned} \text{Gradient} &= \frac{\text{Vertical side}}{\text{Horizontal side}} \\ &= RS / RO \end{aligned}$$

RS represents the change in the distance travelled and RO represents the time taken.

$$\begin{aligned} \therefore \text{Gradient} &= (\text{change in the distance}) / \text{time} \\ &= \text{speed} \end{aligned}$$

Therefore the gradient of the distance – time graph gives the speed of the object.

Speed, velocity and acceleration

Speed means the total distance covered per given time. Mathematically, speed = (distance)/ time. For example, if a car travels a distance of 90m in 10s, then its speed is $90\text{m} / 10\text{s} = 9\text{m/s}$. Speed is a scalar quantity.

Average speed = (total distance)/ total time.

Velocity, v

Velocity is speed in a specified direction.

Therefore, velocity = (displacement)/time

\Rightarrow displacement = velocity \times time

Since distance in a specified direction is displacement, which is a vector quantity, therefore, velocity is also a vector quantity. For example; 10m/s to the right may be represented as $\xrightarrow{+10\text{m/s}}$ and 10m/s to the left may be represented as $\xleftarrow{-10\text{m/s}}$.

Acceleration, a

Acceleration is the change in velocity of an object per given time. Therefore, acceleration = (change in velocity) / time.

For an object undergoing uniform acceleration;

average velocity = $(u + v) / 2$ and

Acceleration = [(Final velocity, v) – (initial velocity, u)] / (time). That is

$a = (v - u) / t$ and

Example

The velocity of a car changes from 2m/s to 14m/s in 4 seconds. What is the acceleration of the car.

Working out

$a = (v - u) / t$, $u = 2\text{m/s}$, $v = 14\text{m/s}$ and $t = 4$

$\therefore a = [(14 - 2) \text{ m/s} / 4\text{s}]$

$a = (12/4) \text{ m/s}^2$

$a = 3 \text{ m/s}^2$

Speed – time Graphs

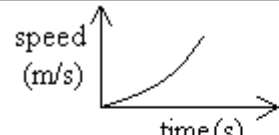
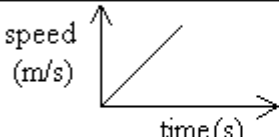
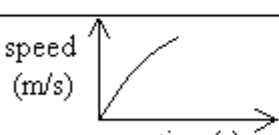
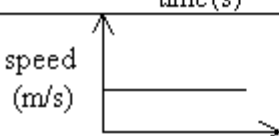
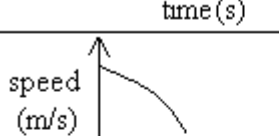
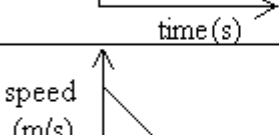
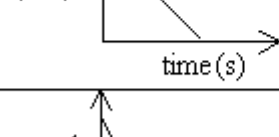
shape of graph	interpretation	meaning
	increase in speed per given time is increasing	the object is moving with increasing acceleration
	increase in speed per given time is constant	the object is moving with constant acceleration
	increase in speed per given time is decreasing	the object is moving with decreasing acceleration
	change in speed per given time is zero	the object is moving with zero acceleration
	decrease in speed is increasing per given time	the object is moving with increasing deceleration
	decrease in speed per given time is constant	the object is moving with constant deceleration
	decrease in speed per given time is decreasing	the object is moving with decreasing deceleration

Table 4.3

Example

Describe the motion of a motorist which is represented each section of the graph in figure 4.57 below.

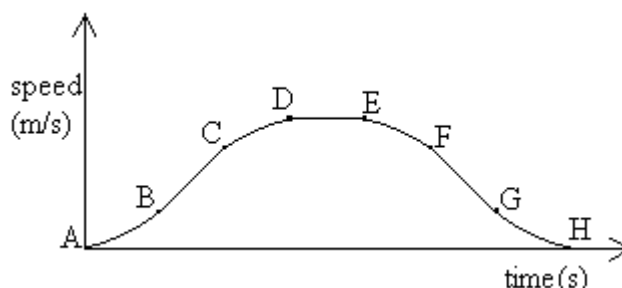


Figure 4.57

On AB: Change in speed per given time is increasing. Therefore the motorist is moving increasing speed. She is moving with increasing acceleration.

On BC: Change in speed per given time is constant. Therefore, the cyclist is moving with constant acceleration.

On CD: Change in speed per given time is decreasing. The motorist is moving decreasing acceleration.

On DE: Change in speed per given time is zero. The cyclist is moving with zero acceleration. Therefore, she is moving with constant speed.

On EF: Decrease in speed per given time is increasing. The motorist is moving with increasing deceleration.

On FG: The decrease in speed per given time is constant. The motorist is moving with constant deceleration.

On GH: The decrease in speed per given time is decreasing. The motorist is, therefore, moving with decreasing deceleration.

The Gradient of the Speed – Time Graph

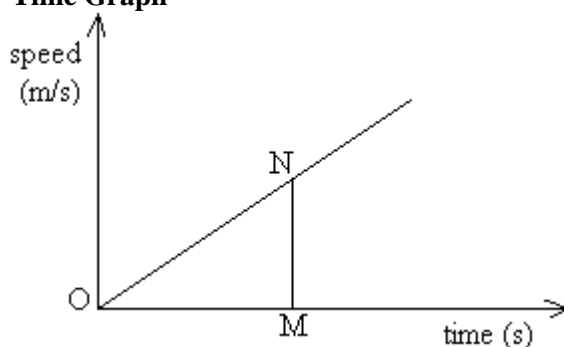


Figure 4.58

The gradient of the graph line = $(MN)/OM$

The gradient of the speed – time = $[\text{change in speed (m/s)}] / [\text{time taken (s)}]$
= acceleration

Therefore, the gradient of the speed – time graph = acceleration (m/s^2).

Area under the Speed – Time Graph

(a) The area under the speed – time graph of an object travelling with constant speed.

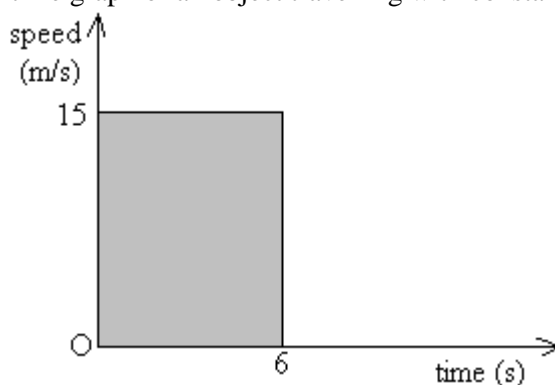


Figure 4.59

The area under the shaded rectangle = $15\text{m/s} \times 6\text{s}$
= 90m
= distance travelled.

(b) The area under the speed – time graph of an object travelling with increasing speed.

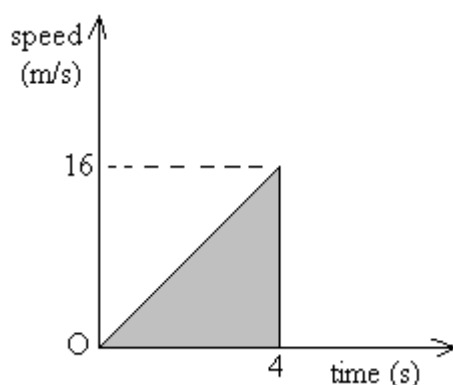


Figure 4.60

The area under the shaded triangle = $\frac{1}{2} \times 4s \times 16 \text{ m/s} = 32\text{m}$
= the distance travelled

Therefore, the area under the speed – time graph = the distance travelled by the object.

Exercise

1. The speed – time graph represents the journey of a motorist travelling along a straight line.

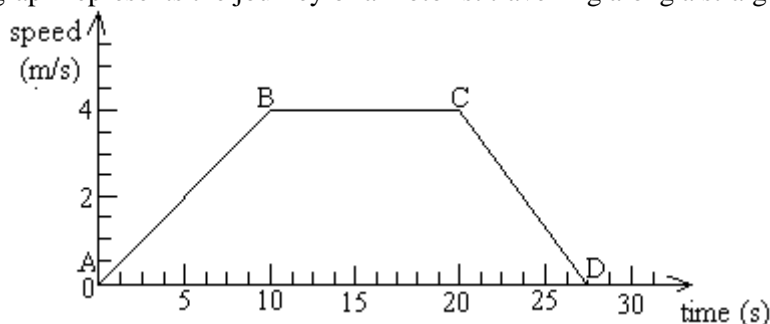


Figure 4.61

- What is the motorist's maximum speed?
- What is the acceleration during first 10 second?
- What is the deceleration during the last 7.5 seconds of the journey?
- What is the distance travelled during the first 20 seconds?
- What is the total distance travelled?
- What is the motorist doing between B and C?
- What is the time taken for the whole journey?
- What is the average speed for the whole journey?

2. Figure 4.61 (a) shows the distance – time graph for a car, and (b) shows the speed – time graph for another car.

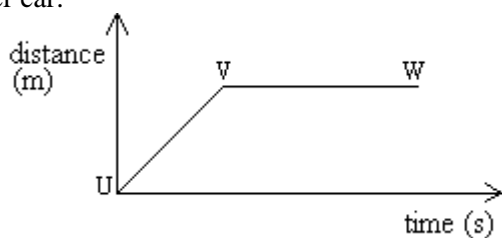


Figure 4.61(a)

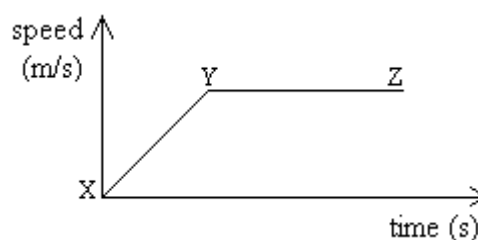


Figure 4.61(b)

Describe the motions of the cars in the parts;

- a. UV
- b. VW
- c. XY
- d. YZ

Types of Accelerations

Since acceleration is a vector quantity, we can have a positive acceleration, negative acceleration or indeed zero acceleration. The velocity-time graph below represents the different types of accelerations.

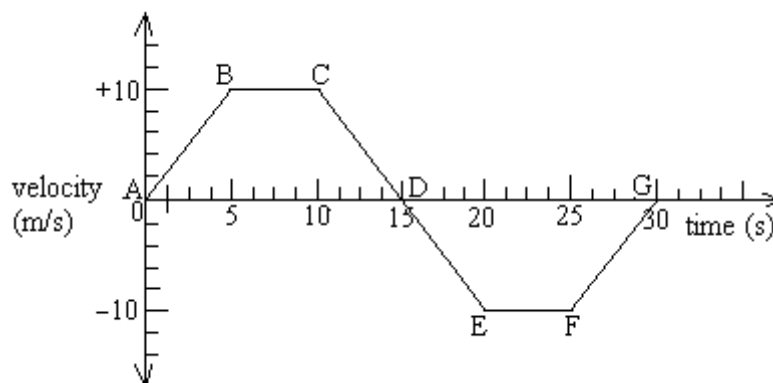


Figure 4.62

The area under the parallelogram ABCD represents the distance travelled by the object in the forward direction while the parallelogram DEFG represents the distance travelled in the reverse direction. The graph line A to G illustrates the following types of accelerations; positive accelerations, zero accelerations and negative accelerations.

Positive acceleration

Acceleration, $a = (v - u)/t$. Between points A and B, $u = 0\text{ m/s}$ and $v = 10\text{ m/s}$. Therefore, between A and B

$$a = [(10 - 0) \text{ m/s}] / 5 \text{ s}$$

$$a = +2\text{ m/s}^2$$

Also between points F and G, $u = -10\text{ m/s}$ and $v = 0 \text{ m/s}$

So, between F and G the acceleration = $\frac{0\text{ m/s} - (-10\text{ m/s})}{5\text{ s}}$

$$= +2 \text{ m/s}^2.$$

Hence positive acceleration means the following;

- (a) Increase in the velocity of an object moving in the forward direction, or
- (b) Decrease in the velocity of an object moving in the reverse (i. e negative) direction.

Zero Acceleration

Consider the portions of the graph between points B and C, and between E and F. Between B and C, $u = 10\text{ m/s}$ and $v = 10\text{ m/s}$ and between E and F, $u = -10\text{ m/s}$ and $v = -10 \text{ m/s}$.

So between B and C, $a = \frac{10\text{ m/s} - 10\text{ m/s}}{5\text{ s}}$

$$= 0\text{ m/s}^2$$

And between F and G, $a = \frac{[-10\text{ m/s} - (-10\text{ m/s})]}{5\text{ s}}$

$$= 0\text{ m/s}^2$$

Therefore, zero acceleration means constant velocity. This 'constant velocity' can be either in the forward direction or in the reverse direction.

Negative acceleration

Consider the parts of the graph between points C and D, and between D and E;

Between C and D, $u = 10\text{ m/s}$ and $v = 0 \text{ m/s}$.

Therefore $a = \frac{0 \text{ m/s} - 10\text{ m/s}}{5\text{ s}}$

$$= -2 \text{ m/s}^2$$

$$= -2\text{m/s}^2$$

And also between D and E, $u = 0 \text{ m/s}$ and $v = -10 \text{ m/s}$

$$\begin{aligned}\text{Therefore, } a &= \frac{-10 \text{ m/s} - 0 \text{ m/s}}{5\text{s}} \\ &= -2\text{m/s}^2\end{aligned}$$

Hence negative acceleration means;

(a) Decrease in the velocity of an object moving in the forward direction.

Decrease in the velocity of an object moving in the forward direction is also known as deceleration.

(b) Increase in velocity of an object moving in the reverse direction.

Equations of motion

Since, for an object undergoing uniform acceleration;

$$\text{Average velocity} = (u + v)/2 \quad \dots\dots\dots (1)$$

$$\text{and acceleration} = (v - u) / t \quad \dots\dots\dots (2)$$

also displacement, $s = \text{average velocity} \times \text{time}$, then

$$s = [(u + v)/2] \times t \quad \dots\dots\dots (3)$$

$$\Rightarrow u + v = (2s)/t \quad \dots\dots\dots (4)$$

From equation (2), $a = (v - u) / t$

$$\Rightarrow v - u = at \quad \dots\dots\dots (5)$$

$$u + at = v$$

$$v = u + at \quad \dots\dots\dots (6)$$

From equation(4), $u + v = (2s)/t$ and from equation (5), $v - u = at$. Multiplying these equations together gives

$$(u + v) \times (v - u) = (2s)/t \times at$$

$$v^2 - u^2 = 2as$$

$$v^2 = u^2 + 2as \quad \dots\dots\dots (7)$$

Substituting equation (6), $v = u + at$ in equation (4), $u + v = (2s)/t$, we get

$$2u + at = 2s/t$$

$$\Rightarrow [(2u + at) \times t] / 2 = s$$

$$\text{That is; } s = [(2u + at) \times t] / 2$$

$$\Rightarrow s = (2ut + at^2)/2$$

$$s = ut + \frac{1}{2} at^2 \quad \dots\dots\dots (8)$$

Problems on objects moving with constant acceleration in a straight line can be solved using the following four equations of motion which should be remembered;

1. $v = u + at$
2. $s = ut + \frac{1}{2} at^2$
3. $s = \frac{1}{2} (u + v) \times t$
4. $v^2 = u^2 + 2as$

Where u = initial velocity, v = final velocity, a = acceleration, s = displacement and t = time taken. To use any of these equations we need to know any 3 of v , u , a , s and t and then we can find the fourth variable by substitution into an appropriate equation.

Note that for an object travelling with constant velocity, $v = u$ and $a = 0$, these equations reduce to $s = ut$.

Examples

Newton's Laws of Motion

In 1600 AD sir Isaac Newton, an English scientist having studied forces and motions of objects formulated three laws of motion popularly commonly known as 'The Newton's laws of motion'.

The laws are stated as follows;

The Newton's first law of motion

Activity: 4.1

Aim: To investigate if objects resist changes to their state of motion.

Materials:

- a piece of cardboard paper
- a coin
- a bottle

Procedure:

(i) Arrange the apparatus as shown in figure 4.63 below.

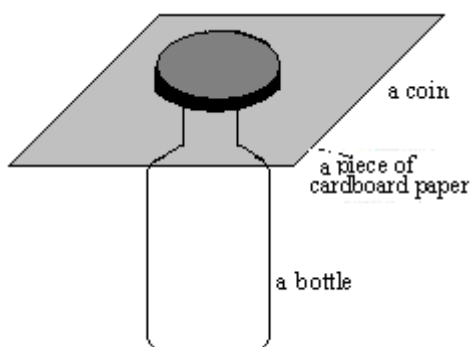


Figure 4.63

(ii) Give the paper a sharp push with your finger.

Discussion

What happened to the coin when the cardboard paper was flicked away?
Explain your observations.

Activity: 4.3

Aim: To find out if objects in motion require a force to stop them.

Materials:

- a plastic bag filled with sand
- a plastic bag filled with cotton wool
- 2 clamps
- 2 clamp stands
- 2 strings, each 30 cm long

Procedure

(i) Arrange the apparatus as shown below

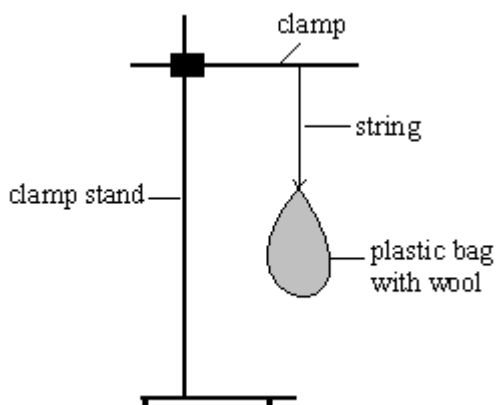


Figure 4.64

- (ii) set the bag in motion by slightly pulling it to one side and releasing it.
- (iii) Try to stop it with your hand.
- (iv) Repeat steps (i) to (iii) with a plastic bag filled with cotton wool instead of sand.

Discussion

Which bag is easier to stop?
Explain the results.

Observations

In activity 4.1, when the paper is given a sharp push, the coin continues to stay as it is when the paper moves away. In activity 4.2, the bag filled with sand is more difficult to stop than the bag filled with cotton wool. The results of these two activities show us that objects which are stationary are reluctant to start moving. They require a force (unbalanced force) to start them moving. Similarly, objects which are moving are reluctant to stop moving. An unbalanced force is required to stop them.

The reluctance of an object to change what it is doing is called inertia. The bigger the mass the greater the inertia, therefore, more force is required to change their state of motion. Sir Isaac Newton summarised these observations in his Newton's first law of motion which states that;

If there is no unbalanced force on an object then;

- if it is at rest, it will always stay at rest and
- if it is moving, it will continue moving with constant velocity.

Newton's second law of motion

Activity; 4.4

Aim: To find out which objects, with smaller masses or with greater masses, accelerate more when pushed by the same size of force.

Materials:

- 2 empty fanta bottle
- sand
- stoppers
- a long straight stick or metal rod.

Procedure

- (i) Fill one bottle with sand
- (ii) Close both of them with the stoppers
- (iii) Arrange the apparatus as shown in figure 4.65 below.

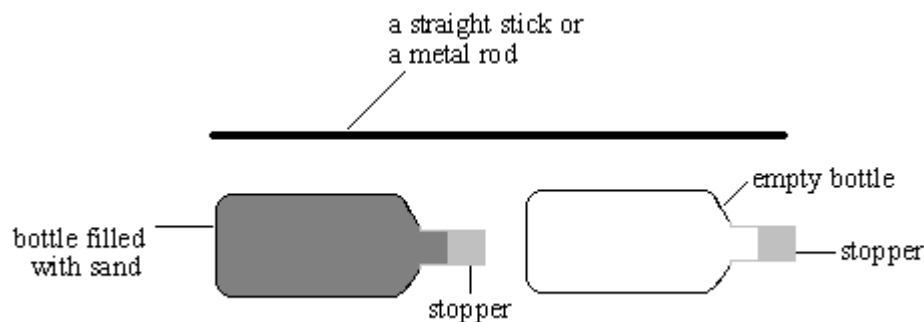


Figure 4.65

(iv) Give both bottles a sharp push with the stick at the same time.

Discussion

Which bottle, the one with sand or the empty one, moved faster than the other? Explain your observation.

Observation

The empty bottle moved faster than the bottle with sand. To make the bottle with the more mass move as fast as the bottle with less mass, a greater force should be applied to it.

This shows that the acceleration (**a**) of an object is directly proportional to the force (**f**) applied to the object and indirectly to the mass (**m**) of the object. Isaac Newton stated this in his Newton's 'second law of motion which states that; $\mathbf{a = f/m}$, rearranging, we have $\mathbf{f = ma}$.

This implies that objects with more mass require more force to accelerate than the objects with smaller masses. When the mass is in kg, the acceleration in m/s^2 , the unit of force is kg.m/s^2 .

Example

A force is applied to an object with mass 1kg and it accelerates by 1m/s^2 . How much force is applied to it?

Working out

$$f = ma$$

$$\therefore f = 1\text{kg} \times \text{m/s}^2 \\ = 1\text{kg.m/s}^2.$$

The unit kg.m/s^2 is given the name newton, N, in honour of Sir Isaac Newton.

Therefore, $1\text{kg.m/s}^2 = 1\text{N}$.

A newton is, therefore, a force that causes an object of mass 1kg to accelerate by 1m/s^2 .

From the definition of acceleration,

$$\mathbf{a = \frac{v - u}{t}}$$
 and the Newton's second law of motion, $f = ma$, we have;

$$F = m \frac{(v - u)}{t}; \quad \text{or}$$

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

where u = initial velocity and v = final velocity of an object.

$$F = \frac{mv - mu}{t},$$
 is the second version of the Newton's second law of motion.

This version is used when given the mass, final velocity, initial velocity and the time.

The first version of the Newton's second law of motion, $F = ma$, is used when given mass and acceleration of the object.

Examples

1.A lorry of mass 15 000kg is travelling at 20 m/s. the driver puts on the brakes and the lorry tops in 10s. What is the average braking force acting on the brakes?

Working out

$$F = m \frac{(v - u)}{t}; \Rightarrow F = \frac{15\,000 (0 - 20)}{10}$$

$$F = - 300\,000$$

$$10$$

$$F = - 30\,000\text{N}$$

∴ the braking force on the lorry is

$$-30,000\text{N}$$

The negative sign means the force is acting in the opposite direction to the motion of the car.

2. A force is applied to an object of mass 1kg and it accelerates from rest to 10m/s². How much force is applied if the force is exerts on the object for;

(a) 1/100 second.

(b) 1/10 second

Working out

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

$$\rightarrow Ft = m(v - u)$$

(i) $t = 1/100\text{s}$, $m = 1\text{kg}$, $v = 10\text{m/s}$, $u = 0\text{m/s}$

$$F \times 1/100 \text{ s} = 1\text{kg} (10 - 0)\text{m/s}$$

$$F = 10\text{kgm/s} \times 100/1\text{s}$$

$$F = 1000\text{kgm/s}^2.$$

$$\text{or } F = 1000\text{N}.$$

(ii) $t = 1/10\text{s}$, $m = 1\text{kg}$, $v = 10\text{m/s}$, $u = 0\text{m/s}$

$$F \times 1/10 \text{ s} = 1\text{kg} (10 - 0)\text{m/s}$$

$$F = 10\text{kgm/s} \times 10/1\text{s}$$

$$F = 100\text{kgm/s}^2.$$

$$\text{or } F = 100\text{N}.$$

Example 2 shows us that the force is reduced when the time the force is exerted is longer.

Applications of the Newton's second law of motion

1. Seat belts stretch slowly. This reduces the force that stops you when the car stops suddenly.
2. The front and the back of cars are collapsible (have crumple zones). This reduces the force used to stop the car during a crash so that the passengers are not injured with large forces.
3. Crush helmets are filled with soft foam to protect the head during collision.
4. When jumping from walls you should bend your knees before hitting the ground in order to make the time the ground applies a force to stop you longer.

Newton's third law of motion

Activity 4.5

Aim: To investigate what happens when one object exerts a force on another object

Materials:

- 2 spring balances that can measure up to 10N.
- clamp stand
- G- clamp

Procedure

- (i) Clamp the clamp stand to the bench using the G- clamp as shown in figure 4.66.
- (ii) Pull spring balance **b** until it reads 2N.
- (iii) Record the reading of spring balance **b** in a table like the one in figure 4.4.

(iv) Repeat steps (i) to (iii) with readings of spring a; 4N, 6N, 7N and 8N

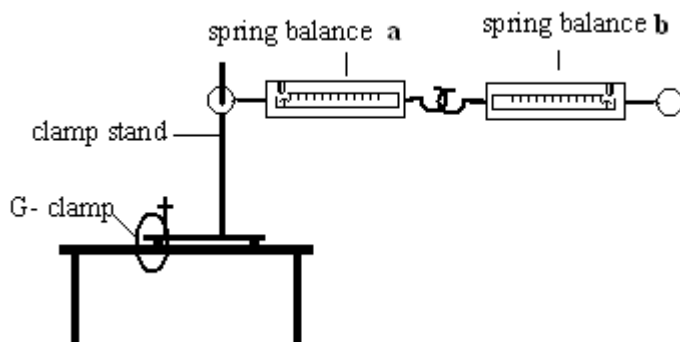


Figure 4.66

Table of results

Reading of spring balance a (N)	Reading of spring balance b (N)
2	
4	
6	
7	
8	

Table 4.4

Discussion

How do the readings of the spring balances compare?

Explain the results

Observation

The values of the readings of the spring balances in each pair are the same. This shows us that when you pull the clamp stand with, the clamp stand pulls you at the same time. The force exerted by the clamp stand on you is equal in magnitude, but opposite in direction to the force you exert on it. In fact, forces always act in pairs. The two forces are always equal in magnitudes, but opposite in directions. These two forces act on two different objects, so they cannot cancel each other out.

Sir Isaac Newton called these forces action force and reaction force, and stated his *Newton's third law of motion as follows*;

- The action force and reaction force are always equal in magnitudes, but opposite in directions, or
- to every action there is equal but opposite reaction, or
- if body A exerts a force on body B, body B will exert an equal but opposite force on body A

The Newton's third law of motion implies that when you hit an object, the object hits back at you with a force equal to the one you exerted on it. For example, when you hit a ball with your toes, you feel some pain on the toes. When you hit it with a larger force, you also feel a greater pain. This is because when you hit the ball with a certain force, the ball hits back at toes with the same amount of force. Also when a car hits a tree with a greater force, the tree hits back at the car with a greater force and it crushes severely.

Free Fall through Resistive Media

Resistive medium is the medium through which the motion of a falling object is opposed by resistive forces. The examples of resistive media are fluids such as liquids and air. The resistive forces on the falling object through a resistive medium are fluid friction, **F_r** and up thrust, **U**

(i)Falling In Liquids

When an object is falling through a liquid, three forces act on it;

- i. the weight, **W** of the ball, which acts downwards,

- ii. the upthrust, U of the displaced liquid onto the object
- iii. fluid friction force, F_r , as shown below;

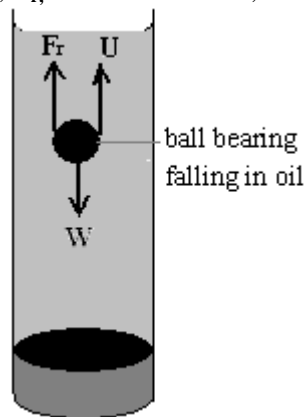


Figure 4.67

The **weight** and the **up thrust** do not change during the fall through the liquid. However, the fluid friction force (F_r) changes when the speed is changing.

As the speed increases, the fluid friction force increases as well. A point is, then, reached when the fluid friction force becomes large enough so that the down ward force is equal to the upward forces, $W = F_r + U$. At this point the speed of the ball has reached its maximum value and the acceleration is zero. It begins to fall with maximum constant velocity. The maximum constant velocity of an object falling through a resistive medium is known as terminal velocity.

The value of the terminal velocity depends on;

- i. Weight. A heavier object will have a higher terminal velocity than a lighter one of the same shape and size.
- ii. Area at right angles to the direction of fall. The larger the area, the lower the terminal velocity.
- iii. Shape. Roughly shaped objects have lower terminal velocity than stream lined ones.

(ii) Falling in air

In the figure 4.68 below, the ball bearing and feather are falling through the air in a long tube. The two forces acting on both the ball bearing and the feather are;

- (i) Weight, W
- (ii) Air friction force, F_r , or air resistance.

The up thrust, in air is negligible because it is very smaller than the weight of the objects. At first an unbalanced resultant force acts on both of them and they both accelerate.

The motion of the ball;

The weight of the ball is much greater than the air friction force, F_r and so the acceleration is very large. The ball continues accelerating until it reaches the bottom because of the unbalanced resultant force, ($W - F_r$). It does not reach its terminal velocity.

Although the air friction force, F_r increases a little as the speed of the ball increases, it is always very small as compared to the weight of the ball.

The motion of the feather

The weight of the feather is much less that of the ball. The air friction force, F_r , is much larger on the feather because of its shape and large surface area.

So the weight, W , and the friction force, F_r , are much closer to each other in value. The unbalanced resultant force, ($W - F_r$) acts on the feather at the top of the jar and by the Newton's first law of motion, this force causes the feather to accelerate. The increased speed of the feather causes the air friction force, F_r , to increase until $W = F_r$.

When the weight and the air friction force are balanced, the resultant force is now equal to zero. The feather then falls with a constant terminal velocity.

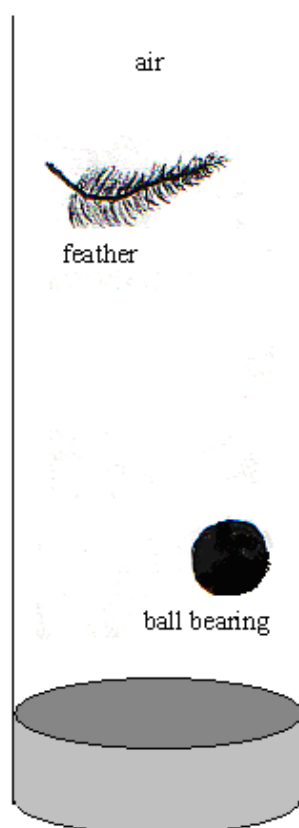


Figure 4.68

Therefore, the ball reaches the bottom first because the average speed of the feather is much less than that of the ball bearing.

(iii) Free Fall through Vacuum

This means the fall of objects under conditions of no air resistance (i.e. $F_r + U = 0$). The only force that acts on an object falling in vacuum is the weight of the object. Weight is the size of the gravitational force on an object of a given mass. The size of the gravitational force on all objects near the earth's surface is approximately $10\text{ N} / \text{kg}$.

But 10 N means $10\text{ kg}\cdot\text{m}/\text{s}^2$.

$$\therefore 10\text{ N} / \text{kg} = \frac{10\text{ kg}\cdot\text{m}/\text{s}^2}{\text{kg}} = 10\text{ m}/\text{s}^2.$$

$10\text{ m}/\text{s}^2$ is, therefore, the acceleration of all objects falling freely under conditions of no air resistance.

This means that all objects, heavy or light, falling freely in vacuum do so with an acceleration of $10\text{ m}/\text{s}^2$.

The acceleration of objects falling under conditions of no air resistance is known ***the acceleration due to gravity***, and it's represented by the symbol ***g***.

Consider the figure 4.69 below which shows a feather and a lead (metal) ball bearing falling in vacuum.

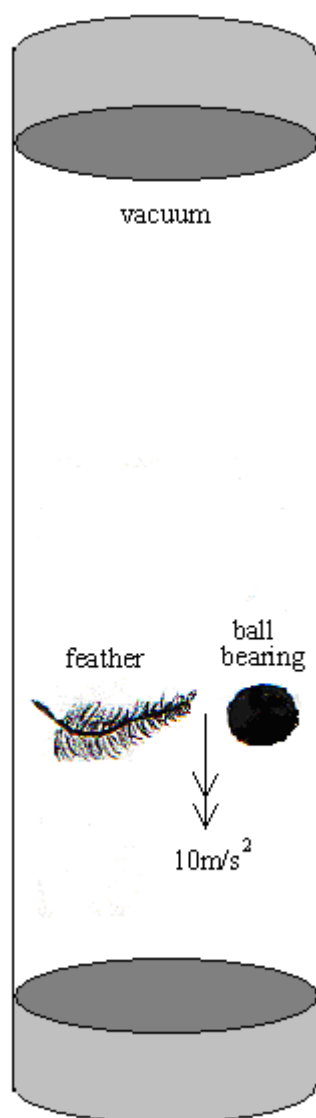


Figure 4.69

Both the feather and the ball bearing are falling with the same downward acceleration of 10 m/s^2 . So both the feather and the ball bearing will reach the bottom at the same time because they are moving with the same acceleration.

Summary

Quantities that are described by magnitudes only are called scalar quantities.

Vectors quantities are the quantities that described by both magnitudes and directions. When adding vectors, both magnitudes and directions are considered.

Each single vector can be split into two vectors that are perpendicular to each other. These two vectors are called components of the vector. The process of splitting a vector into its components is called vector resolution.

Distance is the total length of a path taken by an object in motion.

The gradient of a distance –time graph gives the speed of the object. Speed is distance travelled divided by the time taken.

Velocity is speed in a particular direction. Velocity is a vector quantity.

The change in the velocity of an object is called acceleration.

The gradient of a velocity – time graph gives the acceleration of the object. There are three types of accelerations;

- positive acceleration
- zero acceleration
- negative acceleration

The area under the velocity – time graph gives the distance travelled by the object.

The Newton's first law of motion states that if forces acting on an object are balanced, then;

- if it is at rest, it will always stay at rest
- if it is moving, it will keep on moving with constant velocity.

The Newton's second law of motion states that force = mass x acceleration.

The Newton's third law of motion states that to every action there is equal but opposite reaction.

Objects falling in a resistive medium reach a terminal velocity, which is the maximum velocity for the object.

The size of the terminal velocity depends on the factors; mass, shape of the object, area at right angles to the direction of fall of the object.

In vacuum there are no resistive forces; hence all objects fall with the same acceleration of 10m/s^2 .

Review questions

1. Which of the following quantities are scalar quantities?

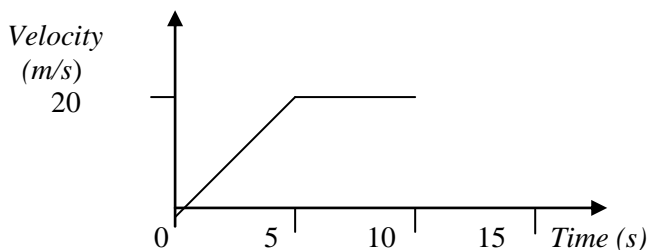
(a) 4m north (b) 4m (c) 80kg (d) 2km/ h due east (e) 4N down ward.

2. Find by drawing or calculation the resultant of two forces each 5 N acting at a point at an angle of 60° with each other.

3. A girl pushes on a handle of a lawnmower with a force of 100N. If the handle of the lawnmower makes an angle of 30° with the horizontal,

(a) Find the vertical and the horizontal components of the force.

- (c) If the loan mower weighs 300N, what is the total down ward force on the ground when the loan mower is being pushed?
- (d) If the loan mower is pulled rather than pushed using the same force of 100N on the handle, what is then is the total down ward force on the ground?
4. (a) A car has an acceleration of 2m/s^2 . What does this tell you about the velocity of the car?
- (b) Explain what is meant by an acceleration of -2m/s^2 ?
5. In the figure below, is a velocity – time graph for a car travelling along a straight road.



- (a) What is the acceleration of the car during the first 5 seconds?
- (b) How far does the car travel after 5 seconds?
- (c) How far does the car travel after 10 seconds?
- (d) What is the average speed of the car during the first 10 seconds?
6. An object travelling at 10m/s accelerates at 4m/s^2 for 8 seconds.
- (a) What is the final velocity of the object?
- (b) How far does it travel during the 8 seconds?
7. (a) A car of mass 1000kg is travelling at the velocity of 15m/s . It collides head – on with a wall. Calculate the force of impact if it stops in (a) 0.5 sec (b) 0.01 sec .
- (b) Which time interval is preferable from the point of passenger's safety? Why?
8. a. What resultant force produces an acceleration of 5m/s^2 in a car of mass 1000kg ?
- (b) What acceleration is produced in a mass 2kg by a resultant of 30N ?
9. A block of mass 500g is pulled from the rest on a horizontal friction less bench by a steady force, F and travels 8m in 2 sec . Find;
- (a) the acceleration of the object.
- (b) the value of F .
10. A ball X of mass 2kg travelling at 2m/s has a head on collision with a an identical ball Y at rest. X stops and Y moves off. What is Y's velocity?
11. A metal ball is released from the surface of glycerine in tall glass tube. Explain the change in velocity of the ball as it falls through the glycerine to the bottom of tube.

5. ORGANIC CHEMISTRY

Functional Group Chemistry

Organic Chemistry is the study of organic compounds. Organic compounds are the compounds that contain the element carbon in their molecule (except CO_2 and metal carbonates)

1. Homologous series

Organic chemistry collects carbon compounds with similar chemical properties into one family, which is known as a *homologous series*. Some of the homologous series are; Alkanes, Alkenes, Alkanols and Alkanoic acids/ carboxylic acids.

The families are also grouped into classes such as hydrocarbons and oxycarbons.

(i) Hydrocarbons

This is a class of organic compounds that contain carbon and hydrogen atoms only in their molecules. The members of this class are the Alkanes e. g methane, CH_4 and the Alkenes e. g. ethene, C_2H_4 .

(ii) Oxycarbonyls

These are organic compounds that contain carbon, hydrogen and oxygen atoms in their molecules. Some members of the Oxycarbonyls are Alkanols (or alcohols), e. g ethanol $\text{C}_2\text{H}_5\text{OH}$, and Carboxylic acids e.g. ethanoic acid, $\text{C}_2\text{H}_3\text{COOH}$.

General Properties of the Homologous Series/Families;

a. Functional group;

A functional group is a single atom or a group of atoms joined together that decides the chemical properties of the members of the family. The only family that does not have a functional group is the Alkanes family. The functional groups of the other families are as follows;

Family	Functional group	Name of the group
Alkenes	$-\text{C}=\text{C}-$	Carbon-carbon double bond
Alkanols	$-\text{OH}$	Hydroxyl group
Carboxylic acids	$-\text{COOH}-$	Carboxyl group

Table5.1

b. General formula;

Each family has a general formula from which the formulae of different members of the family can be worked out. The general formulae of some of the families are as follows;

Family	General formula
Alkanes	$\text{C}_n\text{H}_{2n+2}$
Alkenes	C_nH_{2n}
Alkanols	$\text{C}_n\text{H}_{2n+1}\text{OH}$
Carboxylic acids	$\text{C}_n\text{H}_{2n+1}\text{COOH}$

Table5.2

c. Common nomenclature (i.e. naming system)

All the families have a common naming system for all the members in that family.

The first part (the prefix) of the names is the same for all the organic compounds and it depends on the number of the carbon atoms in the compound. The suffix (i.e. the end part) depends on the family as follows;

Number of carbon atoms	Prefix	Suffix for Alkanes	Suffix for Alkenes	Suffix for Alkanols	Suffix for Carboxylic acids
1	Meth-	-ane	-ene	-anol	-anoic acid
2	Eth-	-ane	-ene	-anol	-anoic acid
3	Prop-	-ane	-ene	-anol	-anoic acid
4	But-	-ane	-ene	-anol	-anoic acid
5	Pent-	-ane	-ene	-anol	-anoic acid
6	Hex-	-ane	-ene	-anol	-anoic acid
7	Hept-	-ane	-ene	-anol	-anoic acid

8	Oct-	-ane	-ene	-anol	-anoic acid
9	Non-	-ane	-ene	-anol	-anoic acid
10	Dec-	-ane	-ene	-anol	-anoic acid

Table5.3

d. Increase in size of the molecules;

In passing long each family;

- the sizes and the masses of the molecules increase.
- the strengths of the intermolecular forces increase.

The increase in the strengths of the intermolecular forces causes the physical properties, such as melting points, the boiling points and the viscosity of the members in each family to increase in passing along the family.

e. Chemical properties;

The chemical properties do not change much on passing long each family. This is because the same functional group which is responsible for the chemical properties is present in every member of the family.

(i) The Alkanes

These are hydrocarbons. Alkanes do not have a functional group; they use the C-H and the C-C single bonds only. The alkanes are said to be saturated hydrocarbons because all their carbon – carbon bonds are completely used up and no other atom can be added to the molecule.

Examples of the Alkanes are paraffin, diesel, and petrol grease e.t.c.

General Formula;

The general formula of the Alkanes is C_nH_{2n+2}

For example when $n = 3$, the formula is $C_3H_{2 \times 3 + 2} = C_3H_8$.

Nomenclature / Naming system;

The prefixes for the Alkane names are the same for as for all the organic compounds.

The suffix for all the Alkane names is **-ane** (ref table 5.4)

Number of carbon atoms	Formula	Prefix	Suffix	Name
1	CH ₄	Meth-	-ane	Methane
2	C ₂ H ₆	Eth-	-ane	Ethane
3	C ₃ H ₈	Prop-	-ane	Propane
4	C ₄ H ₁₀	But-	-ane	Butane

Table5.4

Physical properties of Alkanes

i. **The melting and the boiling points of the Alkanes increase in passing along the family.** This is because the increase in sizes of the molecules in passing along family causes the intermolecular forces to increase and this raises the melting and the boiling points as more heat is needed to break the forces.

ii. **Alkanes are insoluble in water.**

“Like dissolves like”. The Alkanes do not dissolve in water because they are not ‘like’ water because (i) they do not have an – OH group which the water has,

(ii) they are nonpolar while the water is polar.

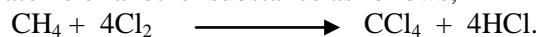
So when the Alkanes are mixed with water two layers are seen, one for the water and another for the Alkane.

4. Chemical Properties of Alkanes;

i. **They undergo combustion reaction (burning) with oxygen** to produce carbon dioxide and water vapour as follows; $2\text{C}_2\text{H}_6 + 7\text{O}_2 \longrightarrow 4\text{CO}_2 + 6\text{H}_2\text{O}$

ii. **They undergo substitution reaction with chlorine gas** to produce chloroalkane;

A substitution reaction is the reaction where by the atoms of one substance are replaced (substituted) by the atoms of another substance as follows;



The product chloroalkane has the same properties as the Alkanes **but it does not burn**.

Inertness of Alkanes;

The strong covalent bonds in the Alkanes plus the absence of the functional group makes the alkanes to be inert (i. e unreactive).

Because of their inertness, the alkanes are used to store reactive metals such as sodium, *Na*, potassium, *K* or lithium, *Li*.

The Alkenes

This is a family of the organic compounds that belongs to the hydrocarbons.

Examples of alkenes are; cooking oils.

a. Functional group

The functional group of the alkenes is the carbon-carbon double bond, $\text{C}=\text{C}$.

One of the bonds in the double bond is weaker than the other.

The weak bond in the alkenes makes in the $\text{C}=\text{C}$ functional group breaks easily during chemical reactions.

This makes the alkenes to be more reactive than the alkanes.

b. General formula

The general formula of the alkenes is C_nH_{2n} .

c. Nomenclature;

Names of the alkenes end in – ene. E.g. but- + -ene =Butene.

d. Physical properties

i. The melting and the boiling points of the alkenes increase with increase in molecular size.

ii. Alkenes do not dissolve in water.

e. Chemical Properties

i. **Alkenes undergo combustion reaction** with oxygen to produce carbon dioxide, CO_2 and water, H_2O ;



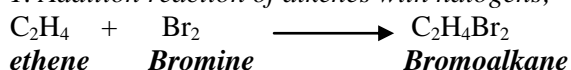
Alkenes burn with sootier flames than alkanes. This is because they have a higher carbon percentage in each molecule than the corresponding alkanes. ‘Soot is carbon’.

ii. **They undergo addition reactions;**

An addition reaction is a reaction where by the atoms of one substance are added to a molecule of another substance.

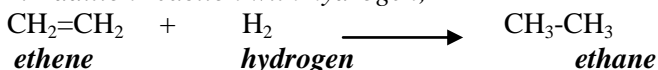
Alkenes are unsaturated hydrocarbons because not all their carbon atoms are bonded by single bonds to other carbon atoms. The carbon-carbon double bond, $\text{C}=\text{C}$, has not been completely used up so that more atoms can be added to the molecule as shown below;

1. **Addition reaction of alkenes with halogens;**



When the alkenes react with bromine, the bromine solution changes its colour from red- brown to colourless. This is because bromoalkane is colourless.

2. *Addition reaction with hydrogen;*



Testing for the Alkenes

The presence of the carbon-carbon double bond, $\text{C}=\text{C}$ -, can be detected by using a bromine test.

Activity: 5.1

Aim: To identify the test for alkenes

Materials

- an alkane (hexane or liquid paraffin)
- an alkene (cyclohexene or cooking oil)
- an alkanol (ethanol)
- a carboxylic acid (ethanoic acid)
- 4 test tubes
- bromine solution

Procedure

- To 15 drops of bromine solution add 2 to 4 drops the hexane.
- Record the observations in a table like the one in table 5.5
- Repeat steps (i) and (ii) with cyclohexene, ethanol and ethanoic acid respectively.

Test liquid	Observation
Hexane	
Cyclohexene	
Ethanol	
Ethanoic acid	

Table 5.5

Discussion

What is the colour of bromine solution?

Which of the solutions decolourised the bromine solution?

What can you conclude from this activity?

Observation

The colour of the bromine solution changes from red/ brown to colourless when an alkene is added to, but it does not change when the other compounds are added to it. Therefore it is alkenes only that decolourise the bromine solution. This shows that we can use the bromine test to identify alkenes.

The Alkanols

Alkanols are a family of organic compounds that belong to class of Oxy carbons. This is because they contain an oxygen atom apart from the carbon and the hydrogen atoms. Alkanols are also called alcohols.

a. Functional group

The functional group of the alkanols is a hydroxyl group, $-\text{OH}$.

b. General formula

The general formula of the alkanols is $C_nH_{2n+1}OH$. For example if the number of the carbon atoms is 3, $n = 3$, then the formula will be $C_3H_{2 \times 3 + 1}OH$, which is C_3H_7OH

c. Nomenclature of the Alkanols

The names of the alkanols end with the suffix –anol. For example Meth- + -anol = Methanol.

The position of the –OH group in the group is indicated by a number before the –ol. The number is found by counting the carbon atoms in the formula in such a way that the carbon atom to which the –OH group is attached is given the lowest number possible (ref table 5.6)

Alkanol	Name
$\begin{array}{cccc} 4 & 3 & 2 & 1 \\ C & -C & -C & -C-OH \end{array}$	Butan-1-ol
$\begin{array}{cccc} & 1 & 2 & 3 & 4 \\ OH-C & -C & -C & -C \end{array}$	Butan-1-ol
$\begin{array}{cccc} 1 & 2 & 3 & 4 \\ C & -C & -C & -C \\ & OH & & \end{array}$	Butan-2-ol
$\begin{array}{ccc} 1 & 2 & 3 \\ C & -C & -C \\ & OH & \end{array}$	Propan-2-ol

Table 5.6

The structures of the first 10 primary alcohols

Number of Carbon Atoms	Structure	Formula
1	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$	$\text{CH}_3 \text{OH}$
2	$\begin{array}{c} \text{H} \text{ H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{OH} \\ \quad \\ \text{H} \text{ H} \end{array}$	$\text{C}_2\text{H}_5\text{OH}$
3	$\begin{array}{c} \text{H} \text{ H} \text{ H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \\ \text{H} \text{ H} \text{ H} \end{array}$	$\text{C}_3\text{H}_7\text{OH}$
4	$\begin{array}{c} \text{H} \text{ H} \text{ H} \text{ H} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \quad \\ \text{H} \text{ H} \text{ H} \text{ H} \end{array}$	$\text{C}_4\text{H}_9 \text{OH}$
5	$\begin{array}{c} \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \\ \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \quad \quad \\ \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \end{array}$	$\text{C}_5\text{H}_{11}\text{OH}$
6	$\begin{array}{c} \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \\ \quad \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \quad \quad \quad \\ \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \end{array}$	$\text{C}_6\text{H}_{13} \text{OH}$
7	$\begin{array}{c} \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \\ \quad \quad \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \quad \quad \quad \quad \\ \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \end{array}$	$\text{C}_7\text{H}_{15} \text{OH}$
8	$\begin{array}{c} \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \\ \quad \quad \quad \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \quad \quad \quad \quad \quad \\ \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \end{array}$	$\text{C}_8\text{H}_{17} \text{OH}$
9	$\begin{array}{c} \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \\ \quad \quad \quad \quad \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \quad \quad \quad \quad \quad \quad \\ \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \end{array}$	$\text{C}_9\text{H}_{19} \text{OH}$
10	$\begin{array}{c} \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \\ \quad \quad \quad \quad \quad \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \quad \quad \quad \quad \quad \quad \quad \\ \text{H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \text{ H} \end{array}$	$\text{C}_{10} \text{H}_{21} \text{OH}$

Table 5.6

Deducing the Molecular Formula and the Structure of an Alkanol given the Percentage composition by mass

The general formula of the alkanols can be used to deduce the molecular formula and the structure of an alkanol given its percentage composition of the masses its elements.

Example;

An alkanol contains 64.6% carbon, 13.6% hydrogen and 21.6% oxygen by mass.

- Find the formula of the alkanol
- Draw the structure of the alkanol.

Working out;

	Carbon	Hydrogen	Oxygen
mass compositions	64.8g	13.6g	21.6g

Convert the masses to number of moles;

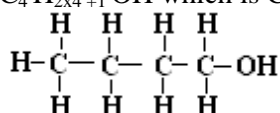
$64.8\text{g} \times \frac{1 \text{ mole}}{12\text{g}}$ $= 5.4\text{moles}$	1g	$13.6\text{g} \times \frac{1 \text{ mole}}{16\text{g}}$ $= 13.6 \text{ moles}$	$21.6\text{g} \times \frac{1 \text{ mole}}{16\text{g}}$ $= 1.35 \text{ moles}$
--	-------------	---	---

Dividing by the smallest Result

$\frac{5.4 \text{ moles}}{1.35\text{moles}} = 4$	$\frac{13.6 \text{ moles}}{1.35 \text{ moles}} = 10$	$\frac{1.35 \text{ moles}}{1.35\text{moles}} = 1$
--	--	---

The formula: $\text{C}_4\text{H}_{10}\text{O}_1$

From the general formula of the alkanols; $\text{C}_n\text{H}_{2n+1}\text{OH}$, the molecular formula of this alkanol is $\text{C}_4\text{H}_{2 \times 4 + 1}\text{OH}$ which is $\text{C}_4\text{H}_9\text{OH}$. The structure of the alkanol will be as follows;



Exercise

An alkanol contains 72.4% carbon, 13.8% hydrogen and 13.8% oxygen.

- i. Find the molecular formula of the alkanol
- ii. Draw the structure of the alkanol.

Ethanol

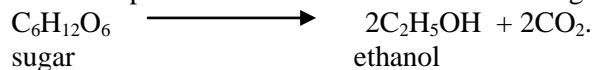
Ethanol is the most common of all the alkanols.

It is an important alkanol because of the following reasons;

- It is the ingredient in alcoholic drinks that makes people drunk
- It is a good solvent for many substances such as glue, printing ink, deodorants because it evaporates easily

a. Preparation of ethanol

Ethanol is produced from the fermentation of sugars as follows;



During the fermentation, carbon dioxide is also produced as shown in the equation above.

In industries, yeast is added to the sugar to speed up the fermentation process.

The yeast acts as a catalyst for the fermentation of sugar to ethanol.

The solution of ethanol produced contains less than 10% ethanol. A solution with high ethanol concentration can be obtained by distillation.

Ethanol can be obtained by distillation because it has a lower boiling point than the other contents of the mixture.

b. Preparation of indigenous alcohols;

The indigenous name for ethanol is *kachaso*. Kachaso is prepared by mixing maize bran (madeya) with sugar or sugarcane or juices of fruits such as mangoes, *masuku*. The mixture is left for a few days (three to five days) for the fermentation to take place. When the fermentation process stops, ethanol is then distilled from the mixture using the apparatus shown in figure 5.1.

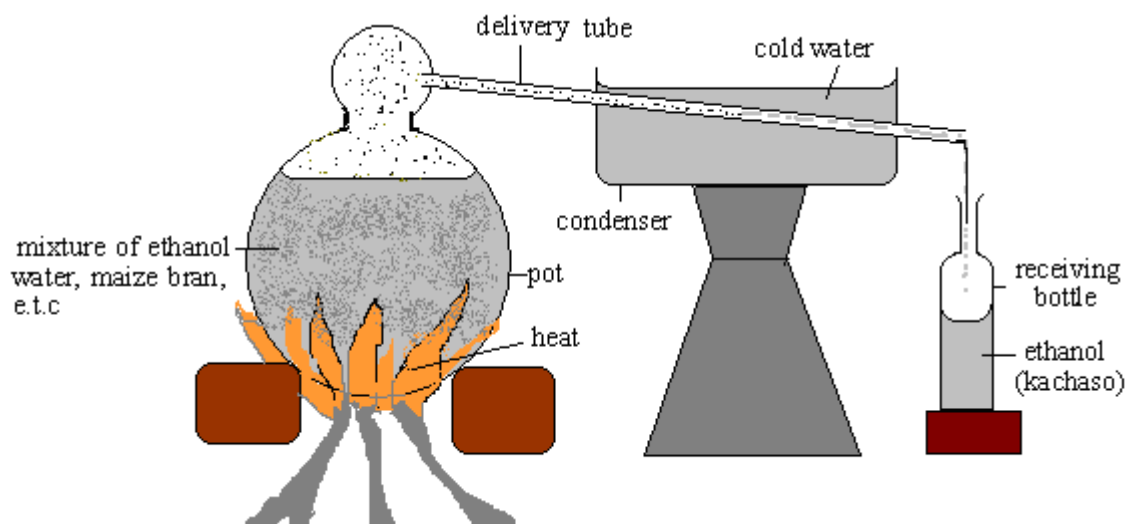
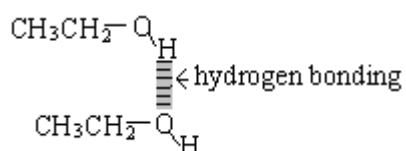


Figure 5.1

When the mixture is heated, ethanol boils faster than the water because of its boiling point is lower. The gaseous ethanol rises up in the pot and passes through the delivery tube. The cold water in the condenser cools down the ethanol gas and it condenses and can then be collected in the receiving bottle.

Physical properties of Alkanols

1. The melting points and the boiling points of the alkanols increase with the increase in the molecular sizes.
2. The melting points and the boiling points of the alkanols are higher than those of the corresponding hydrocarbons (i. e of the alkanes and the alkenes). This is because the intermolecular forces are stronger. The hydrogen bonding between the – OH groups of adjacent alkanol molecules are stronger than the weak van der Waal's forces between the hydrocarbon molecules as follows;



3. The smaller alkanols dissolve in water.

Activity 5.2

Aim: To investigate the effect of the size of the molecules of alkanols on their solubility in water.

Materials

- water
- ethanol
- butanol
- octanol
- 3 test tubes

Procedure

- (i) Pour 3 cm³ of water into a test tube.
- (ii) Add 3 drops of ethanol to the test tube
- (iii) Shake the test tube and wait for 2 minutes
- (iv) Record your observation
- (v) Repeat steps (i) – (v) with butanol and octanol respectively.

Table of results

Liquid added to water	Observation
Ethanol	
Butanol	
Octanol	

Table 5.7

Discussion

How many layers did you observe in each test tube?

What can you conclude from the results of the experiment?

Observation

There was only one layer of the liquids in the test tube with ethanol, while in the test tube with butanol there were two layers, but with no clear boundary whereas in the test tube with octanol there were two layers with clear boundaries. This means that ethanol is very soluble in water, butanol is partially soluble in water while octanol is insoluble in water. Alkanols are like water since the $-OH$ group is common to both water and the alkanols. However, as the size of the molecules increases, the effect of the $-OH$ group on the molecule decreases as well. Therefore, alkanols with bigger molecules behave like alkanes i.e. they do not dissolve in water.

The effects of the Relative size of the OH

The relative size of the –OH group has the following three effects as shown in table 5.7;

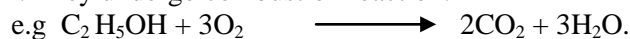
- i - flame colour
- ii - speed of reaction with sodium.
- iii – solubility in water.

Effect on;	Ethanol	Butanol	Octanol
<i>Flame colour</i>	Blue/ yellow	Yellow / little blue	All yellow
<i>Reaction speed</i>	Fast	Medium	Slow
<i>Solubility in water</i>	soluble	Partially soluble	insoluble

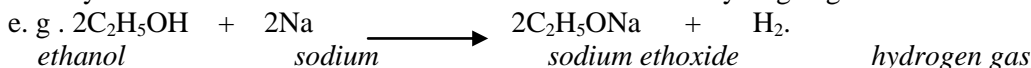
Table 5.8

Chemical properties of alkanols

1. They undergo combustion reaction.

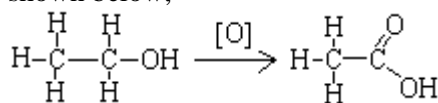


2. They react with sodium to form sodium alkanoxides and hydrogen gas.



3. They undergo oxidation reaction to produce Alkanoic acids.

Oxidation means gaining an oxygen atom. For example the oxidation of ethanol to ethanoic acid is as shown below;



ethnol

ethanoic acid

The alkanols can be oxidized by oxygen from;

- the air
- acidified potassium dichromate, K_2CrO_7 .

To oxidize alkanols to carboxylic acids by the acidified Potassium dichromate, K_2CrO_7 , the alkanol is heated with a mixture of potassium dichromate and sulphuric acid.

An alkanol can also be oxidized by the oxygen from the air by leaving it standing in the air for a long time.

Testing for Alkanols

Sodium test:

Activity: 5. 2

Aim: To demonstrate how to identify alkanols using the sodium test.

Materials

- an alkane (hexane or liquid paraffin)
- an alkene (cyclohexene or cooking oil)
- an alkanol (ethanol)
- a carboxylic acid (ethanoic acid)
- 4 beakers of volume 50 ml each
- sodium metal

Procedure

- Pour 3 ml of hexane into a beaker.
- Add 3 drops of phenolphthalein indicator into the test tube.
- Put a small piece of freshly cut sodium metal into the beaker.
- Record your observations in a table like the one shown in table 5.8.
- Repeat steps (i) and (iv) with cyclohexene, ethanol and ethanoic acid respectively .

Test liquid	Observation
Hexane	
Cyclohexene	
Ethanol	
Ethanoic acid	

Table 5.9

Discussion

Was there any colour change in any of the compounds? If yes in which solutions.

What other observations did you make?

What can you conclude from this activity?

Observation

When the sodium metal was added to ethanol the solution which was formed turned phenolphthalein indicator solution into pink. Also bubbles of a gas were formed. These changes were observed only in ethanol. This activity is called sodium test and it can be used to identify alkanols from different organic compounds.

Carboxylic acids / Alkanoic acids

This is a family of organic compounds that has a $-COOH$ as their functional group.

a. Nomenclature:

They are named by adding a suffix – anoic acid to the stem indicating the number of carbon atoms in the molecule including the carbon atom in the $-COOH$ group. For example;

Number of carbon atoms.	Prefix	Suffix	Name
-------------------------	--------	--------	------

1	Meth-	-anoic acid	Methanoic acid
2	Eth-	-anoic acid	Ethanoic acid
3	Prop-	-anoic acid	Propanoic acid
4	But-	-anoic acid	Butanoic acid
5	Pent-	-anoic acid	Pentanoic acid

Table 5.9

b. The structures and formulae of the first 10 Carboxylic acids



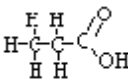
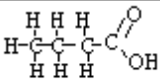
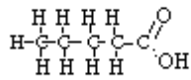
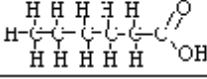
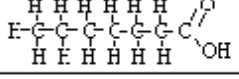
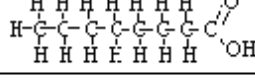
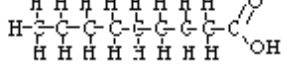
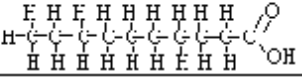
Number of carbon atoms	Name	Structure	Formula
1	Methanoic acid		HCOOH
2	Ethanoic acid		CH ₃ COOH
3	Propanoic acid		C ₂ H ₅ COOH
4	Butanoic acid		C ₃ H ₇ COOH
5	Pentanoic acid		C ₄ H ₉ COOH
6	Hexanoic acid		C ₅ H ₁₁ COOH
7	Heptanoic acid		C ₆ H ₁₃ COOH
8	Octanoic acid		C ₇ H ₁₅ COOH
9	Nonanoic acid		C ₈ H ₁₇ COOH
10	Decanoic acid		C ₉ H ₁₉ COOH

Table 5.10

b. General Formula;

The general formula of the carboxylic acids is C_nH_{2n+1}COOH.

The value of the 'n' in the general formula is not equal to the number of the carbon atoms in the molecule. This is because the number of carbon atoms, 'n' in the general formula does not include the carbon atom in the – COOH group.

Example

What is the molecular formula and the name of a carboxylic acid;

(i). where n = 6 (ii). with 6 carbon atoms.

Working out

i. The general formula is C_nH_{2n+1}COOH

so when n=6 the molecular formula will be;

C₆H_{2x6+1}COOH

Therefore the molecular formula is C₆H₁₃COOH

Its name is heptanoic acid.

ii. The general formula is $C_nH_{2n+1}COOH$
 so the molecular formula of the carboxylic acid with 6 carbon atoms will be;
 $C_5H_{11}COOH$
 Its name is hexanoic acid.

Exercise

What the molecular formula and the name of a carboxylic acid ;

i. with $n = 7$. ii with 8 carbon atoms.

11. Deducing the molecular Formula of a carboxylic acid given its Percentage composition:

The molecular formula of a carboxylic acid can be worked out using its percentage composition and the general formula of the carboxylic acids as shown in *the example* below;

A certain carboxylic acid has the following percentages of elements by mass;
 carbon = 48.7 %, hydrogen = 8.1% and oxygen = 43.2%.

i. Work out the molecular formula of the carboxylic acid.
 ii. What is its name?

Working out;

	Carbon	Hydrogen	Oxygen
mass compositions;	48.7g	8.1g	43.2g
Converting the masses to moles;	$48.7g \times \frac{1 \text{ mole}}{12g}$ = 4.0 moles	$8.1g \times \frac{1 \text{ mole}}{1g}$ = 8.1 moles	$43.2g \times \frac{1 \text{ mole}}{16g}$ = 2.7 moles
Divide by the lowest result;	$\frac{4.0 \text{ moles}}{2.7 \text{ moles}} = 1.5$	$\frac{8.1 \text{ moles}}{2.7 \text{ moles}} = 3$	$\frac{2.7 \text{ moles}}{2.7 \text{ moles}} = 1$
Multiply each above result by 2 to make 1.5 a whole number;	$1.5 \times 2 = 3$	$3 \times 2 = 6$	$1 \times 2 = 2$

Therefore the carboxylic acid has 3 carbon atoms, 6 hydrogen atoms and 2 oxygen atoms.

i. From the general formula, $C_nH_{2n+1}COOH$, then the molecular formula is



ii. Its name is Propanoic acid.

Exercise:

Work out the molecular formula and the structure of a carboxylic acid which has the following percentage compositions by mass;

62.1% carbon, 10.3% hydrogen and 27.6% oxygen.

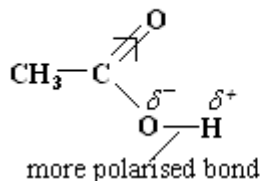
Physical properties of Carboxylic acids;

1. *Their melting and boiling points increase with the increase in the molecular size.*

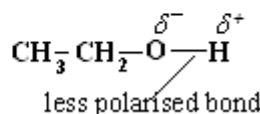
2. *They have higher melting and boiling points than those of the corresponding alkanols.* For example, the boiling point of methanoic acid is 101°C and it is higher than that of *either* methanol, 64°C which has the same number of carbon atoms, or ethanol 78°C which has the same relative molecular mass of 46.
 The melting points and the boiling points of the carboxylic acids are higher than those of the corresponding alkanols because of the following reasons;

-i Carboxylic acids form stronger hydrogen bonds than the alkanols. This is because the -OH group of the carboxylic acids is more polarised due to the presence of the electron-withdrawing -C=O group as shown below;

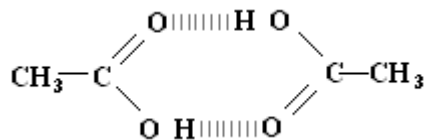
ethanoic acid molecule



ethanol molecule



-ii. Carboxylic acids exist as dimers i.e. two molecules bonded together as follows;



3. *Smaller carboxylic acids dissolve in water.* They dissolve in water because of the – OH group. But as the size of the molecule increases the effect of the – OH group decreases and this makes the bigger carboxylic acids to be insoluble.

4. *The carboxylic acids conduct electricity.*

They conduct more than the alkanols because they ionize to a greater extent in water.

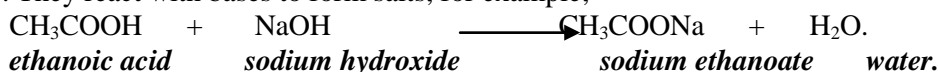
Chemical properties;

1. *They show acidic behaviours.* For example;

a. they affect acid – base indicators as follows

- they turn litmus paper red
- they give pH values of less than 7.

b. They react with bases to form salts, for example;



2. *They undergo esterification reaction.*

Esterification is the reaction of carboxylic acids with alkanols to form esters as follows;



Examples:



An ester is an organic compound whose functional group is – COO –

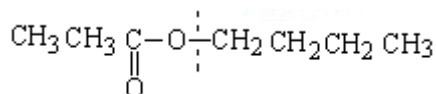
Naming esters

The name of an ester is taken from the prefix of the alkanol from which the ester is formed with the suffix – anol replaced by the suffix – yl (e. g ethanol becomes ethyl)

followed by a stem indicating the carboxylic acid with the suffix – oic replaced by – oate. For example the ester formed from Propanoic acid and methanol is named methyl propanoate.

How to work out the name an ester from its formula;

a. Divide the formula into two parts by mentally drawing a line after the bridging ‘O’ of the ‘–COO’ as follows;



b. Name the portion that does not carry the ‘–COO’ group. This part is an alkyl group – butyl in this example.

c. Name the part that carries the ‘–COO’ group. This part is a carboxylate group, –propanoate in this example.

d. Combine **b** and **c** to give the name of the ester. – butyl propanoate.

Exercise

Write the equation and the products of the following reactions;

- ethanol and hexanoic acid
- methanol and ethanoic acid
- propan-1-ol and ethanoic acid..

Physical properties of esters

a. They have pleasant, fruit smells.

For example;

Ester	Fruit smell
Ethyl butanoate	Pineapple
Pentyl ethanoate	banana

Table 5.11

b. They have lower melting and boiling points than the acids and alcohols of similar molecular mass. For example, ethyl ethanoate boils at 77°C. This is because esters have no free – OH groups so they do not form hydrogen bonds.

c. They are not very soluble in water compared with the acids and the alcohols.

Preparation of Esters

1. Esters can be produced naturally.

For example, the flavours and the smells of fruits and flowers are due to esters produced naturally.

But natural esterification is a very slow process.

2. Esters can be prepared more quickly artificially as follows;

a - mixing an alkanol with a carboxylic acid in the ratio,

alkanol : Carboxylic acid = 2:1

b - adding a few drops of concentrated sulphuric acid or hydrochloric acid to the mixture to act as a catalyst

c - heating the mixture.

Uses of artificial esters

- Flavouring e. g the flavours in sweets and biscuits
- as fragrances in perfumes
- as solvents in glues since they evaporate easily.

Natural Sources of carboxylic acids

Table 5.12 below shows some of the natural sources of carboxylic acids.

Source	Name of acid	Formula
Ant stings	Methanoic acid	HCOOH
Vinegar	Ethanoic acid	CH ₃ COOH
Human breast milk and cow milk	Lactic acid	CH ₃ CHOHCOOH
Citrus fruits	Citric acid	$ \begin{array}{c} \text{CH}_2\text{COOH} \\ \\ \text{HO}-\text{C}-\text{CH}_2\text{COOH} \\ \\ \text{CH}_2\text{COOH} \end{array} $
Goat milk	Hexanoic acid	CH(CH ₂) ₄ COOH

Table 5.12

13. Testing for carboxylic acids

Activity: 5. 2

Aim: To demonstrate how to identify carboxylic acids using the acid test.

Materials

- an alkane (hexane or liquid paraffin)
- an alkene (cyclohexene or cooking oil)
- an alkanol (ethanol)
- a carboxylic acid (ethanoic acid)
- 4 test tubes
- sodium hydroxide solution (NaOH)
- phenolphthalein indicator

Procedure

- Pour 3 ml of sodium hydroxide solution into a beaker.
- Add 3 drops of phenolphthalein indicator into the test tube.
- Record your observations in a table like the one shown in table 5.8.
- Repeat steps (i) and (iii) with cyclohexene, ethanol and ethanoic acid respectively .

Test liquid	Observation
Hexane	
Cyclohexene	
Ethanol	
Ethanoic acid	

Table 5.13

Discussion

What was the colour of the phenolphthalein indicator in sodium hydroxide solution?
Was there any colour change in any of the compounds? If yes, in which solutions?
What can you conclude from this activity?

Observation

The colour of phenolphthalein indicator changes from colourless to pink when it is added to the sodium hydroxide solution. When carboxylic acid is added to the sodium hydroxide, the colour of the solution changes from pink to colourless. This change is observed with a carboxylic acid only. This activity is called acid test and it is used to identify carboxylic acids from other organic compounds.

Flow Diagram

A flow diagram is a picture-way of separating unknown compounds and the identifying them by using special tests for each functional group.

Example

You are given the following organic compounds; an alkane, an alkene, an alkanol and a carboxylic acid in bottles just labelled A, B, C and D not in order. Use a flow diagram to identify them.

Working out

Carry out the tests and fill the brackets with the letters representing the compounds until the compound in each bottle is identified as shown in the flow diagram below.

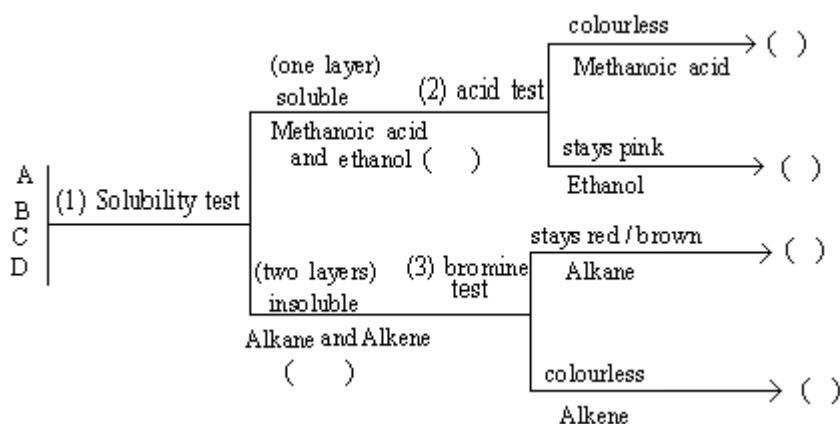


Figure 5.2

Summary

Organic chemistry is the study of organic compounds. The organic compounds are divided into classes, two of which are hydrocarbons and oxycarbons.

The compounds in each class are divided into families (also called homologous series).

Some of the homologous series are;

- alkanes,
- alkenes
- alkanols
- carboxylic acids

Each family has,

- functional group (except the alkanes)
- general formula
- common naming system

The common member of the alkanols is ethanol. Ethanol is produced from the fermentation of sugar.

The melting and boiling points of the alkanols are higher than those of the corresponding alkanes and alkenes because in alkanols there is hydrogen bonding, which is a stronger intermolecular force than the weak van der Waal's forces which are used in the hydrocarbons.

Alkanols dissolve in water because they are like water because of the -OH group. However, as the size of the molecule gets bigger, when going down the family, the relative size of the -OH group gets smaller; hence its effect is reduced. Therefore, bigger molecules do not dissolve in water.

Carboxylic acids are organic compounds whose functional group is -COOH.

Carboxylic acids have higher melting and boiling points than the corresponding alkanols because of the following reasons;

- the hydrogen bonding in carboxylic acids is stronger than it is in the alkanols because it is more polarises due to the presence if the -C=O.
- carboxylic acids exist as dimmers.

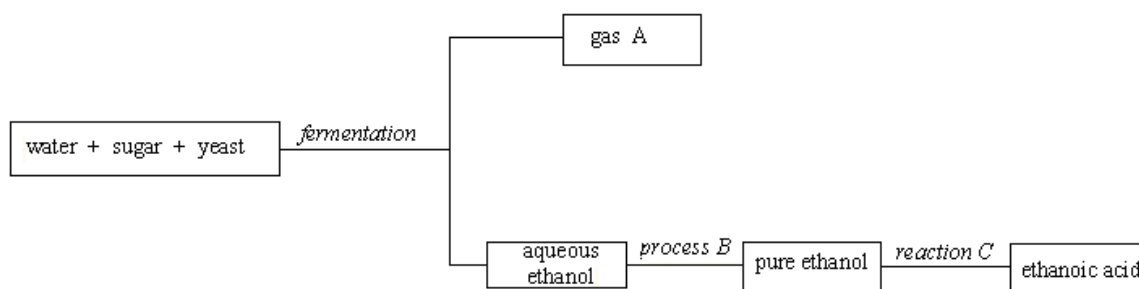
Organic compounds can be identified by testing the presence of a particular functional in the compounds.

Review Questions:

1.
 - a. What are hydrocarbons?
 - b. What is the general formula of the alkanes?
 - c. Draw the structure of an alkane with 14 carbon atoms.
2.
 - a. what is the functional group of the alkenes?
 - b. Describe the test for the alkenes.
3. The table below shows molecular formulae and the boiling points of some compounds;

Compound	Molecular Formula	Boiling Point (°C)
A	C ₂ H ₄	- 104
B	C ₂ H ₅ OH	-79
C	CH ₃ COOH	118
D	H ₂ O	100
E	C ₂ H ₆	- 89

- a. Which compounds in the table are hydrocarbons?
 - b. Which compounds in the table are soluble in water?
 - c. Which compounds in the table are gases at room temperature?
 - d. Explain why the boiling point of C is higher than that of B.
 - e. Describe the test that could be done to distinguish the compounds
 - (i) A and B.
 - (ii) C and D.
4. The figure below shows how ethanol and ethanoic acid are produced in industries;



- a. Give the names of;
 - (i) Gas A
 - (ii) Process B
 - (iii) Reaction C
 - b. Name the substance that is used in reaction C
 - c. What is the function of the substance in 4 (b) above.
5. Given below are the general formulae of some homologous series represented by letters P, Q, R and S.
P: C_n H_{2n}

Q: $C_n H_{2n+2}$.
R: $C_n H_{2n+1} OH$.
S: $C_n H_{2n+1} COOH$

- Name the homologous series represented by the letters P and Q.
- Which general formulae represent hydrocarbons?
- Which class of the organic compounds does the general formula $C_n H_{2n+1} COOH$, represent?
- Draw the structure of a compound when $n = 4$ in homologous series P.
- Name the compound drawn in **5d** above.
- Explain how a compound of homologous series P could be distinguished from a compound of the homologous series Q.

6. ELECTRICITY, MAGNETISM AND ELECTROMAGNETIC INDUCTION I

Electrostatics

Mostly electric charge (or electricity) comes from batteries and generators. But electricity can also come from materials that become charged when are rubbed. The charge on materials caused by rubbing is called electrostatic charge or static electricity. Static electricity just builds up on materials but it does not flow. This is the electricity which causes sparks and crackles when you take off a jersey.

Where does charge come from

- The Atom

An atom is made up of protons, neutrons and electrons. The protons and neutrons are found in the nucleus and around the nucleus there are electrons.

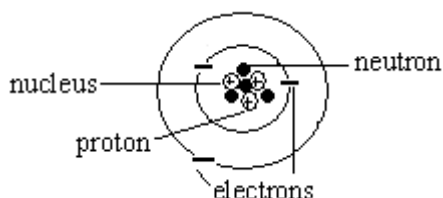


Figure 6.1

Electrons are negatively charged (-) while protons are positively charged (+). Each atom has equal numbers of protons and electrons. The charges cancel each other out and the overall charge on the atom is zero. However when two materials are rubbed together electrons may be transferred from one material to the other. Eventually, one material has more electrons than normal and the other has less. The material with more electrons becomes negatively charged whereas the one with fewer electrons becomes positively charged. For example, some insulators such as polythene become negatively charged when **rubbed** with a woollen cloth. Electrons are transferred from the cloth to the polythene.

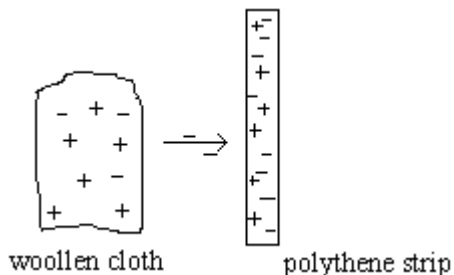


Figure 6.2

The woollen cloth becomes positively charged because it has fewer electrons while the polythene strip becomes negatively charged because it has more electrons.

Other insulators such as perspex become positively charged when rubbed by a woollen cloth. In this case electrons are transferred from the perspex strip to the woollen cloth upon rubbing.

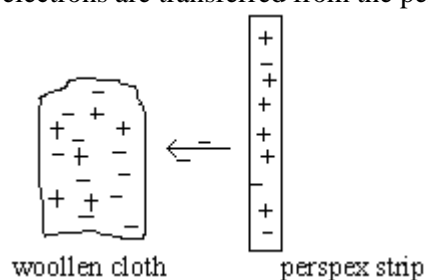


Figure 6.2

The Law of charges between charged materials

When two charged polythene strips are brought together, they repel;

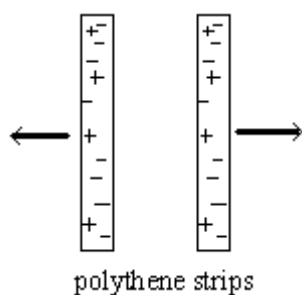


Figure 6.4

When two perspex strips are brought together, they also repel each other;

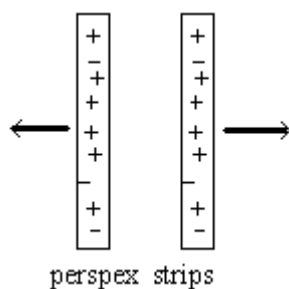


Figure 6. 5

But when a charged polythene strip and a charged perspex strip are brought close together, they attract each other.

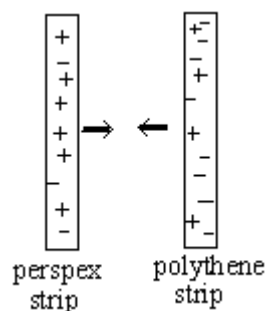


Figure 6.6

We can conclude, therefore, that like charges repel each other while unlike charges attract. The repulsive and the attractive forces between the materials are greater when the charges are closer.

Other Methods of charging:

Apart from rubbing (friction) materials can also be charged by;

(i) Contact

When an uncharged object is touched by a charged object the uncharged object takes on a charge which is the same as that which is on the charged object.

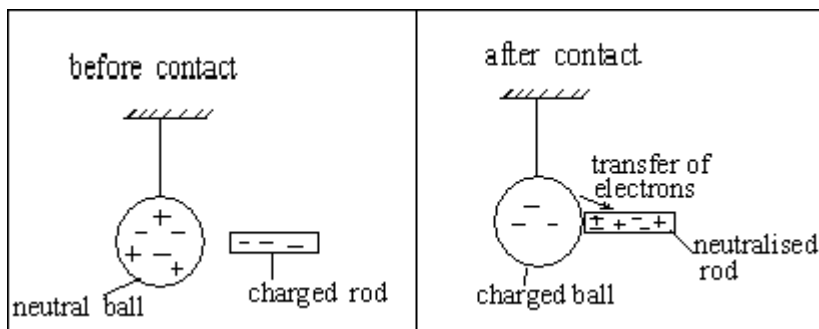


Figure 6.7

(ii) Induction

Activity 6.1: Investigating what happens when a charged balloon is brought closer to a wall.

Materials

- a balloon
- a piece of woollen cloth
- a smooth wall

Procedure

1. Rub the balloon with the piece of cloth (alternatively you can rub it against your hair)
2. Bring the balloon closer to the wall, with the rubbed surface facing the wall.

Observation

The balloon sticks to the wall.

Explanation

When a charged object is brought near an uncharged object, the charge on the charged object repels the like charge on the surface of the uncharged object.

The surface of the uncharged object remains with a charge opposite to that on the charged object. Consider the example below;

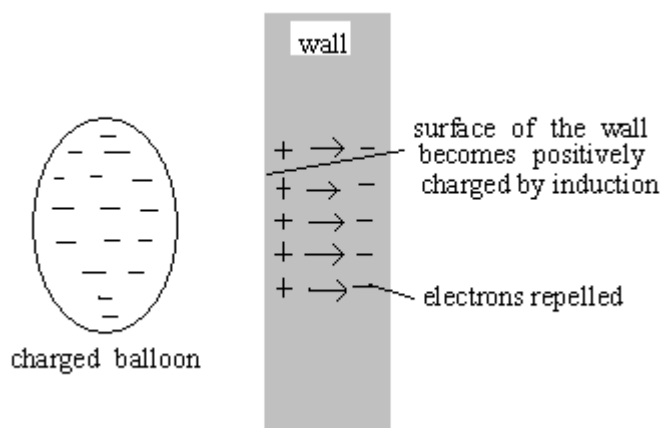


Figure 6.8

This is how a negatively charged balloon is made to stick to a wall.

Uses / Applications of static electricity.

Static electricity is used in the following;

- Capacitors
- Photocopiers
- spray painting
- Electrostatic precipitation.

i. The Capacitors

A capacitor is a device that is used to store charge in electric circuits. The simplest capacitor consists of two small parallel metal plates separated by an insulator as shown in figure 6.9 (a). Figure 6.9 (b) shows the symbol for capacitors.

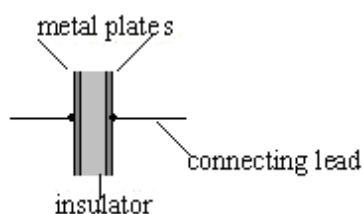


Figure 6.9 (a)

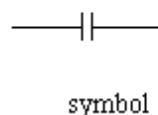


Figure 6.9 (b)

When connected to a battery current flows in the circuit. Electrons are stored in one plate of the capacitor while in the other plate there is a shortage of electrons and so positive charges are stored there. When the voltage between the plates is equal to the applied voltage, the current stops flowing. At this point the capacitor is fully charged and it can store the charge. When connected to a circuit where there is no battery, the capacitor can make current flow until it is fully discharged.

ii. Photocopier

In electrostatic photocopiers a pattern of light and dark from the original copy is allowed to fall on onto a positively charged plate. Charge leaks away from the area exposed to light. The unexposed area, that is the dark part of the original copy, still carries the positive charge. This positively charged image attracts the negatively charged carbon powder, which is called toner. The blackened image on the plate is then attracted onto a piece of paper with the help of a positive charge placed under the paper. The paper is then heated to fuse the powder to the paper.

iii. Spray painting

This is a method of painting metals, such as cars, using electrostatics. In spray painting, cars are given a negative charge. Paint from spray guns becomes positively charged by friction. The charged droplets are then attracted to the car without missing it. This reduces loss and saves money.

iv. Electrostatic precipitation

This is a method of removing ash and dust that goes up in factory chimneys and power station chimneys. Fine wire mesh which is negatively charged is placed inside the chimney. The negatively charged wire mesh gives the negative charge to the rising particles of the ash or the dust.

The negatively charged particles are then attracted to the positively charged metal plates inside the walls of the chimney. The ash particles are, then, removed by washing.

Electrical Resistance

Activity 6.2: Finding the length of a resistor wire that has a given resistance.

Materials

- resistor wire (nichrome or constantan)
- 105cm long,
- ammeter,
- voltmeter,
- 6 connecting leads
- a switch
- 2 cells.

Procedure

- (i) Connect a circuit as shown in figure 6.10 below.

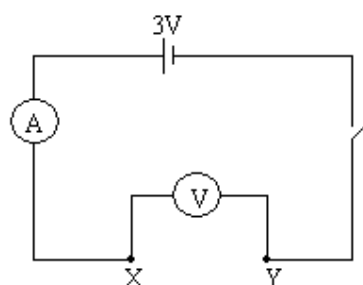


Figure 6.10

- (ii) Connect 20 cm of the resistor wire in the gap XY.
(iii) Close the switch note the ammeter reading and the voltmeter reading.
(iv) Record the readings as shown in table 6.1.
(v) Calculate the resistance and fill the resistance column.
(vi) Repeat steps (ii) – (v) with the lengths of the resistor wire 40cm, 60 cm, 80 cm and 100cm and record the results.

Length (cm)	Voltmeter reading (V)	Ammeter reading (A)	Resistance (Ω)
20			
40			
60			
80			
100			

Table 6.1

(vii) Plot a graph of resistance against length.

Discussion

From your graph,

- how does length affect the resistance of a resistor wire?
- what length of the resistor wire would give you the following resistances?

(i) $0.5\ \Omega$

(ii) $2\ \Omega$

Observation

The longer the wire, the greater the resistance. Other factors that affect the resistance of a wire are;

- thickness of the wire an.
- temperature

The Total Resistance (R_t) of Resistors Connected in Series and in Parallel in a Circuit:

Activity6.2: comparing the total resistances of resistors connected in series and in parallel in circuits.

Materials:

- Resistor wire
- ammeter
- voltmeter,
- connecting leads,
- switch
- 3V

Procedure

- Cut a piece of the resistor wire that has a resistance of $2\ \Omega$ and another with a resistance of $4\ \Omega$.
- Arrange the two resistor wires in series in a circuit as below;

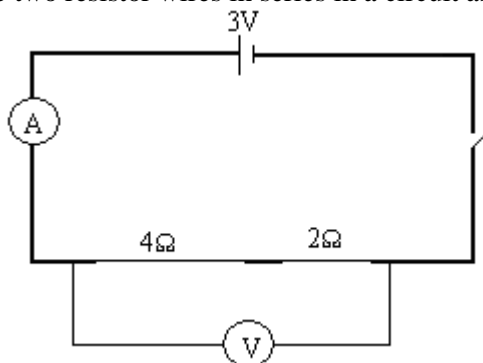


Figure 6.11

- Close the switch and record the ammeter reading and the voltmeter reading in a table as shown in table 7.2 below;

Ammeter reading (A)	
Voltmeter reading (V)	

Table 6.2

- Calculate the total resistance, R_t of the two resistors; $R_t = V/I$
- Reconnect the two resistor wires in parallel in a circuit as shown below;

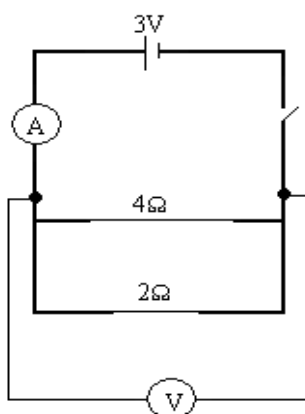


Figure 6.12

(vi) Close the switch and record the ammeter and the voltmeter readings ;

Ammeter reading (A)	
Voltmeter reading (V)	

Table 6.3

vii) Calculate the total resistance, R_t .

Discussion

- Which arrangement gives greater total resistance of the two resistor wires?
- How does the total resistance of the two resistors compare with the resistances of the individual resistors when the resistors are connected in;
 - series?
 - parallel?

Observation

The total resistance of the two resistors is higher in the series circuit than in the parallel circuit. Electrical resistance means the opposition to the flow of electric charge. The electrical resistance of a conductor depends on the voltage, V and the amount of current, I and is given by the equation; $R = V / I$.

Resistance is measured in ohms, Ω .

The formula $R = V / I$, shows that $V = IR$ and $I = V / R$

R , V and I can be connected using the formula triangle shown below.

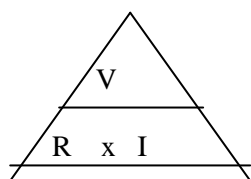


Figure 6.13

(i) The Total Resistance, R_T of Resistors in Series;

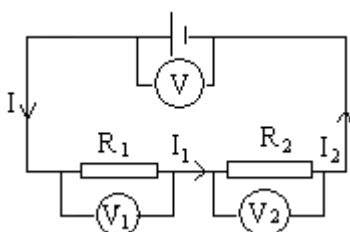


Figure 6.14

In a series circuit, current is the same at all points. That is $I = I_1 = I_2$. And the voltage across the cell (the power supply) is equal to the total sum of the voltages across each component, $V_c = V_1 + V_2$. But $V = IR$. Therefore, $IR_T = IR_1 + IR_2$, since current is the same at all points, then $R_T = R_1 + R_2$. So in a series circuit the total (or effective) resistance is equal to the sum of the resistances of individual resistors.

(ii) The Total Resistance, R_T of Resistors in Parallel:

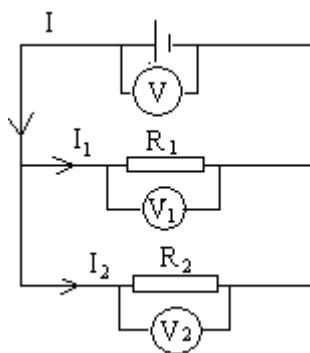


Figure 6.15

In a parallel circuit,

- the current, I , in the main branch is equal to the sum of the currents in the separate branches, and
- voltage, V , is the same across all components i. e in a parallel circuit, $I = I_1 + I_2$ and $V = V_1 = V_2$

But $I = V / R_T$

Therefore, the equation, $I = I_1 + I_2$

$$\Rightarrow V / R_T = V / R_1 = V / R_2$$

Since voltage, V is the same then

$$1 / R_T = 1 / R_1 + 1 / R_2$$

Example;

6Ω , 3Ω , 5Ω and 1Ω resistors are connected in parallel. Find the total resistance in the circuit.

Working out

Let the resistances of the 6Ω , 3Ω and 5Ω resistors be R_1 , R_2 , R_3 and R_4 respectively;

Then $R_T = 1 / R_1 + 1 / R_2 + 1 / R_3$.

Therefore, $1 / R_T = 1 / 6 + 1 / 3 + 1 / 5$

$$\frac{1}{R_T} = \frac{5+10+6}{30}$$

R_1

$$\frac{1}{R_T} = \frac{21}{30}$$

$$R_T = \frac{30}{21}$$

$$R_T = 1.4 \Omega$$

\therefore the total resistance is 1.4Ω

Resistance of Resistors

A resistor is a device that is designed to give specific resistance in a circuit. Resistors keep currents and voltages at the levels needed for other components to work properly. The resistances of the resistors are marked on the resistors using either;

- (i). colour codes
- (ii) letter and number code.

i. The Resistor colour codes

Resistors are colour coded to show their resistances as follows;

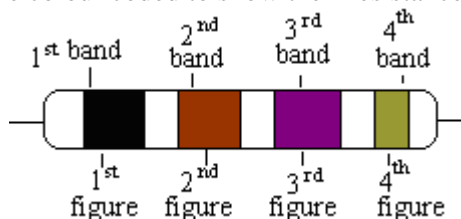


Figure 6.16

- The first colour band gives the first digit of the value of the resistance of the resistor.
- *The second colour band gives the second digit of the value of the resistance.*
- *The third colour band gives either;*
 - (i) the number of zeros after the first two digits, or
 - (ii) the decimal multiplier of the first two digits (if it is gold or silver).
- *The fourth colour band tells us;*
 - (i) the tolerance of the resistor,
 - (ii) to start reading from the other end, (if pink, gold, silver or no band).

The value colour codes are as follows;

Colour	Code
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

Table 6.4

Tolerances of resistors

Tolerance means limits of accuracy. The smaller the limit of accuracy of a resistor, the more accurate its resistor is.

The tolerance of the colour codes are as follows;

Colour	Tolerance
Pink	$\pm 1\%$
Gold	$\pm 5\%$
Silver	$\pm 10\%$
No band	$\pm 20\%$

Table 6.5

For example, if the colours are orange, blue, brown, and silver then the resistance is

$$3 \quad 6 \quad 0 \quad \pm 10 = 360 \, \Omega \pm 10 \%$$

The order of the colour codes may be remembered using the following mnemonic

Black Brown Raped Our Young Girl But Violet Gave Willingly and Probably Gladly Since Noon.

This can be interpreted as **Black Brown Red Orange Yellow Green Blue Violet White Pink Gold Silver**. If the third band is gold or silver, the value of the first two digits must be multiplied by the decimal multiplier codes of gold or silver. The decimal multiplier codes are as follows;

3 rd Colour band	Code
Gold	0.1
Silver	0.01

Table 6.6

E. g If the colour bands on a resistor are Red, white, gold, silver, then the resistance is

$$(\text{red}) \, 2 \quad (\text{white}) \, 9 \quad \times \quad (\text{gold}) \, 0.1 \quad (\text{silver}) \, \pm 10\% = 2.9 \, \Omega \pm 10\%$$

Exercise

Calculate the resistance of the resistors with the following colour bands;

- grey, black, silver
- green, violet, white, pink,
- red, black, silver, silver.
- orange, grey, gold, gold

(ii) The letter and number code the Resistances of the Resistors

In the standard notation, the codes of letters and numbers representing the resistances are printed in on the resistors. The resistance of each resistor is given by figures and two letters, for example;

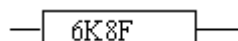


Figure 6.17

The first letter may be **R**, **K** or **M**, where **R** represents the *resistance in ohms, Ω*

K represents the *resistance in kilo ohms, $k \, \Omega$*

M, the resistance in *mega ohms, $m\Omega$*

The position of the first letter gives the position of the decimal point. The second letter gives the tolerance of the resistor. The letter codes for the tolerances are as follows;

Letter code	Tolerance
F	$\pm 1\%$
G	$\pm 2\%$
J	$\pm 5\%$
K	$\pm 10\%$
M	$\pm 20\%$

Table 6.7

These letter codes may be remembered by using the following mnemonic;

Foolish Girls Join Kilometre Races with Metres.

Example;

Give the resistances of the following resistances;

- 8M1M

b. R34G

Working out

a. $8.1\text{ m}\Omega \pm 20\%$ b. $0.34\Omega \pm 2\%$

Exercise

1. Work out the resistances of the following resistors;

(i). K4 6 F,

(ii). 4M0J,

(iii). 96KK.

2. Figure 6.18 shows two resistors

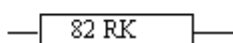
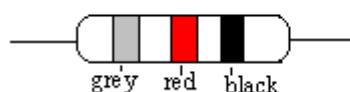


Figure 6.18 (a)

Figure

6.18(b)

(a) Calculate the resistance of each resistor

(b) Which resistor is more accurate? Give a reason.

Electrical Power

i. Charge, Q

Charge is the measure of the amount of electrons. It is measured in coulombs, C. One coulomb of charge is equal to the charge on 6.25×10^{18} electrons.

ii. Voltage, V

Voltage is the amount of energy given to one coulomb of charge by a battery. This voltage is known as electromotive force, (emf). The energy given to the coulomb of charge is transferred to an electrical component such as an electric bulb or a radio receiver in a circuit. This voltage is called potential difference, p.d. This means that when the electrons pass through a power supply such as a battery, they are given energy. The battery does work on the electrons. And when the electrons flow around the circuit they transfer the energy to the electrical components. The energy transferred is observed as light, heat, sound etc

$$\therefore \text{Voltage, } v = \frac{\text{Work done (J)}}{\text{Charge, } Q} = \frac{\text{Energy transferred (J)}}{\text{Charge, } Q}$$

$$\Rightarrow \text{Work done, } w = Q \times v.$$

Voltage is measured in volts, V, by an instrument called voltmeter. The voltmeter is made up of a wire of a very high resistance. When measuring voltage, the voltmeter is connected in parallel to the component so that it measures the potential difference, *pd*, between the ends of the component without altering the current that is flowing through the component due to its high resistance wire.

Example

If a battery gives 12j of energy to each coulomb of charge, what is its voltage?

Working out;

Since it gives 12j to each coulomb of charge, then its voltage is 12 volts.

iii. Current, I

Current is the amount of charge that leaves the battery every second.

$$I = \frac{Q}{t \text{ (s)}}$$

$$\Rightarrow I \times t = Q$$

Current is measured in amperes, A. It is measured by an instrument called ammeter. The ammeter is made up of very low resistance wire. When measuring the current the ammeter is connected in series with the component in the circuit so that it can measure the current flowing through the component.

Example

If 4 coulombs of charge leave a battery every 2 seconds, how much current is flowing through the circuit?

Working out

$$I = \frac{Q}{t \text{ (s)}}$$

$$\therefore I = \frac{4}{2s}$$

$$= 2A$$

Power is the rate at which work is done, or the rate at which energy is changed from one form to another.

$$\text{Power} = \frac{\text{work done (J)}}{\text{time (s)}}$$

$$= \frac{\text{Energy changed (J)}}{\text{time (s)}}$$

Power is measured in watts, W

$$\text{From the equation; Power} = \frac{\text{work done (J)}}{\text{time (s)}}$$

$$\Rightarrow \text{Work done} = \text{Power} \times \text{time(s)}$$

But also, **work done** = $Q \times V$.

$$\therefore Q \times V = \text{Power} \times \text{time(s)}$$

$$\Rightarrow \frac{Q \times V}{\text{time (s)}} = \text{Power} \quad \text{or} \quad \text{Power} = \frac{Q \times V}{t}$$

$$\text{But } \frac{Q}{\text{Time}} = \text{Current, } I$$

$$\Rightarrow \text{Electrical power} = \text{Voltage, } V \times \text{Current, } I$$

$$\therefore \text{Electrical power} = VI$$

$$\text{Also from the equation, } R = \frac{V}{I}, \quad \Rightarrow I = \frac{V}{R},$$

$$\Rightarrow \text{Electrical power} = V \times \frac{V}{R},$$

$$\therefore \text{Electrical power} = \frac{V^2}{R},$$

Also $V = IR$, so the equation electrical **power** = VI becomes electrical **power** = $IR \times I$

$$\therefore \text{Electrical power} = I^2 R$$

Example

What is the power of a lamp rated 12v: 2A

Working out

$$\text{Power} = VI$$

$$= 12v \times 2 A$$

$$= 24 \text{ watts}$$

Exercise

1. Calculate the power output of a resistor wire of resistance 5Ω , if the potential difference across its ends is 12V.
2. Find the current through a resistor wire of resistance 4Ω , if it uses 2J of electrical energy per second.

Electrical Energy

Electrical energy = power \times time. Electrical energy is measured in joules. 1 joule = 1 watt \times 1 second.

$\Rightarrow 1\text{J} = 1\text{ watt-second}$.

It is measured by an instrument known as joule meter.

Example

How much electrical energy does a 100 watt transfers in; (i) 5 seconds.(ii) 1 minute.

Working out;

Electrical energy = power \times time (s).

i. Electrical energy = 100watts \times 5 sec
 $= 500\text{ J}$

ii. Electrical energy = 100watts \times 60 sec.
 $= 6000\text{ J}$

Cost of Electrical Energy

Electricity supply boards charge for the electrical energy which they supply. They charge the electrical energy in kilowatt-hours (kWh). This is because a joule, which is a watt-second, is a very small amount of electrical energy for practical purposes.

1 kWh = 1000watts \times 3600 seconds.

$= 3\,600\,000\text{ watt-seconds}$

$= 3\,600\,000\text{ joules}$

$= 3.6\text{ MJ}$

A kilowatt-hour is the amount of electrical energy used by a 1kw (or 1000 watts) electrical appliance in 1 hour. For example, a 3 000W (or 3kw) appliance working for 2 hours uses (3 kW \times 2hours) 6kWh of electrical energy. The kilowatt- hours (kWh) are usually called units.

Exercise

What is the cost of heating a tank of water with a 3 000 W water heater for 90 minutes, if electricity costs K4.00 per kWh?

Flux / Field Patterns for a Conductor Carrying Electricity;

Activity 6.3: Investigating what happens around a conductor when current is flowing through it.

Materials:

- a clamp and a clamp stand
- iron filings
- connecting leads
- a cell
- a switch
- a piece of card board paper
- a plotting compass

Procedure

- (i) Arrange the apparatus as shown in figure 6.19 below.

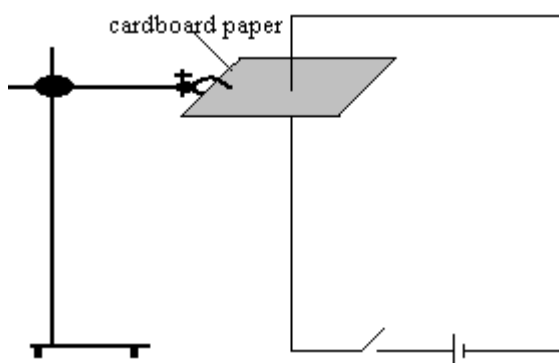


figure 6.19

- (ii) Close the switch.
- (iii) Spread the iron filings around the conductor.
- (iv) Tap the cardboard gently with your fingers.
- (v) Observe the arrangement of the iron filings on the cardboard paper.
- (vi) Mark the arrangement of the iron filings on the cardboard paper with a pencil.
- (vii) Open the switch and remove the iron filings from the cardboard paper.
- (viii) Place a compass near the conductor on the cardboard paper.
- (viii) Observe the direction which the compass needle is pointing.
- (ix) Move the compass around the conductor while taking note of the direction in which the compass needle is pointing each time the compass is moved.
- (x) Draw arrows on the marks made in step (vi) to indicate the direction in which the compass needle was pointing.
- (xi) Repeat steps (i) to (x) with the terminals of the cell reversed.

Discussion

- How did the iron filings arrange themselves around the conductor?
- What does the arrangement of the iron filings represent?
- What does the direction of the compass needle represent?
- What is the relationship between the direction of the field lines and the direction of current?
- What do the results of this experiment tell you about the area (space) around the current carrying conductor?

Observations

We have observed that the iron filings arrange themselves in circles around the conductor. This shows that a magnetic field is created around a conductor through which electric current is flowing. The arrangement and the direction of the magnetic field lines is referred to as flux pattern. There is a relationship between the direction of the current through the conductor and the direction of the magnetic field around the conductor. The direction of the magnetic field around the conductor can be predicted using the right hand grip rule, which states that if you grip the conductor with your right hand, with the thumb pointing in the direction of current, then the fingers point in the direction of the field lines. The direction of the magnetic field is also given by the right hand screw rule, which states that if a right handed screw moves forward in the direction of the current, the direction of the rotation of the screw gives the direction of the field.

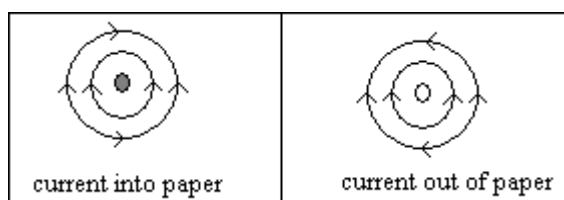


Figure 6.20

If the conductor is coiled into a solenoid the magnetic field lines run in the coils from one face of the coil to the other. The magnetic field, similar to that produced by a bar magnet, is produced and the solenoid acts as if it has a N-pole on one face and a S- pole on the other face as shown in figure 6.21 below.

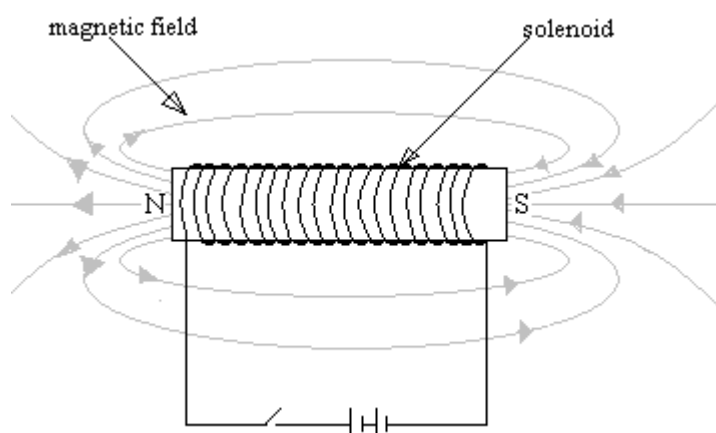
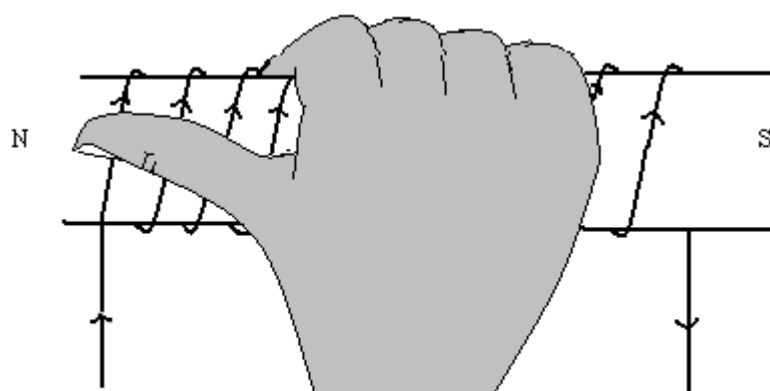


Figure 6.21

The magnetic poles on each face of the solenoid depend on the direction of the electric current flowing through the conductor. They are given by the right hand grip rule, which states that if the fingers of the right hand grip the solenoid in the direction of the current, then the thumb points to the north pole (N- pole) as shown in figure 6.22 below.



The right hand

Figure 6.22

Magnetisation

Activity 6.4: Investigating what happens when a magnetic material is stroked with a bar magnet

Materials

- a bar magnet
- a steel metal bar
- paper clips

Procedure

- Bring the steel metal bar close to the paper clips.
- Observe and record what happens to the paper clips in a table of results as the one shown below.

- (iii) Stroke the steel metal bar with one end of the bar magnet ten times in the same direction, lifting the bar magnet high up after each stroke.
(iv) Repeat steps (i) and (ii).

Table of results

Observations before stroking the steel metal bar	Observation after stroking the steel metal bar

Table 6.8

Discussion

- (i) What happened to the paper clip when the steel metal bar was brought close to it:
(a) before stroking it.
(b) after stroking it.
(ii) Explain your observations.

Activity 6.5: Finding out what happens to a steel metal bar when it is placed inside a solenoid.

Materials

- a steel metal bar
- a solenoid
- 2 cells
- connecting leads
- a switch
- paper clips

Procedure

- (i) Set up the apparatus as shown in figure 6. 23 below.

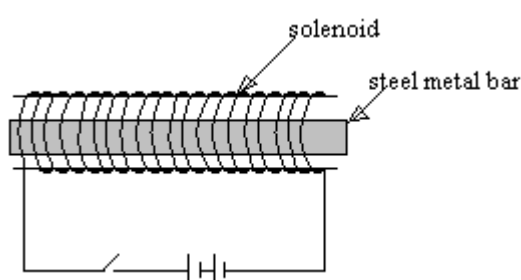


Figure 6.23

- (ii) Bring the paper clips close to the ends of the steel metal bar.
(iii) Record your observations in a table of results.
(iv) Close the switch and repeat steps (ii) and (iii).
(v) Open the switch and remove the steel metal bar from the solenoid.
(vi) Bring the steel metal bar close to the paper clips and record your observations.

Table of results

Observations before closing the switch	Observations while the switch is closed	Observations after the steel metal bar is removed from the solenoid.
--	---	--

Table 6.9

Discussion

- Explain your observations.

Observations

We have observed that the steel metal bar could not attract the metal paper clips before it was stroked with a bar magnet. However, it was able to attract the paper clips after it was stroked with a bar magnet.

A steel metal bar was also able to attract a steel metal bar while it was inside a solenoid through which electric current was flowing. After removing it from the solenoid it was still able to attract the paper clips.

The results of the two experiments above show that the steel metal bars become magnets either when they were stroked with a magnet or when placed inside a current carrying solenoid. The process of making magnets from magnetic materials is known as magnetization. Therefore, magnetic materials can be magnetized by using either stroking method or electrical method.

The stroking methods

This method involves stroking (touching) steel bars with a magnet. There are two ways of making magnets by stroking.

(a) Single touch

In a single touch the steel bar to be magnetised is stroked from end to end several times (about 20 times) in the same direction and with the same pole of the magnet. Between successive strokes, the magnet is lifted high above the bar as shown in the diagram. This prevents the magnetism already induced from being weakened.

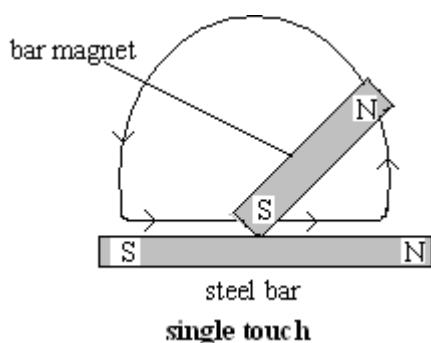


Figure 6.24

The pole produced at the end of the bar where the stroking ends is of the opposite kind to that of the stroking pole. The single touch method is disadvantageous because it produces magnets in which the one pole is nearer the end of the bar than the other.

(b) Divided / double touch

In the divided touch method, the bar to be magnetized is stroked from the centre outwards with unlike poles of two magnets at the same time.

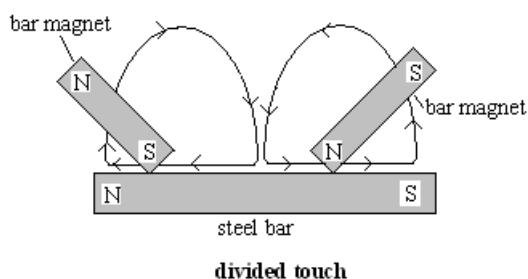


Figure 6.25

The pole produced at the end of the steel bar where the stroke ends is of the opposite to that of the stroking pole. If the steel bar is magnetized by divided touch using *like poles* such as two S-poles, the bar will obtain N-poles at both ends, and a double S-pole at the centre as shown in the figure below,

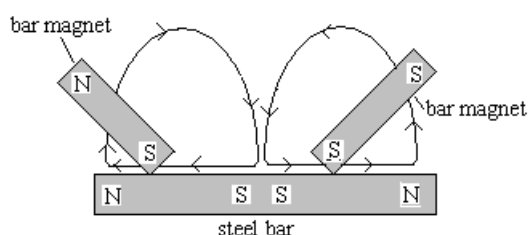


Figure 6.26

The bar of such kind is said to possess consequent poles.

(ii) Electrical Methods

To magnetize a steel bar by electrical method, the bar is placed inside a solenoid and direct current (d.c.) of 6 – 12 v is switched on and off.

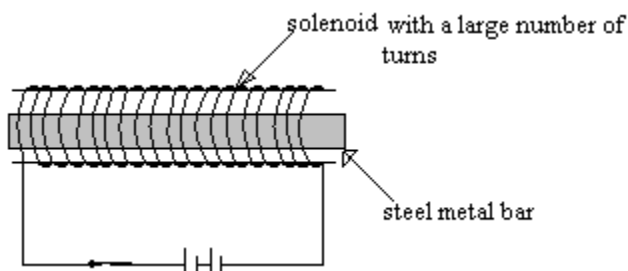


Figure 6.27

When the current is finally switched off permanently the steel metal bar stays magnetized.

Magnetic and nonmagnetic materials

Magnetic materials are these materials which can be attracted by magnets and can also be magnetized. Nonmagnetic materials are those materials that cannot be attracted by magnets and cannot be magnetized. Magnetic materials can be soft or hard.

Soft magnetic materials

These are materials that are easy to magnetize but also lose their magnetism easily. An example of a soft magnetic material is iron. Soft magnetic materials are used in electromagnets and as cores in transformers.

Hard magnetic materials

Hard magnetic materials are those magnetic materials which are difficult to magnetize and do not lose their magnetism easily. Steel is an example of hard magnetic materials. Hard magnetic materials are used to make permanent magnets.

The origin of magnetism

The magnetic effects of all materials originate from electric currents. In all types of matter there are small magnetic fields created by electric currents of electrons as they move around the nucleus. The path taken by each electron around the nucleus inside the atom acts as a current carrying coil with one end being the north pole and the other south pole.

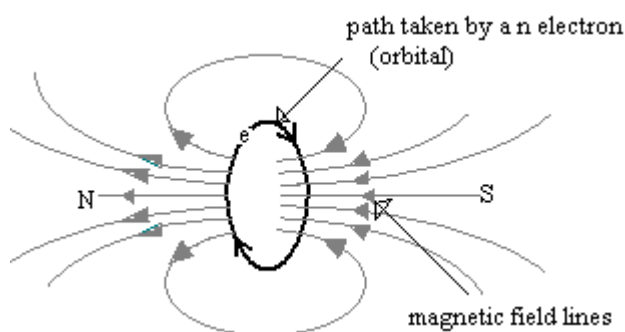


Figure 6.28

In atoms of some materials the small magnetic fields point in different directions and they cancel each other out. The materials which are made of the atoms of that kind cannot be magnetized. These materials are known as nonmagnetic materials.

In magnetic materials, the magnetic fields in each atom point in the same direction and so do not cancel each other out. This means that each atom behaves like a small magnet. When the small atomic magnets in a piece of material point in different directions, then the material is unmagnetized. For the material to become magnetized more atomic magnets must line up in the same direction.

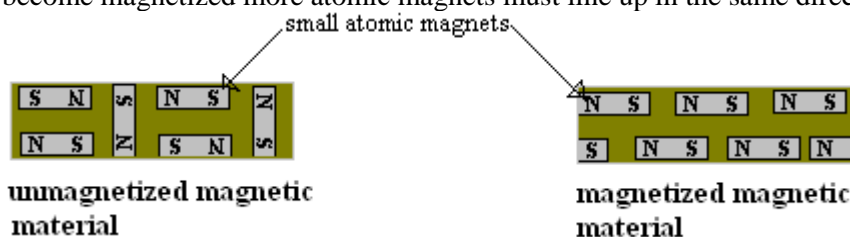


Figure 6.29

Demagnetization

Activity 6.6: Investigating what happens when a magnetized material is hammered.

Materials

- a strongly magnetized steel metal bar
- a hammer
- paper

Procedure

- (i) Bring a strongly magnetized material close to paper clips.
- (ii) Observe and record what happens.
- (iii) Hammer the magnetized steel metal bar.
- (iv) Repeat steps (i) and (ii).

Table of results

Observations before hammering the magnetized steel metal bar	Observations after hammering the magnetized steel metal bar

Table 6.10

Discussion

Explain your observations.

Activity 6.8: Investigating what happens when a magnetized steel metal bar is heated.

Material

- a strongly magnetized steel metal bar
- a source of fire
- paper clips

Procedure

- (i) Bring the magnetized steel metal bar close to the paper clips.
- (ii) Observe and record your observations.
- (iii) Heat the magnetized steel metal bar in a flame of fire.
- (iv) Let it cool down.
- (v) Repeat steps (i) and (ii)

Table of results

Observations before heating the magnetized steel metal bar	Observations after heating the magnetized steel metal bar

Table 6.11

Discussion

- (i) What happened to the steel metal bar after it was heated?
- (ii) Explain your observations

Observations

The magnetised metal bar did not attract the paper clips after it was hammered. It did not also attract the paper clips after it was heated. This means that hammering or heating the magnetized steel metal bar caused it to lose its magnetism. This is because hammering or heating a magnet causes its atoms to vibrate faster and hence being thrown out of their lines. The process of causing a magnet to lose its magnetism is called demagnetization.

Alternating current (ac) can also demagnetize magnets. In this process the magnet is placed inside a solenoid through which alternating current is flowing. Then, while the current is flowing the bar magnet is pulled slowly to a distance away from the solenoid.

Caring for magnets

Storing magnets improperly can cause them to be demagnetized slowly. Storing them in the following ways can prevent them from losing their magnetism.

(a) Storing them with keeper

Bar magnets should be kept with opposite poles together, with keepers across each end and with a piece of wood or plastic between them as shown in the figure below.

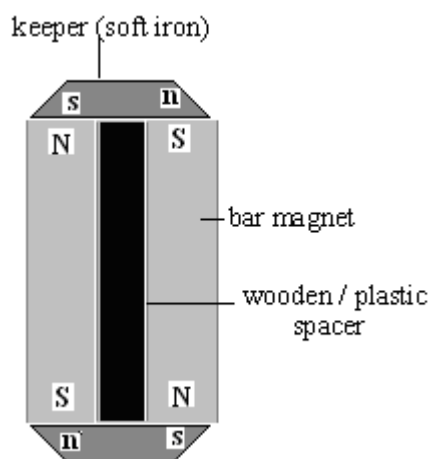


Figure 6.30

Horse shoe magnets should be stored with a keeper across the poles as shown in the figure below.

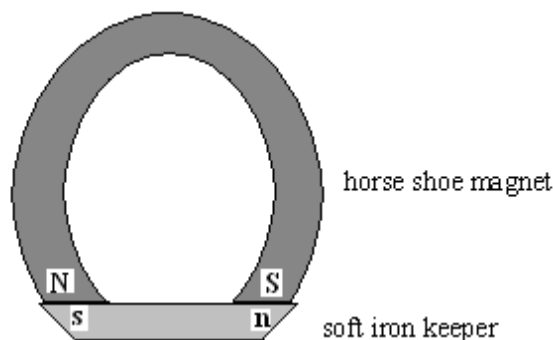
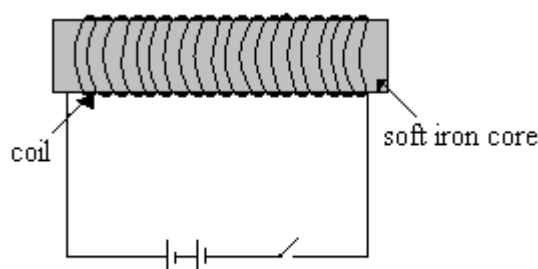


Figure 6.31

Electromagnetism Electromagnetism means the ability iron or steel bars placed inside a solenoid to attract magnetic materials. The magnets made in this way are called electromagnets.



A simple electromagnet

Figure 6.32

The magnetism of an electromagnet made by an iron bar is temporary and can be switched on and off. The strength of electromagnets can be increased by;

- i – Increasing the current.
- ii – increasing the number of turns in the coil
- iii –by making the poles closer as in the C shaped (horse shoe)magnet.

Uses of Electromagnets;

1. Electromagnets are used in electric bells

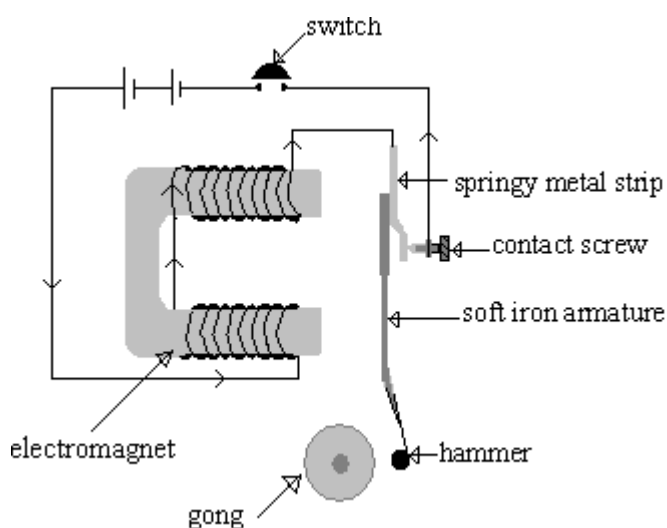


Figure 6.33

How electric bells work

When the switch is closed, current flows through the coil. The electromagnet attracts the hammer and the hammer hits the gong. The movement of the hammer towards the gong switches off the electromagnet at the contact, and the springy metal strip pulls the hammer back, and reconnecting the circuit. The cycle is repeated so long as the switch is on, and continuous ringing occurs.

Uses of Electric bells

Electric bells can be used in the following ways;

- (i) Fire alarms
- (ii) Flood alarms

i. Fire alarms

In large forests, it can be difficult for people to realise the fire has started somewhere. However, using fire alarm systems with bimetallic strips and contacts at different locations in the forest can help to warn people whenever there is fire in the forest. Consider figure 6.34 below.

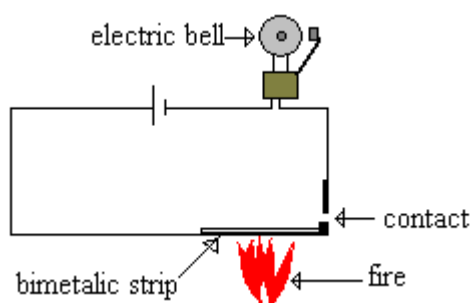


Figure 6.34

Heat from fire makes the bimetallic strip to bend and complete the electric circuit and so making the bell will ring.

ii. Floods alarms

In flood prone areas, flood alarm systems can help to warn people whenever flooding water is coming. Consider the figure below;

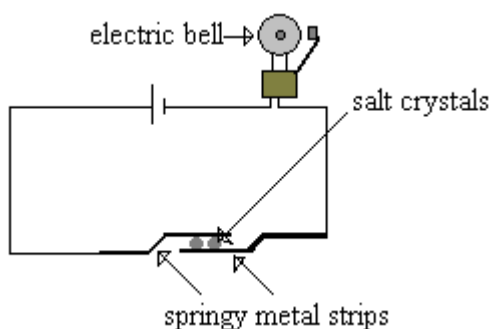


Figure 6.35

The contact with the salt crystal is placed in a shade at a place where flooding water passes through. Water from the floods will dissolve the salt and the springy metal contact will complete the circuit, and the bell will start ringing, thus warning people that flooding water is coming.

Force on a conductor in a magnetic field: The Motor Rule

Activity 6.9: Investigating what happens when a current carrying conductor is placed in a magnetic field.

Materials

- a thin light and flexible conductor.
- 3 connecting leads
- 2 cells
- 2 bar magnets (or a horse shoe magnet)
- a clamp stand

Procedure

(i) Set up the apparatus as follows.

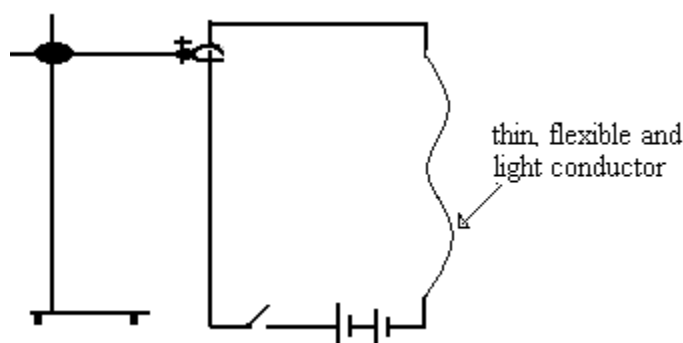


Figure 6.36

- (ii) Bring the two bar magnets close the thin and flexible conductor side by side with opposite poles facing each other.
- (iii) With the switch still open, observe what happens to the thin flexible conductor.
- (iv) Record your observations.
- (v) Repeat steps (i) to (iv) with the switch closed.
- (vi) Reverse the terminals of the cells and repeat steps (i) to (iv).

Table of results

Observations when the switch is open	Observations when the switch is closed	Observations when the terminals of the cells are reversed and the switch
--------------------------------------	--	--

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		is closed

Table 6.12

Discussion

- What happened to the conductor when it was placed in a magnetic field with the switch open?
- What happened to the conductor when it was placed in a magnetic field with the switch closed?
- How did the direction of movement of the conductor relate to the direction of the magnetic field of the magnets and to the direction of the flow of the electric current in the conductor?

Observations

When a current carrying conductor is placed in a magnetic field it experiences a force (it is pushed). In fact, there are three directions of movements involved whenever a current carrying conductor is placed in a magnetic field, all perpendicular to each other. These directions are as follows:

- the direction of the force (or thrust) on the conductor,
- the direction of flow of current through the conductor and
- the direction of field between the opposite poles of the magnets.

The direction of the force (***the Thrust***) on the wire is determined by the Fleming's left hand rule (also called the motor rule). The rule states that if you hold the thumb and the first two fingers of your left hand at right angles to each other, then the **F**irst finger points in the direction of **F**ield, the **s**eCond in the direction of **C**urrent and the **T**humb in the direction of the **T**hrust (force).

Explanation

When a current carrying conductor is placed in a magnetic field of the magnets, then two magnetic fields are involved; the magnetic field around the conductor and another magnetic field between the poles of the magnets. On one side of conductor, the field lines of the two fields point in opposite direction while on the other side they point in the same direction as shown in figure 6. 36 below.

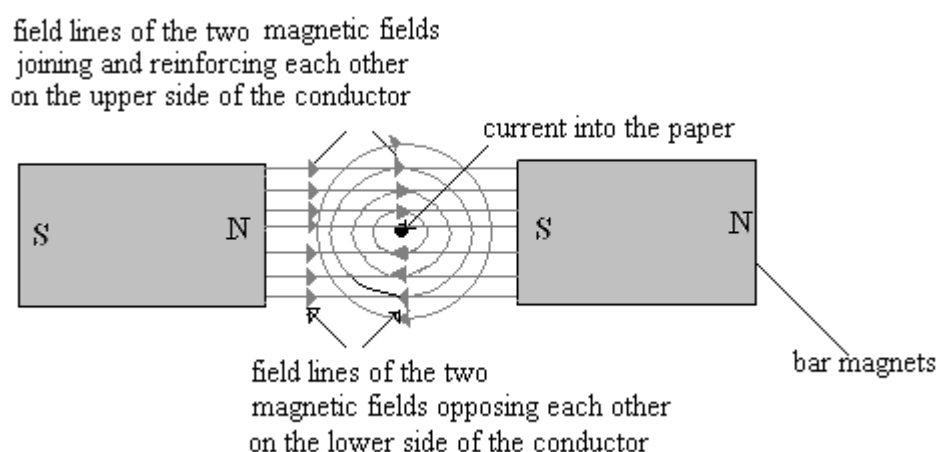


Figure 6.36

The magnetic field lines that point in opposite directions cancel each other out, while those that point in the direction join together and reinforce each other. It is the resultant magnetic field lines that push the conductor out as illustrated in figure 6.37 below.

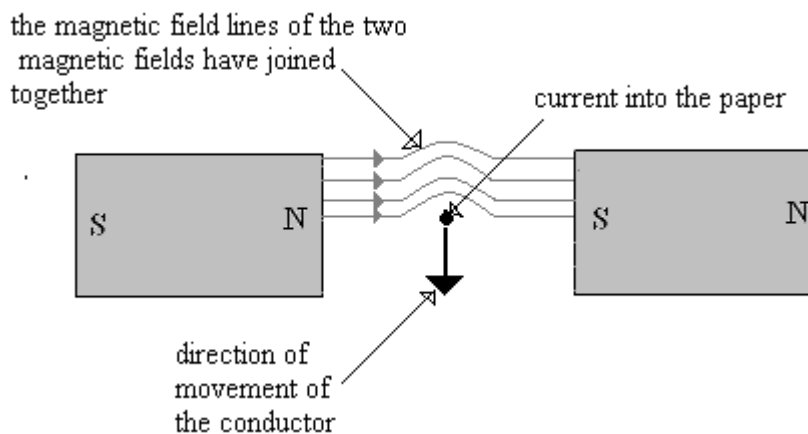


Figure 6.37

Application of the force on a conductor in a magnetic field

The force on a conductor in a magnetic field is applied in the following appliances

- (i) electric motor
- (ii) loud speakers.

(i) The electric motors

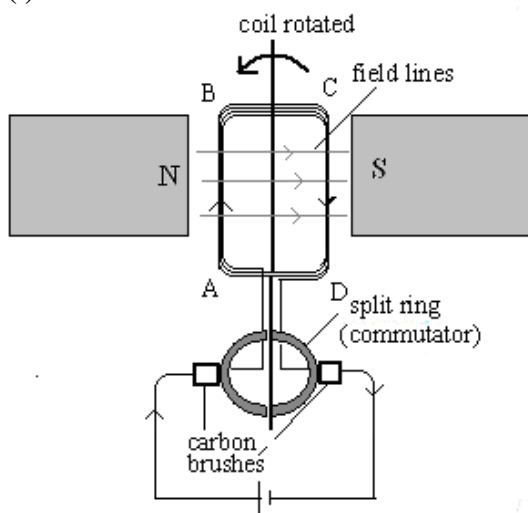


Figure 6.38

An electric motor contains a rectangular coil of wire of many turns mounted on an axle between two poles of a permanent magnet. Current passes into the coil via two brushes that are pushed against a *split-ring*, known as the commutator. The commutator rotates with the coil and reverses the current into the coil every half cycle to ensure the current flows in the same direction near each pole and so the coil continues to rotate in one direction.

How electric motors work

When current flows through the coil, forces are set up on the two sides of the coil labelled

CD and AB. These two forces are equal in magnitude but opposite in direction and so cause the coil to rotate. When the coil reaches the vertical position, no current flows for a moment, but the coil keeps on rotating because of its inertia.

(ii) The loud speaker

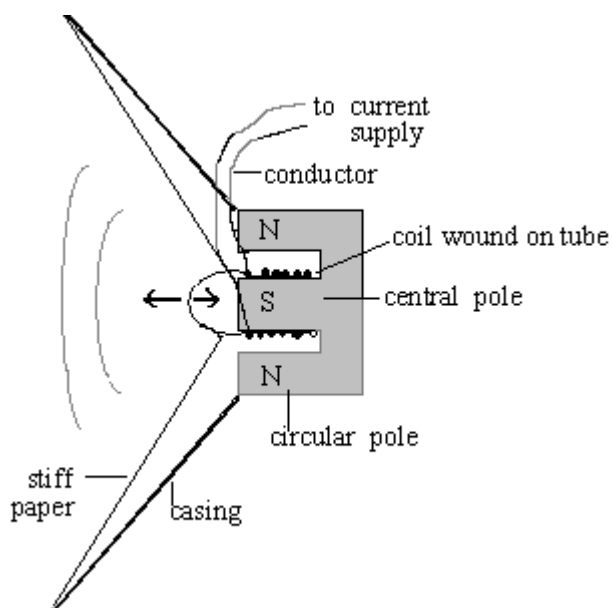


Figure 6. 39

The moving coil loud speaker consists of a cylindrical permanent magnet which produces a strong radial magnetic field, a coil which is free to move short distances backwards and forwards in the magnetic field and a stiff paper cone attached to the coil.

How the moving coil loud speaker works

The wire in the coil lies at right angles to the magnetic field. If an alternating current is passed through the coil, the coil is pushed alternately backwards and forwards. This makes the paper cone to vibrate and sound waves are given out as a result. The nature of the sound produced depends on the frequency and the amplitude of the current flowing through the coil.

Electromagnetic induction

Activity 6.10: Investigating if magnetism can induce an electric current.

Materials

- a bar magnet
- a solenoid
- connecting leads
- a zero centred galvanometer (or an ammeter)

Procedure

- (i) Set up the apparatus as in figure 6.40 below
- (ii) Observe the pointer as the magnet is being pushed into the solenoid.
- (iii) Leave the magnet inside the solenoid and observe the pointer.
- (iv) Pull the magnet out of the solenoid and observe the pointer again as the magnet is being pulled out.
- (v) Record your observations

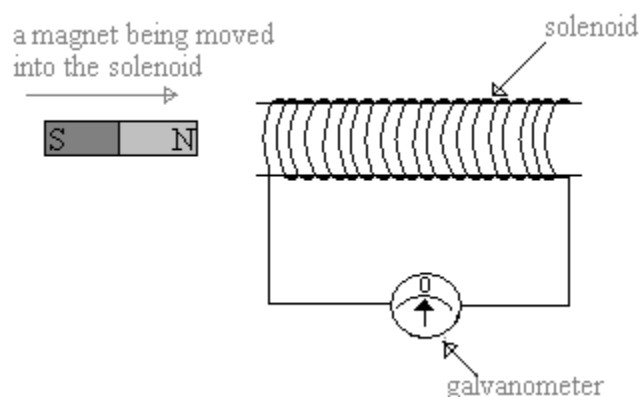


Figure 6.40

Table of results

Observations when the magnet is being pushed in	Observations when the magnet is left inside the solenoid	Observations when the magnet is being pulled out.

Table 6.13

Discussion

- What happened to the pointer of the galvanometer when the magnet was;
 - (a) being moved into the solenoid?
 - (b) stationary inside the solenoid
 - (c) being moved out from the solenoid?
- What does the movement of the pointer mean?
- What is the relationship between the direction of movement of the pointer and the direction of movement of the magnet?

Activity 6.11: Investigating if magnetism in one coil can induce an electric current in another coil.

Materials

- 2 coils of insulated conductor with many turns
- a switch
- a zero centred galvanometer
- 5 connecting leads
- 3 cells

Procedure

- Arrange the apparatus as shown in figure 6.41 below.
- Close the switch in the first coil and observe the pointer in the second coil as the switch is being closed.
- Leave the switch closed and observe the pointer.
- Open the switch and observe the pointer as the switch is being opened.
- Record your observations.

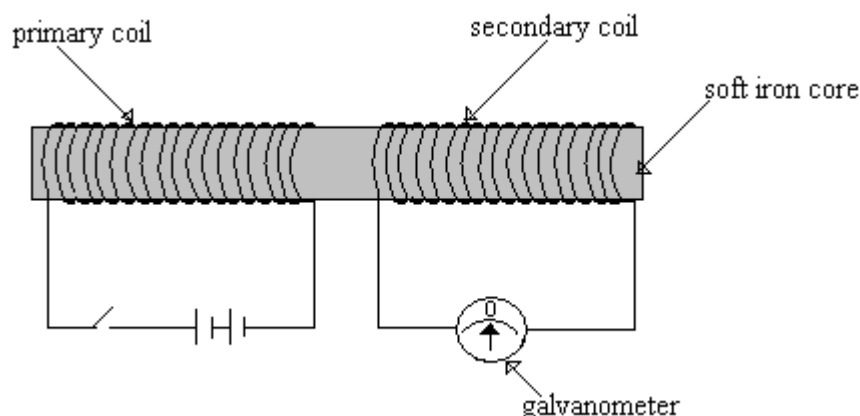


Figure 6.41

Table of results

Observations when the switch is being closed	Observations when the switch is left closed	Observations when the switch is being opened.

Table 6.13

Discussion

- What happened to the pointer of the galvanometer as the switch was;
 - (a) being closed?
 - (b) left closed?
 - (c) being opened?
- Was there any relationship between the direction of movement of the pointer and what was being done to the switch?
- Explain your observations.

Observations

We have seen that the pointer of the galvanometer was moving when the bar magnet was being moved into or out of the solenoid and when the switch was being closed or opened. There was no movement of the pointer when the bar magnet was stationary inside the solenoid and when switch was kept closed or open. The movement of the pointer indicates that current was flowing through the conductor. This means that an emf, which caused the flow of the current, was induced in the coil which was connected to the galvanometer either by the movement of the magnet in or out of the solenoid or by the switching on and off of the current in the first coil.

How does the emf get induced?

As the bar magnet is being moved into or out of the solenoid its magnetic field lines interact with (or are being cut by) the conductor. There is no cutting of the conductor by the magnetic field lines when the magnet is stationary inside the solenoid. When current in one coil is being used to induce emf in another coil, the magnetic field lines in the first coil interact with or are cut by the conductor in the other coil only when the current in the first coil being switched on or off. When switching on, the magnetic field lines are cut as they grow and when switching off they are cut as they die out. Therefore, an emf is induced when magnetic field lines are being cut by the conductor.

The process of using magnetism to generate an electric current in a coil of a conductor is called electromagnetic induction.

The Direction of the induced current

There is a relationship between the direction of the induced current and the magnetic field that causes it. The direction can be determined by using the Lenz's law or the Fleming's right hand rule.

i. Lenz's law

The Lenz's law states that an induced current always flows in a direction such that it opposes the change in the magnetic field that produces it. Consider figure 6.42 below;

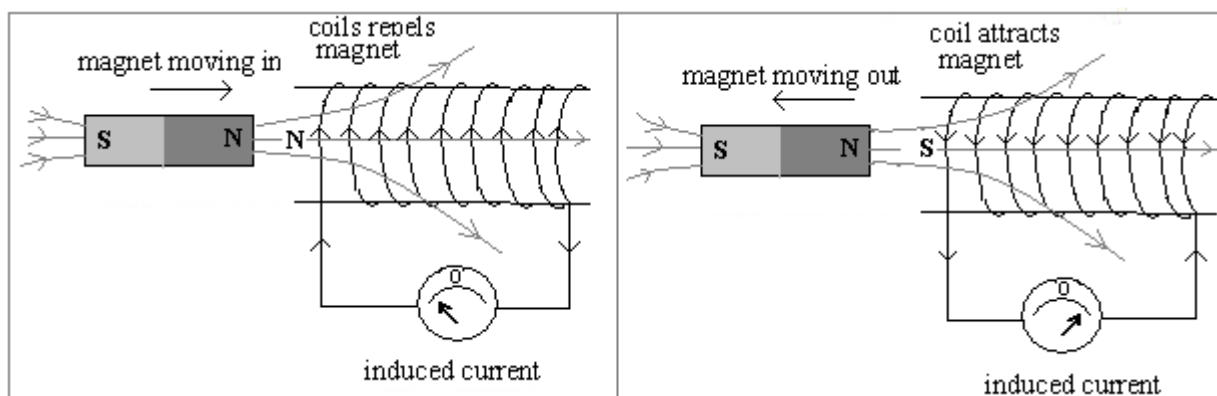


Figure 6.42

It can be observed the figure that when the magnet is being pushed into the coil, current flows in one direction and makes the coil to become a magnet whose N-pole opposes the approaching N- pole of the magnet (like poles repel/ oppose each other). When the magnet pulled out of the coil, the current flows in the opposite direction and the poles of the coil are reversed so that the S-pole of the coil opposes the moving out of the magnet by attracting it. The same also happens when current in one coil induces current in another coil. When current in the first coil is switched on the magnetic field lines grow around it. As the magnet field lines grow around it and are cutting the conductor in the second coil, current flows in the second coil in such a direction that the magnetic field lines around it should oppose the magnetic field lines that are growing in the first coil. The opposite happens when the switch is being opened. As such the induced current keeps on changing its directions. It is an alternating current.

ii. Fleming's right hand rule

The Fleming's right hand rule states that if you hold the first two fingers of your right hand at right angles to each other, then the **F**irst finger points in the direction of the magnetic **F**ield, the **s**econd finger points in the direction **C**urrent, and the **T**humb the direction of **M**otion.

Applications of electromagnetic induction

The electromagnetic induction has a wide application in our everyday life. For instance, the use of magnet to induce emf is applied in generators and microphones. While the use of current in one coil to induce current in another coil is applied in transformers.

The generators

There are two types of generators; the alternating current (ac) generator and the direct current (dc) generator

(a) Ac Generator (the alternator)

An ac generator consists of a coil made up of an insulated copper wire which is rotated by turning an axle, **slip rings** and carbon brushes. The **slip rings** are fixed to the coil and rotate with it.

The brushes are two contacts which rub against the slip ring and keep the coil connected to the outside part of the circuit.

How ac generators work

When the coil is rotated, it cuts magnetic field lines, so an emf is generated (induced). This generated emf makes the current flow. As the coil rotates, each side travels upwards, downwards, upwards, downwards... and so on. So an alternating current is generated.

The size of the induced emf (and the current) can be increased by;

- increasing the number of turns on the coil.
- increasing the area of the coil
- using a stronger magnet
- rotating the coil faster.

(b) The dc generator

The dc generator, just like an electric motor, consists of a wire of many turns mounted on an axle between two poles of a permanent magnet, brushes and *split-ring* or commutators. The difference between the dc generator and the electric motor is that in the motor, current is used to make the coil in the magnetic field rotate (turn), where as in the dc generator, the coil is rotated physically in the magnetic field to produce current.

How dc generators work

When the coil is rotated, an emf and current is generated in the coil. The split rings reverse the connection with the outside circuit every time the coil passes through the vertical. So the current in the outside circuit always flows in the same direction.

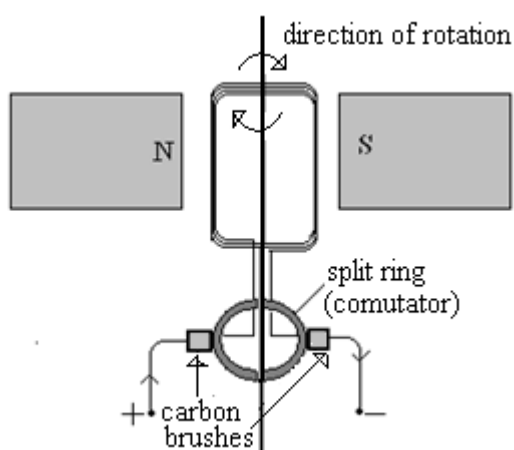


Figure 6. 43

ii. The microphone

A moving-coil microphone contains a thin metal foil diaphragm and a coil attached to the rear of the diaphragm in a magnetic field of a permanent magnet.

The current can be amplified (made larger) and heard in a loud speaker.

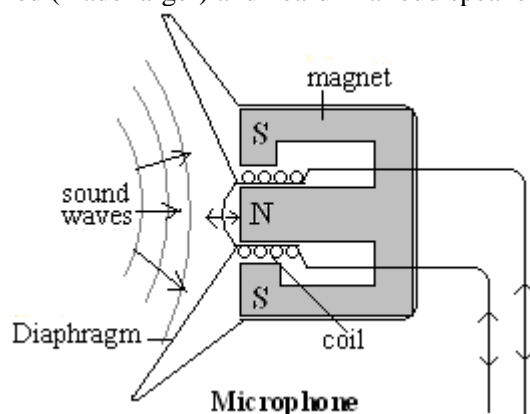


Figure 6. 44

How microphones work

When you speak into a microphone, the sound waves cause the diaphragm to vibrate.

This makes the coil to move in and out between the poles of the magnet. As the coil moves in the magnetic field, a current is induced in it.

The transformers

The induction of emf in the first coil, voltage by changing magnetic field in another coil is referred to as mutual induction. Mutual induction occurs when the current in the first coil is changing. Instead of switching on and off the current in the first coil, the easiest way is to use the alternating current in the first coil because it is always changing on its own.

Mutual induction is used in transformers to change (transforms) voltage and current from one value to another. The transformer consists of two coils of wire wound on a soft iron core. The soft iron core helps to increase the amount of the induced current by concentrating and directing the field lines from the first coil into the second coil.

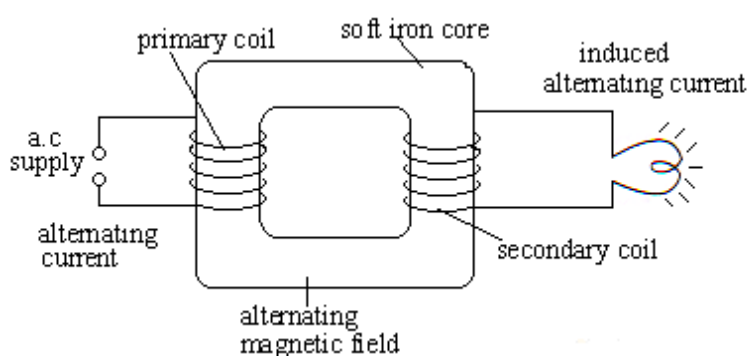


Figure 6.45

The coil connected to the ac supply is called **primary**, and the coil connected to the induced output voltage is called **secondary**.

Types of transformers

There are two principal types of transformers; the step up transformer and the step down transformer

(i) The step up transformer

A step up transformer has more turns in the secondary coil than in the primary coil as shown in figure 6.45 (a). Figure 6.45 (b) shows the symbol for the step up transformer is as follows;

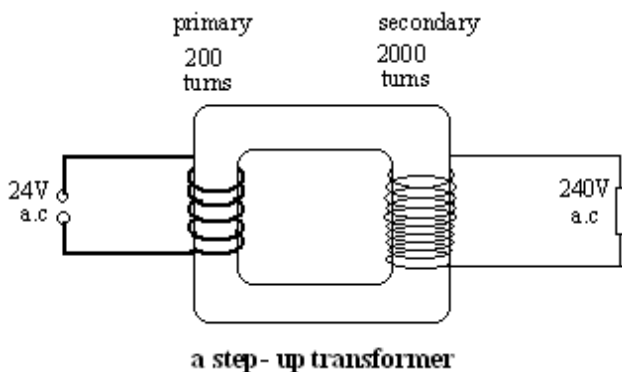


Figure 6.45 (a)

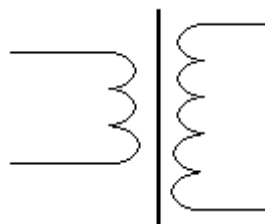


Figure 6.45(b)

In a step up transformer the value of the output voltage (emf) is greater than the value of input voltage.

ii. The step down transformer

A step down transformer has more turns in the primary coil than in the secondary (figure 6.46 (a)). Figure 6.46(b) shows the symbol for the step down transformer.

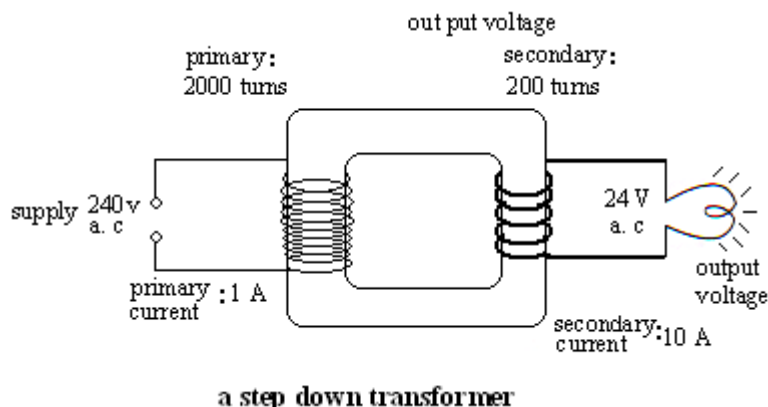


Figure 6.46 (a)

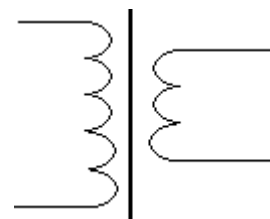


Figure 6.46 (b)

In a step down transformer the value of the output voltage in the primary coil is lower than the value of the input voltage in the secondary coil.

Transformer Equation

The value of the induced emf (V_s) depends on the value of the primary voltage (V_p), the number of turns of wire on the primary coils (N_p) and number of turns of wire on the secondary (N_s).

The primary voltage, the secondary voltage, the number of turns on the primary coil and the number of turns on the secondary coil, are related by the following equation;

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

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

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

Example

What is the output voltage if the input voltage is 12V, the primary coil has 100 turns and the secondary coil has 25 turns?

Working out

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

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

$$V_s = \frac{12}{100} \times 25$$

$$= 3\text{v}$$

Exercise

A transformer steps down the mains supply from 230V to 10v to operate an answering machine.

- What is the turn ratio of the transformer windings?
- How many turns are on the primary if the secondary has 100 turns?
- What is the current in the primary if the transformer the current in the machine is 2A?

Transformer and Electrical Power

An electrical power = VI. In a transformer, the power in the primary coil = the power in the secondary coil. If the current in the primary coil is I_s and the current in the secondary coil is I_p , then; $V_p \times I_p = V_s \times I_s$.

$$\Rightarrow \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

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

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

$$\Rightarrow I_s = \frac{N_p}{N_s} \times I_p$$

In a step up transformer, N_p is smaller than the N_s , therefore current is stepped down, where as in a step down transformer, N_p is greater than the N_s and so current is stepped up. This means that in a step up transformer, it is the voltage that is stepped up while current is stepped down, and in a step down, the voltage is stepped down while current is stepped up and always $V_p \times I_p = V_s \times I_s$.

The importance of transmitting electricity at high voltage and low current

The power loss across a conductor = I^2R . When electricity is transmitted from the power stations to the consumers through the cables, some of the power is lost as heat. **The power lost = I^2R .**

To reduce the power loss the electricity is transmitted at a very high voltage and a very low current so that the ' I^2 ' is as small as possible.

Advantages of ac over dc

- ac in one coil can easily induce another current in another coil.
- ac can easily be transmitted long distances without losing much power because it can easily be stepped up and down in transformers.

Example

Cables of resistance 2Ω supply 2kW of power. Calculate the power loss in the cable if power is transmitted at:

- (a) 200 V (b) 2000 V.

Working out:

(a) $P = VI$

$$I = \frac{P}{V} \\ = \frac{2000}{200} \\ = 10A$$

$$\begin{aligned} \text{Power loss} &= I^2R \\ &= 10^2 \times 2 \\ &= 200W \end{aligned}$$

$$\begin{aligned} \text{(b) } I &= \frac{P}{V} \\ &= \frac{2000}{2000} \\ &= 1A \end{aligned}$$

$$\begin{aligned} \text{Power loss} &= I^2R \\ &= 1^2 \times 2 \\ &= 2W \end{aligned}$$

Notice that the higher the voltage, the lower the power loss.

Exercise

The figure below shows an electrical transmission system. The resistance of the transmission wire on each side is 4Ω . The 6 V, 24W lamp is operated at its correct rating.

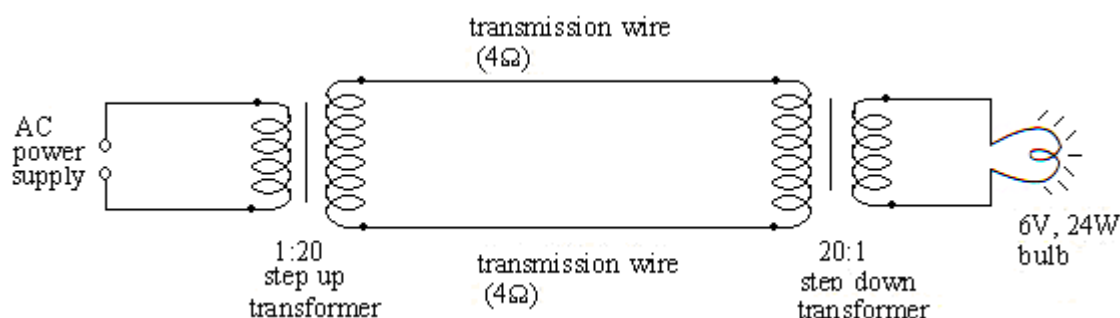


Figure 6.47

Assuming no energy is lost in the transformer, calculate;

- the current through the bulb.
- the current through the transmission wire
- the power loss in the transmission wire

Energy loss in transformers

In transformers, not all the electrical energy in the primary coil is transferred to the secondary coil. Some of the energy is lost in transformers due to the following factors; the resistance of the wires in the coils, heating effect of eddy currents and leakage.

Resistance of the wires in the coils

Energy in the form of heat is lost in both the primary coil and the secondary coil due to resistance of the wire. In large transformers oil is used to cool down the wires to avoid overheating.

Heating effect of eddy currents

The iron core is in a changing magnetic field of the primary coil. This induces an emf and hence small circulating currents called eddy currents in the core. Some of the input energy is lost as heat energy produced by these eddy currents.

The energy loss due to eddy currents is reduced by using laminated (layered) iron core rather than a solid block. A laminated iron core is a core made up of sheets of iron insulated from each other.

Leakage of field lines

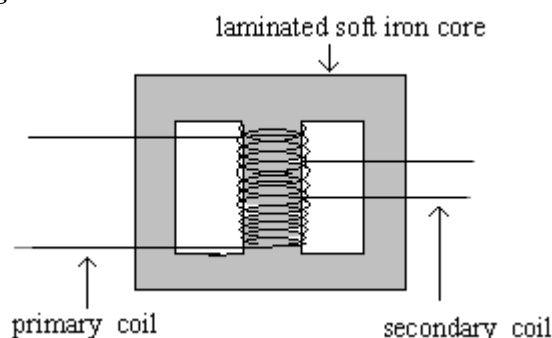


Figure 6.48

All the field lines produced by the primary coil may not cut the secondary coil.

Energy loss due to leakage of field lines may be prevented by winding the primary and the secondary coils one on top of the other as shown 6.45;

Review Questions

1. (a) A transformer is used on the 240 V a.c. supply to deliver 9 A at 80 V to a heating coil. 10 % of the energy is lost in the transformer itself, what is the current in the primary coil?
- (b) Give three reasons why transformers are not 100% efficient.
2. A step up transformer is designed to operate from a 20 V supply and deliver energy at 250 V. If the transformer is 90 % efficient, determine the current its primary coil when the output terminals are connected to a 250 V 100 W bulb.
3. a. Explain why a voltmeter is connected in parallel while an ammeter is connected in series.
- b. What is the resistance of the following resistors?

(i)

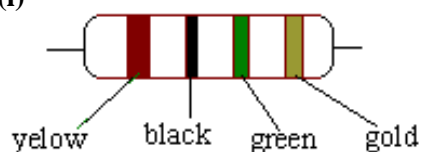


Figure 6.52

(ii)



Figure 6.53

- (i) Explain the difference between an electric motor and a d.c generator.
- (ii) State two ways by which the speed of an electric motor can be increased.
- d. (i) Explain how a steel bar can be magnetised by double touch method.
- (ii) Explain why iron bars cannot be used to make permanent bar magnets.

4. a. The figure below is a circuit diagram

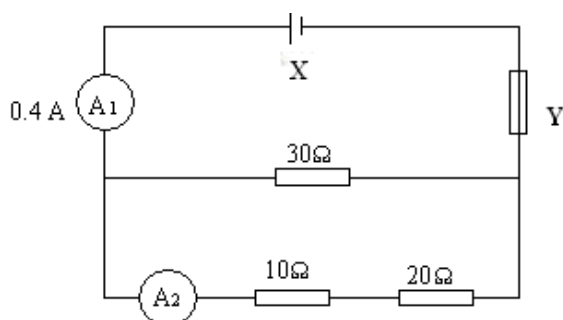


Figure 6.54

- (i) Name components labelled X and Y.
- (ii) Calculate the total resistance of the resistors.
- (iii) Calculate the current in the 30 Ω resistor.
- (iv). Work out the voltage across the 10Ω resistor.
- b. (i) Define a kilowatt – hour.
- (ii) The power rating of a television is 150W. How much power in kilowatt – hours will it use if it is on for 15hours.

- (iii) If the cost of power is K5.00 per kilowatt – hour, what will be the cost for running the television in **b. (ii)** for 8 hour per day for 5 days?

5. The following information appears on the rating plate of an electric heater in normal use;

Electrical supply - 220V Maximum power - 22000 W WARNING: This appliance must be earthed

- a. Calculate the current that will flow through the element of the heater.
b. Calculate the resistance of the element of the electric heater.
c. How much electrical energy, in joules, would this heater use in 5 minutes?
d. If the electrical energy costs K4.00 per kwh, what is the cost of using this heater for 12 hours at its maximum rating?
e. Why is it important to earth this appliance?
6. a. What is the advantage of high power voltage transmission?
b. What is the main advantage of a.c power transmission over d.c. power transmission?
c. What is the function of transformers in power transmission?
d. Cables of resistance 8Ω supply 4kW of power. Calculate the power loss in the cable if the power is transmitted at;
(i) 200V
(ii) 2000V
7. a. A transformer has a primary coil with 100 turns and a secondary coil with 250 turns.
(i) The primary voltage is 12V. Is this a step up or a step down transformer?
(ii) Calculate the secondary voltage.
b. A current of 2A is passed through the primary coil of 50 turns.
The secondary coil has 400 turns. What current would be obtained from this transformer?
c. A step – down transformer gives current of 5A at 12 V. If the primary Voltage is 240V, find; (i) the primary current
(ii) the power input
(iii) the power out put
8. A magnet is used to induce current in a coil of wire. List three things that could be done to increase the current produced.
9. a. Give two advantages of connecting bulbs in parallel.
b. The figure below is an electric circuit

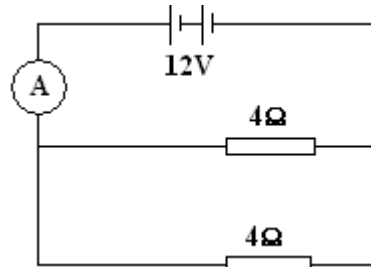


Figure 6.55

- (i) What does the ammeter read when the switch is open (OFF)?
(ii) What is the current through each of the 4Ω resistors when the switch is closed (ON)?
(iii) What does the ammeter read when switch is closed?

(iv) What is the combined resistance of the resistors when the switch is closed?

c. Consider the resistor arrangement shown below;

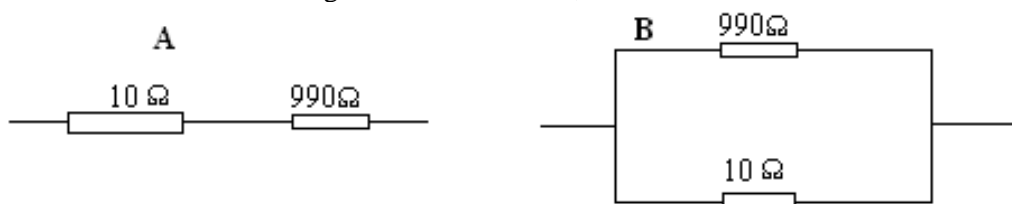


Figure 6.56

Which arrangement, A or B has the lower resistance?
Show your working.

13. With a well labelled diagram, describe how an a.c. generator is modified to produce a direct current.

1 OSCILLATIONS AND WAVES

Oscillations

Definition

An oscillation is defined as a to and fro, or an up and down, movement of an object from its rest position. Examples of oscillating systems are pendulums and vibrating springs. In each oscillating system there is an interchange of potential energy (PE) and kinetic energy (KE) as shown in figure below:

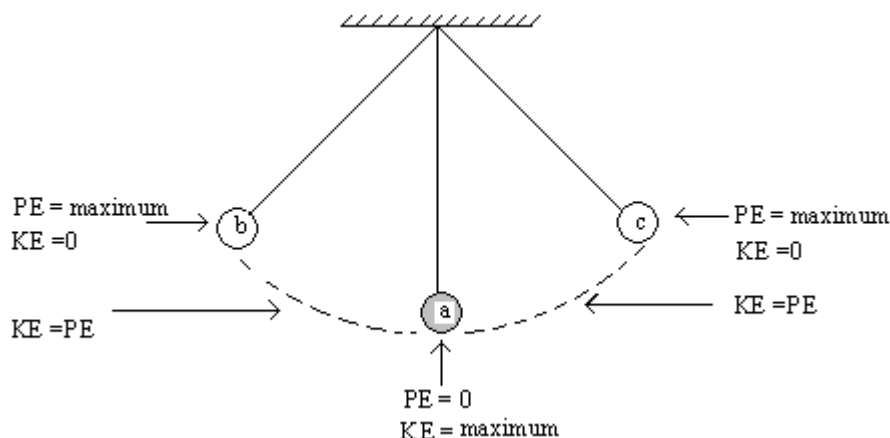


Figure 1.1

A complete oscillation is made when the mass moves from position b to c and back to b. The graphs representing oscillating systems have a sinusoidal shape as shown in figure below;

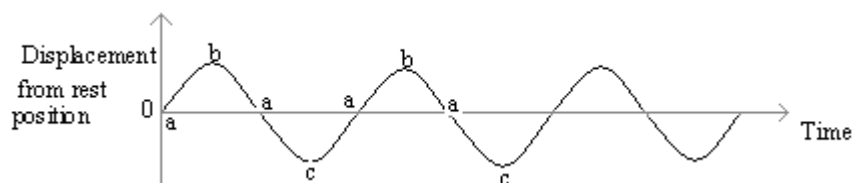


Figure 1.2

Characteristics of Oscillations:

(i) Amplitude, a .

Amplitude is distance (or displacement) between rest position (i.e. equilibrium position) and the extreme positions of an oscillating system as shown in figures below:

(a) Pendulum

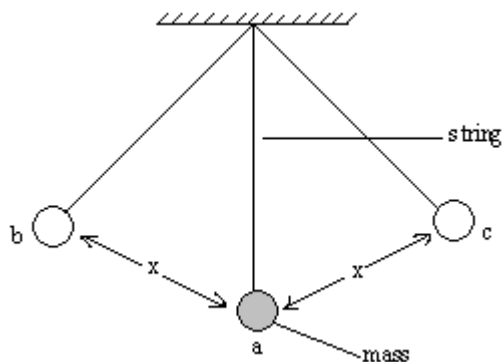


Figure 1.3

(b) Mass on spring system

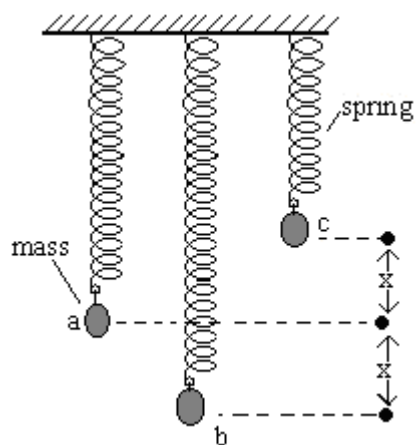


Figure 1.4

x = amplitude

b and **c** = extreme positions.

a = rest position.

Graphically the amplitude is represented as follows:

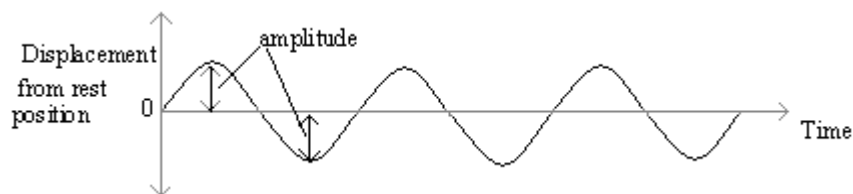


Figure1.5

The Amplitude in Ideal and Real Oscillations:

Ideal oscillations are the perfect oscillations whereby both potential energy and kinetic energy are conserved. The amplitude of an ideal oscillation remains constant as shown in figure 1.6 below:

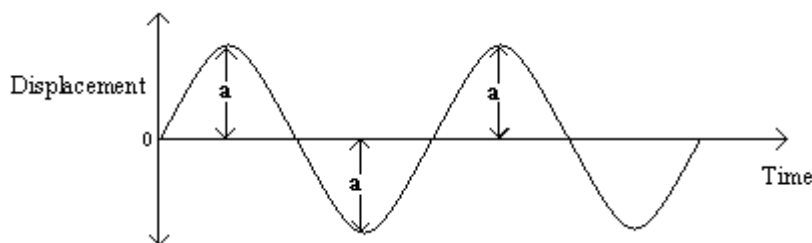


Figure1.6

The ideal oscillations cannot be achieved due to:

- (i) air resistance on the bob
- (ii) friction at the pivot
- (iii) gravitational force on the bob.

In real oscillations the potential and kinetic energies are not conserved. The amplitude (a) of the oscillating system decreases with time as shown in the figure 1.7 below

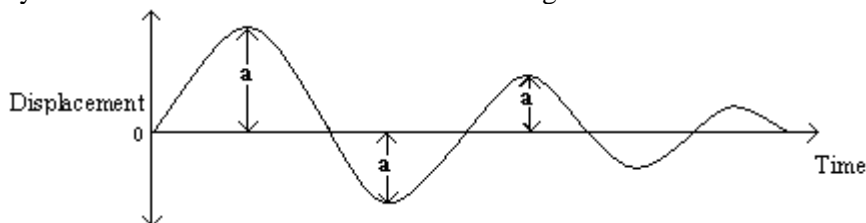


Figure1.7

(ii)Period, T.

The period of an oscillating system means the time taken for one complete oscillation.

i. e. from *b* to *c* and back to *b*, or from *c* to *b* and back to *c*.

$$T = \frac{\text{Total time taken}}{\text{Number of complete oscillations.}}$$

The SI unit for period is second, *s*.

(iii)Frequency, f:

Frequency means the number of complete oscillations made in one second.

$$f = \frac{\text{Number of complete oscillations}}{\text{Total time taken}}$$

The SI unit for frequency is hertz, Hz.

The relationship between the frequency, f and period, T

$$f = 1/T \quad \text{or} \\ T = 1/f.$$

Question

The graph in figure 1.8 shows the oscillations of a swinging pendulum;

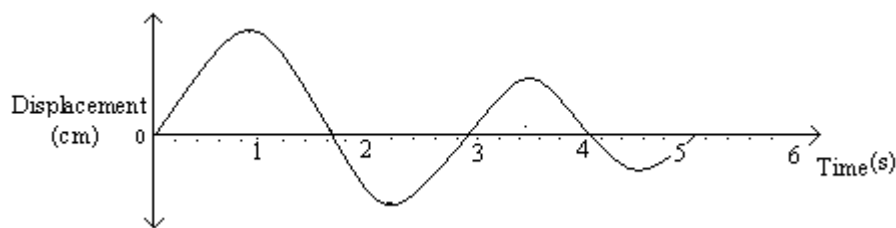


Figure1.8

- What name is give to a graph of such shape?
- What was the initial amplitude of the pendulum?
- How many complete oscillations were made in 5 seconds?
- Calculate the period T of the pendulum.
- Calculate the frequency of the pendulum.
- Why does the amplitude of the pendulum decreasing with time?
- Comment on PE and KE in the system.

Activity 1.1

Aim To investigate the effect of mass on the frequency of vibrating spring

Materials:

- Spring
- 50g mass slots (50g bags of sand)
- Clamp stand
- Wrist watch or stop clock

Procedure:

- Arrange the apparatus as shown in the figure below:

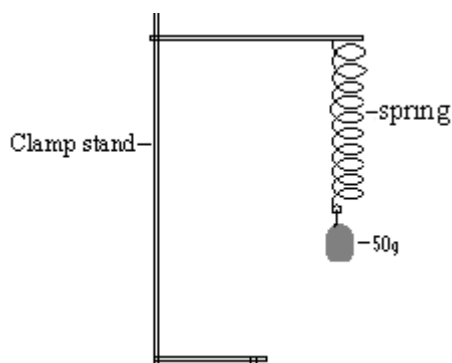


Figure1.9

- Pull the mass vertically downwards a few centimetres, and release it so that it oscillates up and down above and below its rest position.
- Find time taken for the mass to make 10 complete oscillations.
- Record the time in the table as shown below.

Mass (g)	Time taken for 10 complete oscillations (s)	Period , T (s)	Frequency, f (Hz)
50			
100			
150			
200			

Table 1.1

(vi). Repeat steps (i) to (iv) with a mass of 100g, 150g, and 200g.

Discussion

How does the increase in the mass affect

(a) the period of the system?

(b) the frequency of the system?

Observation

As the mass increases, the period increases. As the period increases, the frequency decreases.

Activity 1.2

Aim: To investigate the effect of amplitude on the frequency of a pendulum

Materials:

- String (30 cm long)
- 50g mass slot (50g bag of sand)
- Clamp stand
- Wrist watch or stop clock

Procedure:

(i) Arrange the apparatus as shown below:

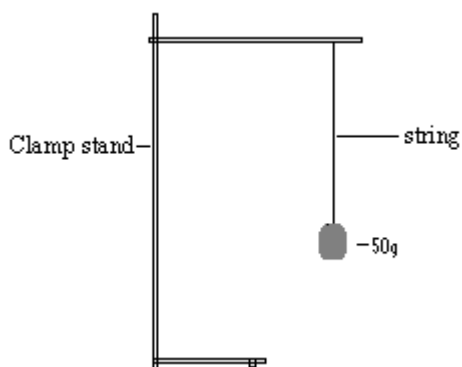


Figure1.10

(ii) Measure the time for 20 complete oscillations when the bob is given the amplitude of 4 cm, 6cm, 8cm and 10cm respectively.

(iii) Record the results in the table below;

Amplitude, a (cm)	Time taken for 10 complete oscillations (s)	Period , T (s)	Frequency, f (Hz)
4			
6			
8			
10			

Table 1.2

(iv) Plot a graph of the period, T against amplitude, a.

Discussion;

How does the amplitude affect :

(a) the period of the pendulum?

(b) the frequency of the pendulum?

Observation

As the amplitude increases, the period does not change much. Since the frequency depends on the period, then amplitude does not affect the frequency over a certain range.

Activity 1.3

Aim: To investigate the effect of mass on the frequency of a pendulum

Materials:

- String (30 cm long)
- 50g mass slot (50g bag of sand)
- Clamp stand
- Wrist watch or stop clock

Procedure:

- Measure the time for 20 complete oscillations when the mass of the bob is 50g, 100g, 150g and 200g respectively.
- Record the results in the table below;

Mass (g)	Period (T)	Frequency, (f)
50		
100		
150		
200		

Table 1.3

- Plot a graph of period against the mass of the bob.

Discussion

What is happening to the frequency when mass is increased?

Observation:

The mass has no effect on the period of the pendulum. The period depends on the maximum speed at the lowest point and the maximum speed only depends on the height at the highest point. Since the frequency depends on the period of the pendulum, then mass has no effect on the frequency.

Activity 1.4

Aim: To investigate the effect length on the frequency, f of a pendulum

Materials:

- a string of length 100cm
- 50g mass
- a clamp stand
- a stop clock
- 1 meter rule

Procedure:

- set up the apparatus as shown in figure 1.11 below with the length of string 20 cm long.

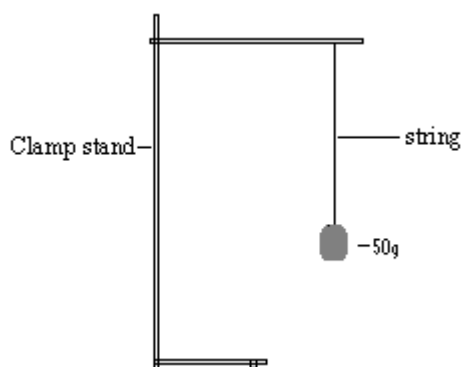


Figure 1.11

- (ii) Set up the pendulum to oscillate and record the time taken for 10 complete oscillations when the length of the string is 20 cm, 40 cm, 80 cm and 100 cm respectively.
 (iii) Record the results in the table below;

Length, L (cm)	Period (T)	Frequency, (f)
10		
20		
30		
40		

Table 1.4

Discussion:

What is happening to the frequency, f when the length of the string is increasing?

Observation:

As the length increases the height through which the mass moves decreases. When the height decreases potential energy of the mass will decrease, so the kinetic energy decreases also. Speed, therefore decreases. As the speed decreases the period will decrease hence decreasing the frequency.

Factors that affect the Frequency of Oscillating System:

The factors that affect the frequency of oscillating systems are as follows:

Oscillating System	Factors affecting frequency, f
Vibrating spring	- mass on the spring - force constant of the spring
Pendulum	- length of the string - considerable amplitude change

Table 1.5

1.2 Waves:

Introduction

Activity 1.5

Aim: To demonstrate a wave on a rope.

Materials:

- A long rope (about 10 m long)
- A piece of paper.

Procedure:

- Tie the piece of paper to the rope at a point as shown in figure 1.12 below



Figure 1.12

b. Let one student hold one end while another shakes the other end.

Discussion

What is happening to the rope and the piece of paper?

What does the other person feel at the other end while the other one is shaking the other end?

Observation:

When the rope is disturbed at one end by shaking it from side to side, all the particles of the rope also shake from side to side up to the end until the person holding it at the other end feels a pull. This means that the disturbance at one end has spread to all the other parts of the rope and energy is transferred from one end to the other end. Each individual particle in the rope is temporarily displaced and returns to its original position.

Definition

A wave is the travelling disturbance which carries energy with it from a source to another place without transferring of matter. Examples of waves include sound light, radio waves e.t.c. Waves that require medium of transmission are called mechanical waves. Examples of mechanical waves include sound wave. The waves that do not require medium of transmission are called electromagnetic waves and their examples include radio waves. Electromagnetic waves can carry energy through vacuum.

Types of waves:

Activity: 1.6

Aim: Observing the direction of movement of particles relative to direction of the wave.

Requirements: slinky spring, a small piece of cloth or plastic paper and a long bench.

- Procedure:**
- (1) Tie the piece of paper / cloth to the slinky spring somewhere at the middle.
 - (2) Let one student hold the spring to the bench at one end along the central line of the bench.
 - (3) Hold the other end of the spring to the other end of the bench.
 - (4) Move one end of the spring from side to side.
 - (5) Mark the path taken by the cloth as the spring is moved from side to side.
 - (6) Copy the path of the cloth into an exercise book.
 - (7) Repeat steps 1 – 6 but this time move the spring forward and backward.

Discussion;

How did the direction of oscillations of the cloth / plastic paper relate to the direction of the wave when the end of the spring was moved,

- (a) from side to side?
- (b) forward and back ward ?

Observation

When the end of the spring was moved from side to side, the direction of oscillations of the cloth were at right angles the direction of the wave. When the end was moved forward and back ward, the direction of the oscillations were parallel to the direction of the wave. The directions of the oscillations of the cloth / plastic paper are the directions of the oscillations of all the particles in the spring when the spring was moved from

side to side and when the spring was moved forward and backward respectively. There, therefore, are two types of waves depending on the directions of oscillations of the particles in the medium of a wave.

(a) Transverse wave;

This is a wave where particles oscillate at right angles to direction of the travelling wave.

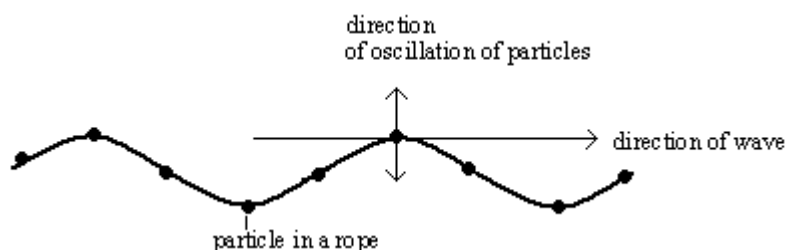


Figure 1.13

Examples of transverse

-Water waves

-waves in a rope and slinky spring.

-All electromagnetic waves, that is; light, infrared radiation, radio waves, ultraviolet, X- rays, gamma rays and microwaves.

Transverse waves have hilly shaped and valley shaped parts. The hilly shaped part is known as a crest and the valley shaped part is known as a trough as shown in figure 1.14 below;

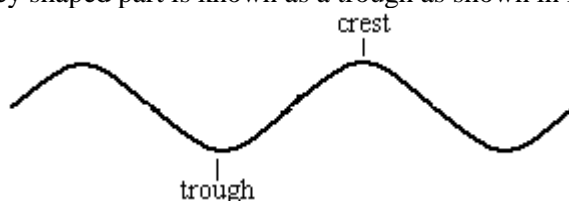


Figure 1.14

(b) Longitudinal Waves;

A longitudinal is the wave where the particles oscillate parallel to the direction of the wave.

e.g

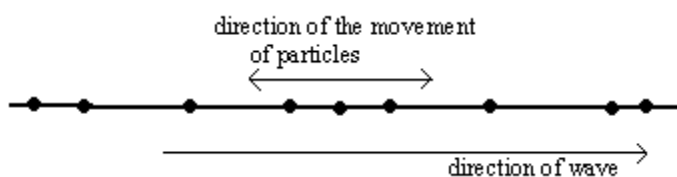


Figure 1.15

An example of longitudinal wave is the sound wave.

Longitudinal waves have points where particles move together and other points where particles move further apart. The points where particles move together are called compressions and the points where particles move further apart are called rarefactions.

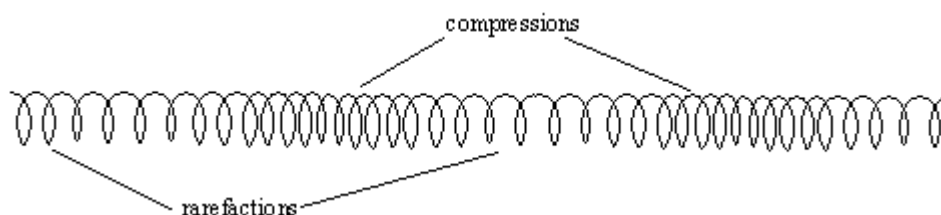


Figure 1.15

Characteristics of waves;

i- Amplitude, a ;

This is the maximum displacement of particles from their rest positions (i. e. the undisturbed position). It is measured in centimetres or meters.

ii- Frequency, f .

Frequency means the number of complete waves that pass through a point in one second or the number of waves produced per second. It is measured in Hertz (Hz).

iii- Period, T .

This is the time taken for one complete wave. It is measured in seconds.

iv - Wave length, λ .

Wavelength is the distance occupied by one complete wave or the distance between adjacent crests or troughs.

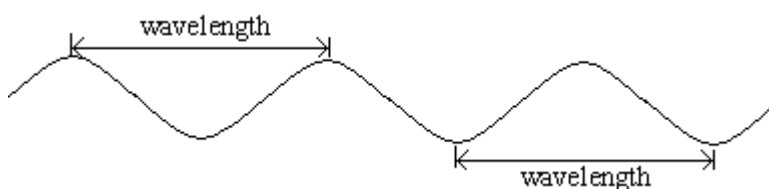


Figure 1.16

Wavelength also means the distance between adjacent rarefactions or compressions.

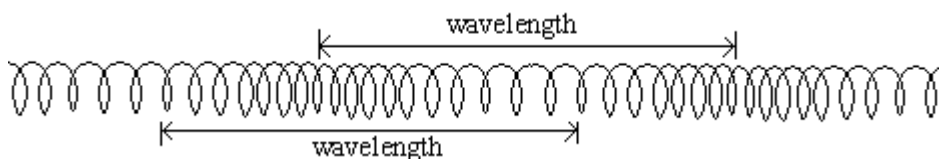


Figure 1.17

Wave length is equal to the distance moved by a particle in one complete wave.

v - Wave speed, v :

This is the distance moved by crest or a trough in one complete wave per second.

$$= \frac{\text{Wave length}}{\text{Period}}$$

$$v = \lambda / T$$

Phase

Particles are said to be in phase if they are in the same state of motion.

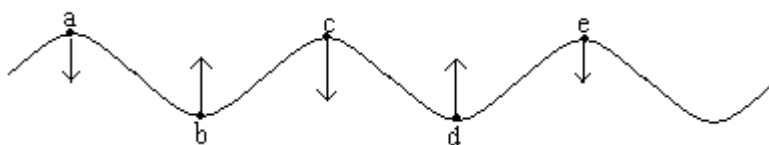


Figure 1.18

Points *a*, *c* and *e* are in phase, and also points *b*, and *d* are in phase. However, points *a* and *b* are out of phase.

Wave fronts:

A wave front is a line joining all points on the wave that have the same phase.

They could be crests or troughs of waves which spread out in all directions such as water waves as shown below.

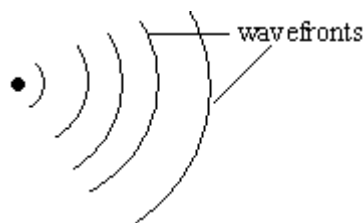


Figure 1.19

The wave Equation;

From the wave speed we have;

$$v = \frac{\lambda}{T} \quad \text{which means} \quad v = \frac{1}{T} \times \lambda$$

$$\text{But } \frac{1}{T} = f$$

$$\therefore v = f\lambda$$

Examples

1. A wave of wavelength, λ 20cm has a frequency of 3 Hz. What is the speed of the wave, v .

$$v = f\lambda$$

$$\lambda = 20\text{cm/wavelength}, f = 3 \text{ Hz (i.e 3 waves/second),}$$

$$\begin{aligned} \therefore v &= \frac{20\text{cm}}{\text{Wavelength}} \times \frac{3 \text{ wavelengths}}{\text{second}} \\ &= 60 \text{ cm/s} \end{aligned}$$

2. What is the speed of a wave of frequency 400Hz with wavelength 2m? What is the period of the wave?

Working out

$$v = f\lambda; \quad f = 400\text{Hz}, \quad \lambda = 2\text{m}$$

$$\begin{aligned} \therefore v &= 400 \times 2 \\ &= 800\text{m / s} \end{aligned}$$

$$\begin{aligned} \text{Period} &= 1/f \\ &= 1/400 \\ &= 0.0025 \text{ s} \end{aligned}$$

Exercise

1. A sound wave of frequency 200Hz and wavelength 3m is travelling in water. Calculate the speed and the period of the wave.
2. A radio station broadcasts on a frequency of 200 000 Hz and the wavelength of its signal is 1500 m.
 - (a). calculate the speed of the wave in m / s.
 - (b). the wavelength of the signal of another station that broadcasts on a frequency of 1 250 000 Hz.

Representing Waves:

- (a). *Graphical representation;*

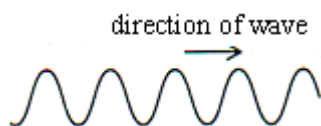


Figure 1.20

(b). Wavefronts;

Wavefront is a line joining all points on the wave that have the same phase.

A wave front can be a crest in a transverse wave or a compression in a longitudinal wave.

If the source is periodic, successions of wave fronts, all of them with same shape are produced.

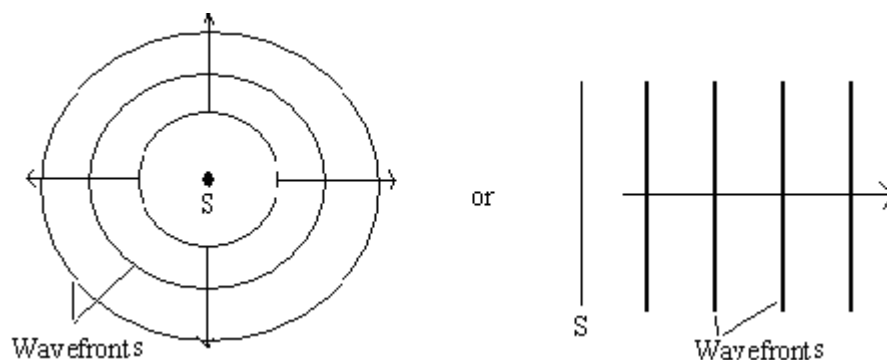


Figure 1.21

The line at right angles to the wavefronts that shows the direction of travel of the wave is called a ray.

Exercise:

The figure below is a representation of water waves 1 second after a stone was thrown into the water. The lines represent crests.

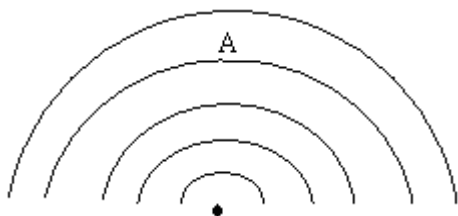


Figure 1.22

- i. What is represented at A at this instant?
- ii. Find;
(a) wavelength
(b) period
(c) speed of the wave
(d) frequency of the wave.

Properties of waves:

i. Reflection:

Reflection means sending back of a wave when it strikes an obstacle.

All waves are reflected when an obstacle is placed in their path.

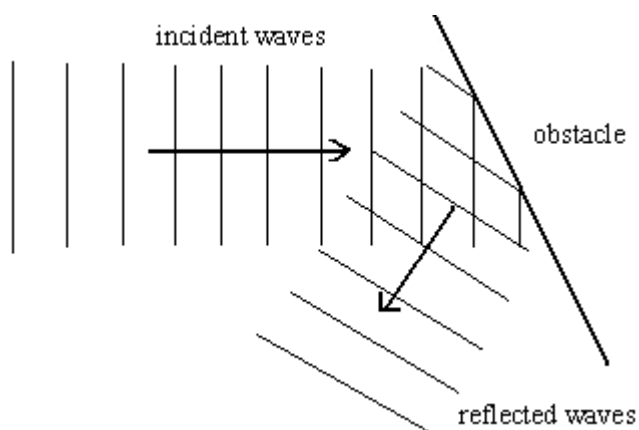


Figure 1.24

ii. Refraction:

All waves are refracted when their speed is changed. They bend towards the normal if their speed is reduced and away from the normal if their speed is increased.

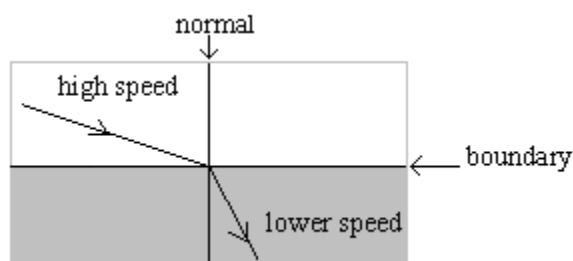


Figure 1.25

Refraction of water waves

Water waves undergo refraction when they are slowed down. The speed of the water waves is reduced when they enter shallow water and can be refracted if they enter the shallow water at an angle.

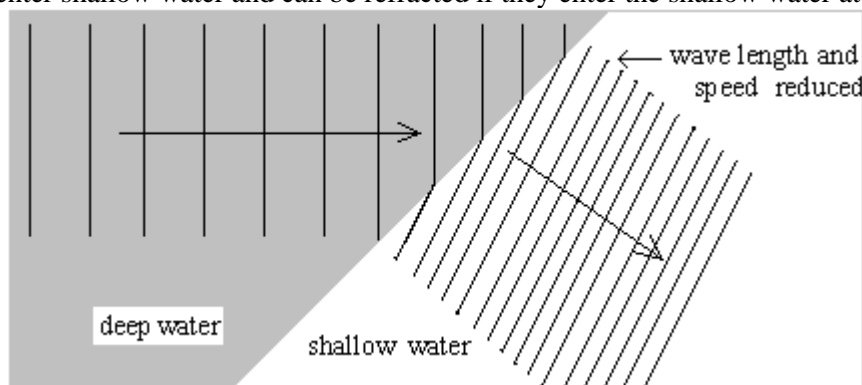


Figure 1.26

The frequency of the water waves depends on the source (vibrator) only. So there is no change in the frequency of the waves when they enter shallow water. The change in the speed of the waves is caused by the change in the wavelength of the waves.

Consider the wave equation:

The wave speed, $v = \text{frequency, } f \times \text{wavelength, } \lambda$. The frequency of the wave is constant because it depends on the source. Therefore, the speed of any wave depends on its wavelength, λ . When the wavelength is reduced, the speed is also reduced. For example when the water waves enter shallow water their wave length reduces as shown below:

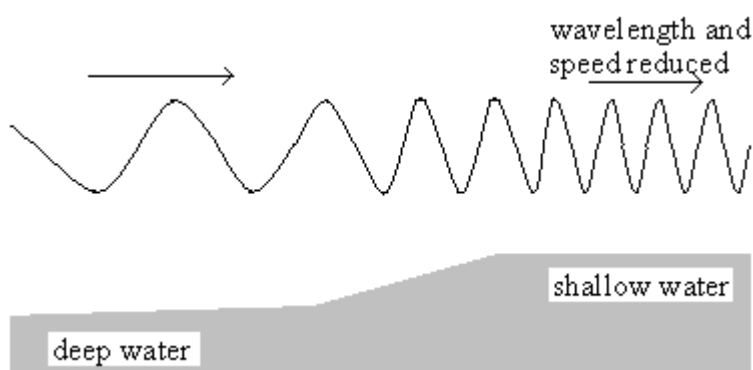


Figure 1.27

The waves change their direction as they close up if they enter the shallow water at an angle between 0° and 90° .

Exercise:

A set of plane waves on a ripple tank reaches a portion of the tank where water is shallower. Explain with the aid of a diagram what happens to the waves if they enter the area of the shallow water at an angle of;

- (i) 45°
- (ii) 90°

iii. Diffraction:

Diffraction means bending of a wave as it passes around an obstacle.

The extent of the diffraction depends on the size of the gap formed by the obstacle. When the size of gap is about the same size as the wave length of the wave, the waves that pass through the gap come out circular and spread out in all directions as shown below:

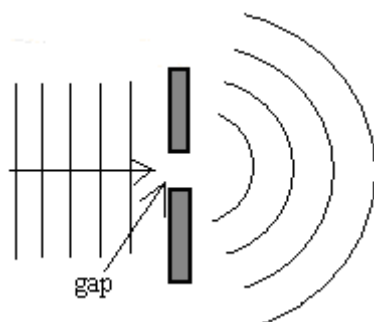


Figure 1.28

When the size of the gap is wider as compared to the wavelength of the wave, the waves that pass through the gap are straight with slight bends at the edges as shown below:

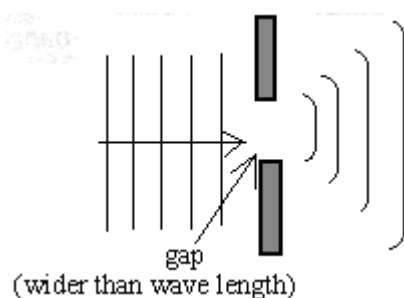


Figure 1.29

iv. Interference:

Interference means combination of waves. There are two types of interferences.

a. Constructive Interference:

Constructive interference is when the crest of one wave meets the crest of another wave and a wave with a bigger crest is formed or when troughs of two waves meet.

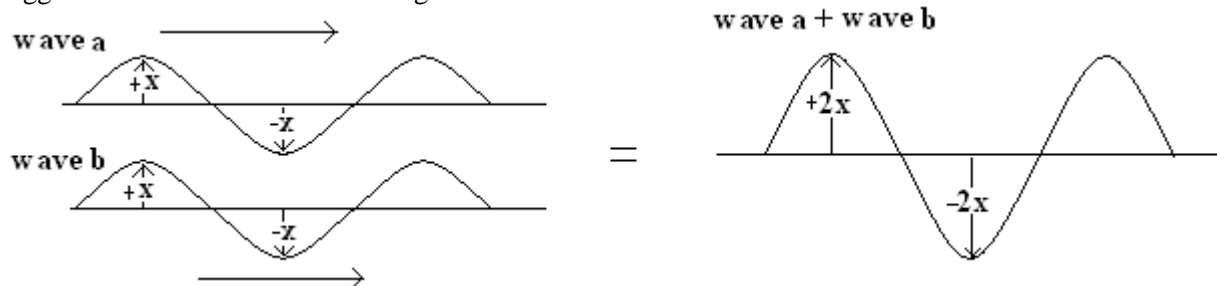


Figure 1.30

When this happens the amplitude is doubled, but the frequency and the wavelength do not change.

b. Destructive Interference:

This happens when the crest of one wave and the trough of another wave meet. When this happens the two waves cancel each other out as shown in figure 1.31 below.

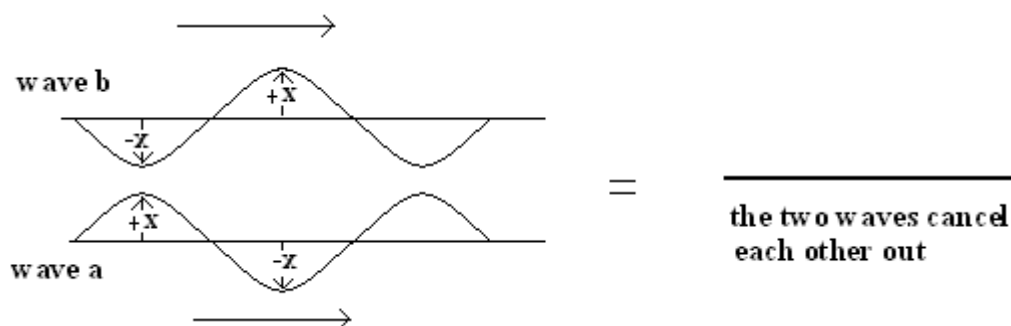


Figure 1.31

There is no wave after the destructive interference.

The interference of water waves:

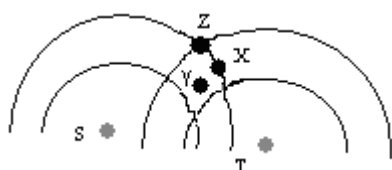


Figure 1.32

At X, a crest of the wave from the source T meets a trough of a wave from the source S. The result is a destructive interference.

At Y, troughs of both waves meet, and the result is a wave with a deeper trough.

At Z, crests meet and the result is a bigger crest.

Lenses

Definition

A lens is a transparent material with curved surfaces. Parallel light rays are refracted (bend) when they pass through the lens.

Types of lenses:

There are two types of lenses depending on whether their surfaces are curved inwards or outwards. These are convex lenses and concave lenses.

i. Convex Lenses

These are the lenses which are thickest through the middle. Light rays converge (meet) at one point after passing through the convex lens.

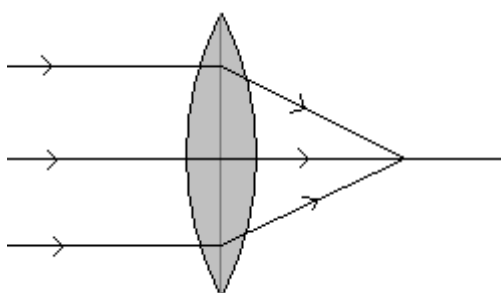


Figure 1.33

Because of this the convex lenses are also called converging lenses.

ii. Concave Lenses:

These are lenses which are thickest around the edges as shown in figure 1.34 below. Light rays diverge after passing through the concave lens.

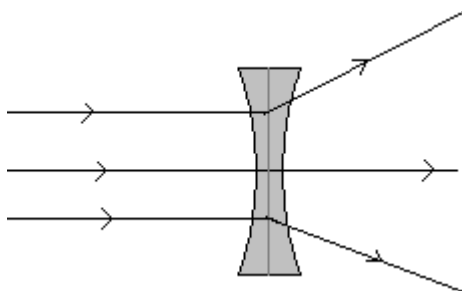


Figure 1.34

Because the light rays diverge after passing through the concave lenses, these lenses are also referred to as diverging lenses.

Terms associated with Lenses and ray diagrams:

The terms that are associated with lenses are optical centre, principal axis, principal focus, focal length, focal plane, object distance, and image distance.

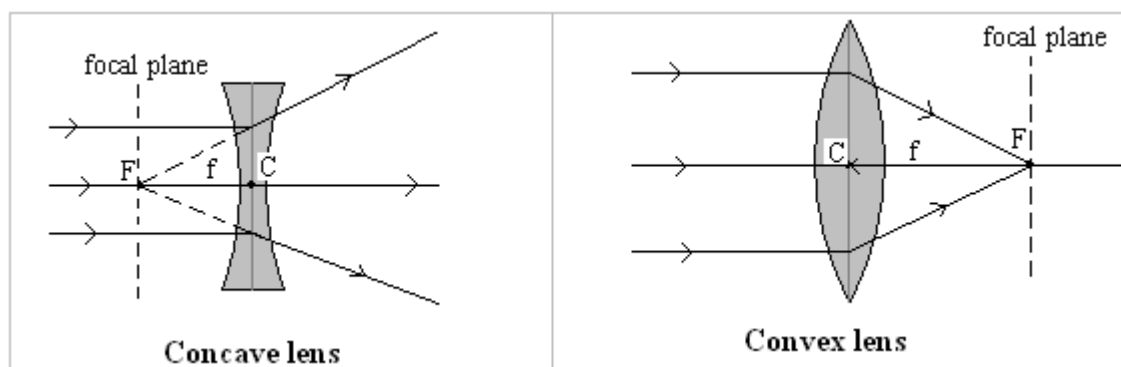


Figure 1.35

1. Optical centre, C :

This is the centre of the lens. All the rays of light that pass through the optical centre, C , in the lens do not bend.

b. Principal axis, $P.A.$

This is an imaginary line through the centre of the lens which is at right angles to the lens.

c. Principal focus, or Focal point, F .

This is a point on the principal axis where the rays of light, which are parallel to each other and to the principal axis, meet after coming out of the lens.

For a convex lens, the focal point is real, while for the concave lens it is virtual and is behind the lens.

d. Focal length, f

This is the distance between the focal point and the optical centre. Conventionally, the focal length of a convex lens is positive (+) whereas the focal length of a concave lens is negative (-).

e. Focal plane.

This is an imaginary plane passing through the focal point and at right angles to the principal axis. The focal point lies on the focal plane.

All rays of light which are parallel to each other before entering the lens converge at a point on this plane. For example, in the diagram below the rays of light parallel to the principal axis meet at point F_1 and those rays not parallel to the principal axis meet at F_2 . Both points F_1 and F_2 lie in the focal plane.

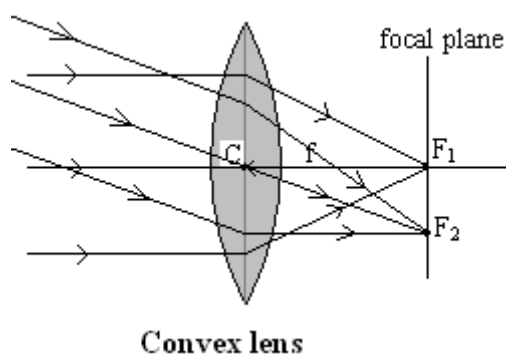


Figure 1.36

f. Object distance, u .

This is the distance between the object and the optical centre.

g. Image distance, v .

This is the distance between the optical centre and the image.

Magnification, m

Magnification is the comparison of the image formed to the object. Mathematically,

$$m = \frac{\text{image distance, } v}{\text{object distance, } u} \quad (\text{numerical values only})$$

$$\text{Also } m = \frac{\text{Image height, } h_2}{\text{Object height, } h_1}$$

When the image is larger than the object, it is said to be magnified and when it is smaller than object it is said to be diminished.

Image Formation

The position, size and the nature an image formed by a lens can be determined by using the following way;

- (a) ray diagrams
- (b) the lens formula
- (c) experiments

a. Ray diagrams

A ray diagram is a diagram used to predict the point where the image of an object will be formed by the lens. Ray diagrams are always drawn to scale using lines to represent the light rays. Usually two scales are used, one scale for the object distance, u , image distance, v and the focal length, f and another scale for the object height, h_1 and the image height, h_2 . When constructing a ray diagram the following rules are followed;

1. A ray parallel to the principal axis (P.A) is refracted through the focal point, F , on the other side of a converging lens. This ray is called the principal ray.

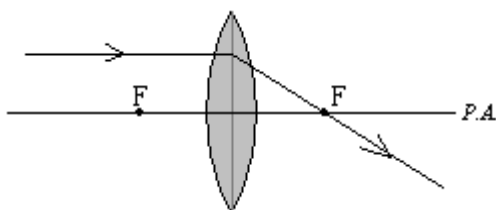


Figure 1.37

2. A ray passing through the centre of the lens is not refracted. This is called central ray.

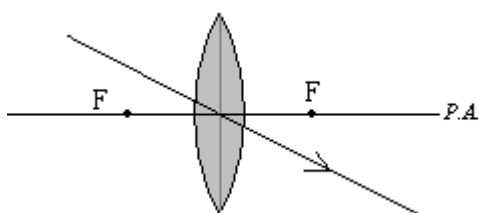


Figure 1.38

3. A ray passing through F before entering the lens is refracted parallel to the P.A on the other side of the lens. This ray is called focal ray.

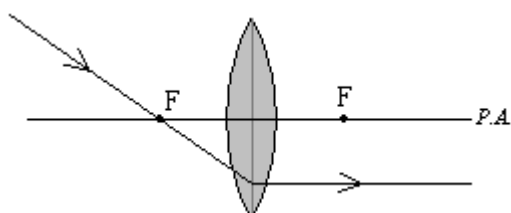


Figure 1.39

4. All these rays start from the same point.

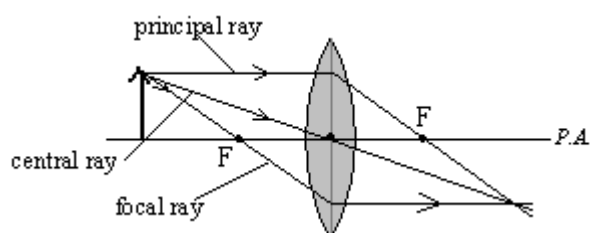


Figure 1.40

A combination of two rays of the three rays can be used to determine the position of the image. The images formed from the objects which are placed at different object distances have different characteristics. These characteristics are as follows: -

a. Real or virtual.

A real image is the one that can be focused on a screen where as a virtual image is the image that cannot be focussed on the screen.

b. Upright or upside down (inverted).

c. Magnified or diminished.

All the images which are formed on the other side of the lens are real and inverted.

Image formation by convex lenses:

1. An object beyond $2f$ (at infinity).

If the object is far beyond $2f$, rays from it arriving at the lens are nearly parallel to each other and its image is formed very close to the focal point.

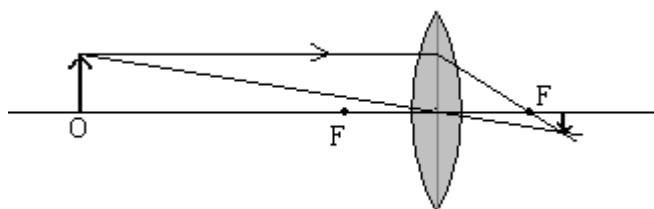


Figure 1.41

Nature of an image of an object beyond F:

The image is:

- real. This means the image can be focused on a screen.
- inverted
- diminished (smaller than the object).

As the object moves towards the lens, the position of the image moves away from the lens and becomes bigger.

2. Object at $2F$.

When the object is placed at $2F$, the image is also $2F$.

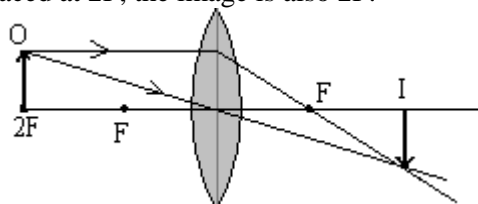


Figure 1.42

The image of an object at $2f$ is;

- real.
- inverted,
- same size as the object.

NB: The minimum distance between an object and its image is equal to $4f$. It is found when the object is at $2f$.

3. The object between f and $2f$.

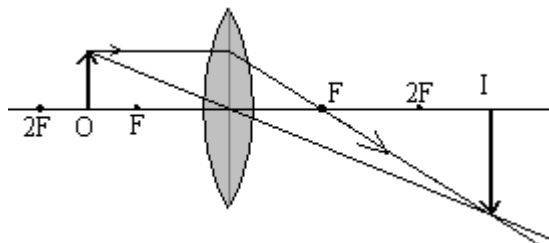


Figure 1.43

The image is;

- real
- inverted
- magnified.

4. Object at F

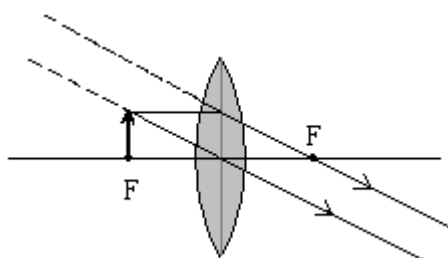


Figure 1.44

When the object is at f , the rays from the object are parallel to each other and two images are formed; one behind the object, on the same side of the lens as and the other on the other side of the lens.

The image behind the object is:

- upright
- magnified
- virtual, but can be seen by the eye.

The image formed on the other side of the lens is;

- inverted.
- magnified
- real.
- it is at infinity (there is *no* fixed image distance)

5. Object between F and C .

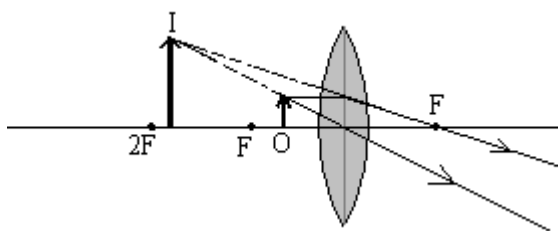


Figure 1.45

The image is;

virtual
upright
magnified.

When the object is between F and C, the convex lens is used as magnifying glass.

b. Lens formula

The position and the nature of an image of an object can be worked out using the following lens formula:

$$1/u + 1/v = 1/f$$

When using this formula, f is positive (e.g. $f = 6$) when the lens is convex and it is negative (e.g. $f = -6$) when the lens is concave.

When v is positive, the image is real, and when it is negative, the image is virtual.

Example;

An object is placed 20cm from

- (a) a converging lens of focal length 15 cm
- (b) Diverging lens of focal length 15cm as well.

Calculate (i) the image position

(ii) Magnification

(iii) The nature of the image.

Working out

$$1/u + 1/v = 1/f.$$

$$(a) \quad u = 20 \text{ cm}, f = 15 \text{ cm}$$

$$\therefore 1/20 + 1/v = 1/15$$

$$\Rightarrow 1/v = 1/15 - 1/20$$

$$1/v = \frac{4-3}{60}$$

$$1/v = 1/60$$

$$v = 60$$

$$\text{Magnification} = v/u$$

$$= 60/20$$

$$= 3$$

The image is;

- 60 cm from the lens

- real,

- magnified (three times as big as the object)

$$(b) \quad u = 20 \text{ cm}, f = -15 \text{ cm}.$$

$$\therefore 1/20 + 1/v = 1/-15$$

$$\Rightarrow 1/v = 1/-15 - (1/20)$$

$$= \frac{-4-3}{60}$$

$$1/v = -7/60$$

$$\text{So } v = -60/7$$

$$= -8.57 \text{ cm}$$

$$M = v/u \\ 8.57/20 \\ = 0.43$$

The image is:

- 8.57cm in front of the lens.
- virtual
- diminished. (0.43 times smaller than the object)

Exercise:

1. An object 2 cm high stands on the principal axis at a distance of 9 cm from a convex lens. If the focal length is 6cm, find

- (i) the image position,
- (ii) height and
- (iii) nature of the image.

2. (a) An object 5 cm high is placed 20 cm away from a lens of focal length 8 cm. Find the position, height and the nature of the image by;

- (i) scale drawing.
- (i) calculation.

(b) If the object is moved to a point only 5 cm from the lens, what is the new position height and the nature of the image.

c. Experiment

To find the position and nature of an image experimentally, you focus the image of an object on a screen with different object distances and note the image distances and the nature of the images.

The following table summarizes the relationships between the object distance, image distance and the nature of the images formed:

Object distance, u	Image distance, v	Nature of image
At infinity	F	Real, Upside down and diminished
At 2F	At 2F	Real, Upside down, same size as the object.
Between F and 2F	Beyond 2F	Real, Upside down and magnified
At F	Two images are formed, one behind the lens and the other behind the object. both of them are at infinity.	Image behind the lens is Real, Upside down, magnified Image behind the object is Virtual, upright and magnified
Between F and C	Between F and 2F	Virtual, Upright and magnified.

Table 1.6

Ways of finding the focal length of a convex lens:

There are different ways which are used to determine the focal lengths of lenses. Some of them are as follows:

- (i) - the distant object method
- (ii) - the plane mirror method
- (iii) - graph of $u + v$ against u .
- (iv) - the object and image distance method.

Activity 1.7

Aim: to determine the focal length of a lens using the distant object method.

Materials:

- 1 metre rule,
- a lens
- a white screen (or a white wall)

Procedure

1. Focus the image of a distant object on a screen.
2. Measure the distance between the screen and the lens, v .

Discussion

The light rays from a distant object are nearly parallel to each other and so when they come out of the lens, they converge almost at the focal point. Therefore distance between the lens and the screen is almost equal to the focal length of the lens.

Activity 1.8

Aim: to determine the focal length of a lens using the plane mirror method.

Materials:

- 1 metre rule,
- a converging lens
- a white screen (or a white wall)
- a box with a small hole
- a torch
- plane mirror
- wire grid

Procedure

- (i)- arrange an illuminated object, O, the lens and a mirror in a straight line as shown below.

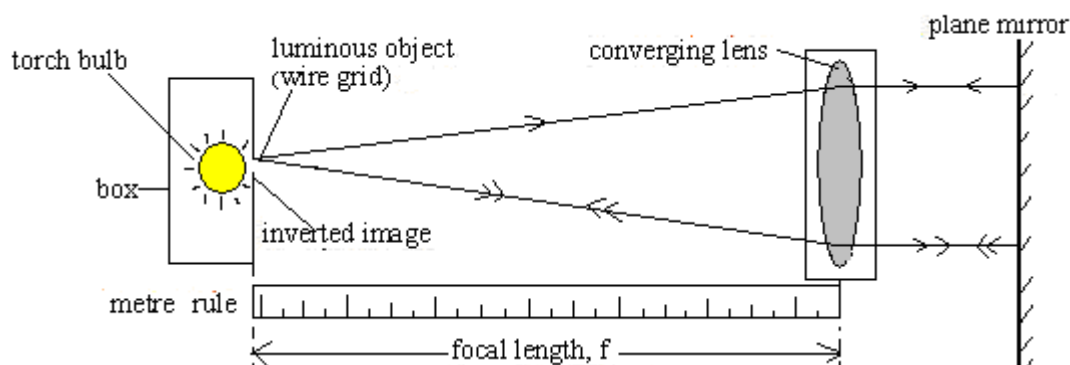


Figure 1.46

An illuminated wire grid as shown in the figure below is a suitable object which can be focused to give a sharp image.



Figure 1.47

- (ii)- adjust the lens, until an inverted image is focused on the screen next to the object as shown in figure 1.48 below.

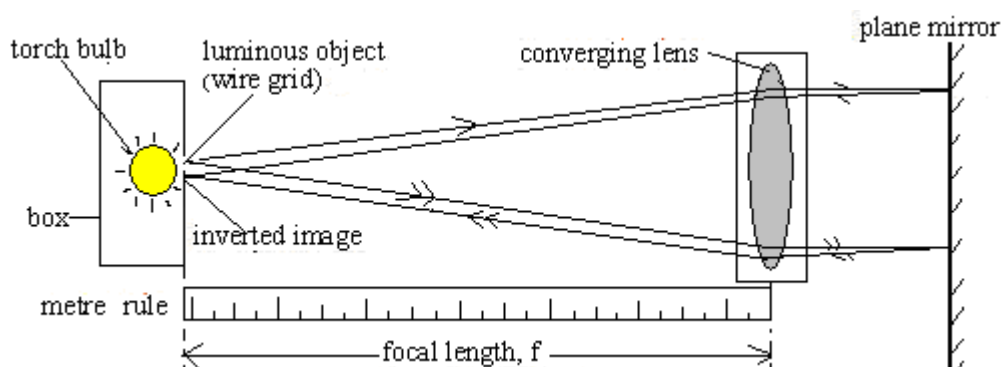


Figure 1.48

iii- measure the distance between the lens and the screen.

Discussion

What is the distance between the lens and the screen?

When an object is at F how do the light rays come out on the other side of the lens?

Observation

When an object is placed F, the light rays come out parallel to each other on the other side of the lens. These rays are reflected by the mirror. These reflected parallel rays converge and form an image at F when they come out of the lens.

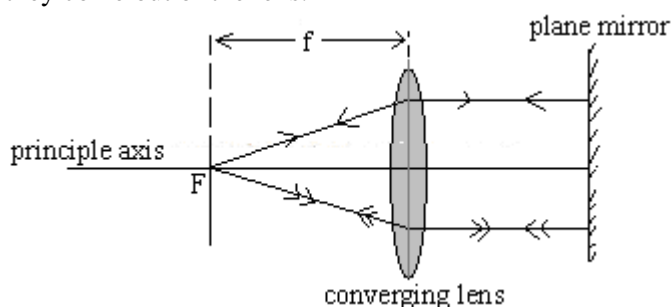


Figure 1.49

The distance between the image and the lens is, therefore, equal to the focal length of the lens because rays which are parallel to each other before entering the lens converge at F when they come out of the lens.

Activity 1.9

Aim: to determine the focal length of a lens using the graph of $u + v$ against u .

Materials:

- 1 metre rule,
- a converging lens (of focal length 20 cm, for example)
- a white screen
- a candle
- matches

Procedure

- light the candle.
- arrange the candle, (the object, O), the lens and the screen in a straight line.
- place candle 25 cm from the lens (object distance between F and 2F).
- move the screen until a sharp is focused on the screen.
- measure the image distance and record in the table of results.

(vi) - repeat steps (iv) and (v) five times, each time increasing the object distance by 10 cm.

Object distance, u (cm)	Image distance, v (cm)	$u + v$ (cm)

Table 1.7 (table of results)

(vii) - fill the column for $u + v$.

(viii) - plot the graph of $u + v$ against u .

Discussion

What is the minimum of the graph?

What are the values of the image distance, u and the $u + v$ at the minimum point of the graph?

What is the relationship between;

(a) u at the minimum of the graph and the focal length of the graph?

(b) $u + v$ at the minimum of the graph and the focal length of the graph?

Observation

The results of the experiment might be as following in table 1.7.

Object distance, u (cm)	Image distance, v (cm)	$u + v$ (cm)
25	77	102
35	47	82
45	36.5	81.5
55	33	88
65	28	93
75	26.5	101.5

Table 1.8

The graph of u against $u + v$ drawn from the results of the experiment is shown in Figure 1.50 and has a minimum point, M, which is reached when the object distance, $u = 40$ cm and

$u + v = 80$ cm. Since the focal length, f , of the lens was 20 cm then $u = \frac{40 \text{ cm}}{20 \text{ cm}} f = 2f$ or

$u + v = \frac{80 \text{ cm}}{20 \text{ cm}} = 4f$

In general when the object is at $2f$, $u = 2f$ and $u + v = 4f$. Therefore, at the minimum of the graph, $f = \frac{u}{2}$ or $f = \frac{u + v}{4}$.

2 4

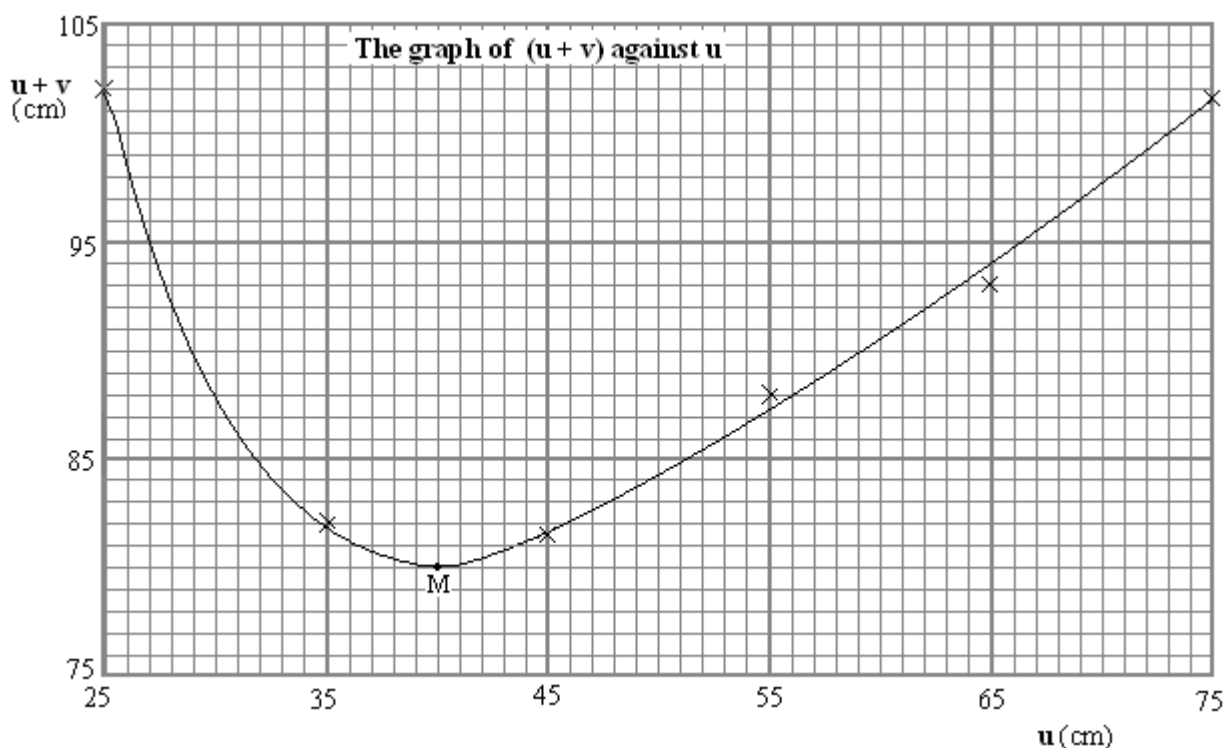


Figure 1.50

Activity 1.10

Aim: to determine the focal length of a lens using the object and image distance method.

Materials:

- 1 metre rule,
- a converging lens
- a white screen
- a candle (or any illuminated object)
- matches

Procedure

- (i) set up an illuminated object, a converging lens and a screen in a straight line as shown in figure 1.51 below.

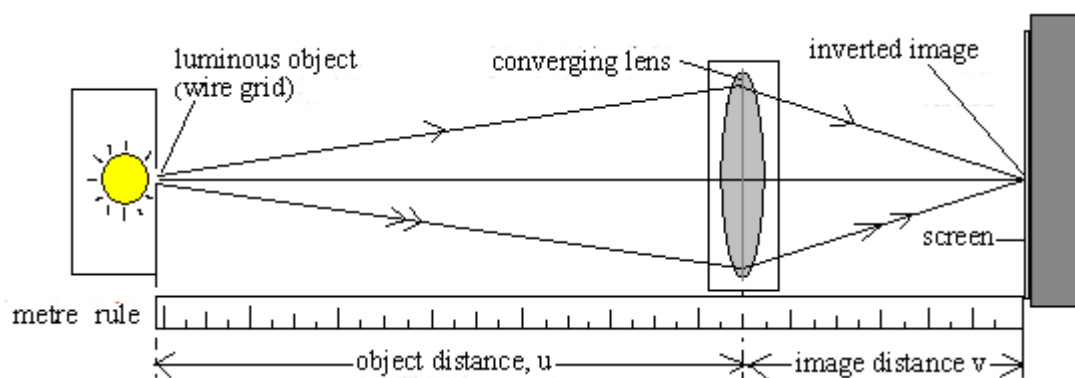


Figure 1.51

- (ii) move the screen until a sharp, inverted image is focused on the screen.
(An illuminated wire grid is a suitable object which can be focused to give a sharp image).
- (iii) measure the object distance u , from the centre of the lens to the object and the image distance v , from the centre of the lens to the sharp image formed on the screen.

(iv) record the values of u and v in a table of results like the one below;

Object distance, u (cm)	Image distance, v (cm)	Focal length, f (cm)

Table 1.9

(v). repeat the experiment for other values of u (such as 70cm, 60 cm, 50 cm and 40 cm) and measure the corresponding values of v .

Discussion

With the values of u and v , how can you use them to find the focal length of the lens?

Taking each pair of values of u and v , the focal length, f of the lens can be calculated using the lens formula, $1/u + 1/v = 1/f$. The average value of the different focal lengths can then be worked out in order to minimize errors associated with the experiment.

Optical Instruments

There are different kinds of instruments which use light, called optical instrument. Some of the instruments are the camera, the human eye, and the projector.

(i). The camera

A camera is light tight box in which a converging lens forms a real image on a film (the screen).

Parts of a camera

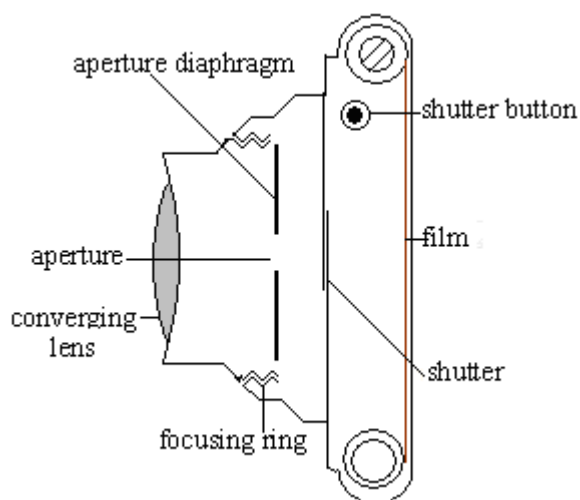


Figure 1.52

Functions of the parts of a camera:

a. The lens:

The lens focuses light from an object to form an image on the film. The image is real, inverted, and smaller than the object. In some cameras the lens can be moved in or out to make the focusing.

b. The shutter.

The shutter opens and shuts quickly to let a small amount of light into the camera.

c. The aperture.

This is a hole through which light passes into the camera.

The aperture controls the amount of light passing through the lens and onto the film.

d. Aperture diaphragm

This is a set of sliding plates between the lens and the film.

The aperture controls the size of the aperture. It becomes wider when light from the object is not enough and it is narrow when the light from the object is too bright. The aperture together with the diaphragm is known as a stop.

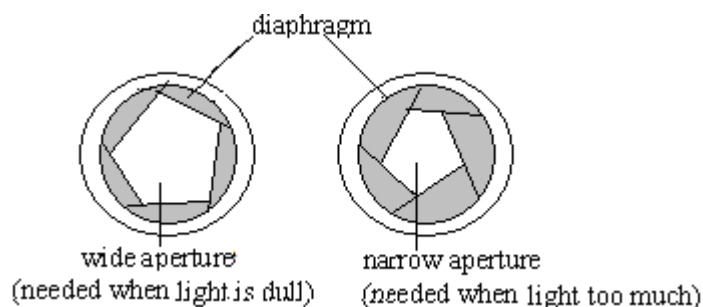


Figure 1.53

e. The film.

This is a plate coated with light sensitive chemicals which are changed by different shades and colours. It is always kept in the dark until the shutter opens.

When the film is processed these changes are fixed and the developed film can be used to print a photograph.

Focusing

In cameras in which the lens is fixed, focusing is done by changing the object distance. The photographer moves forward or backward until a clear image is focused. In other cameras where the lens is not fixed, focusing is done by changing the positions of the lens using the focusing ring. In this way both the image and the object distances change. If the object is near, the lens is moved away from the film.

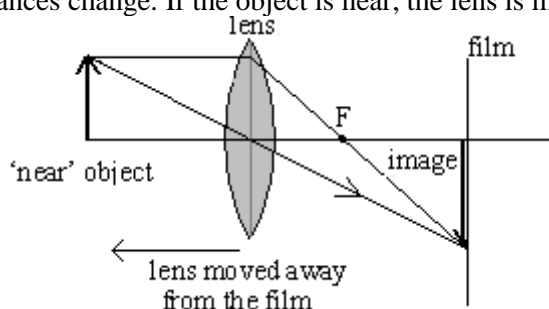


Figure 1.54

If the object is far away the lens is moved closer to the film.

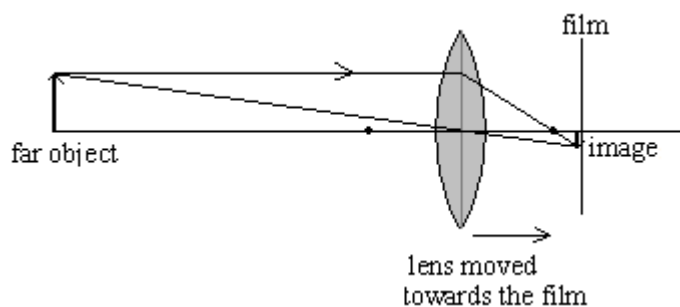


Figure 1.55

(ii). The human eye:

Parts of the eye

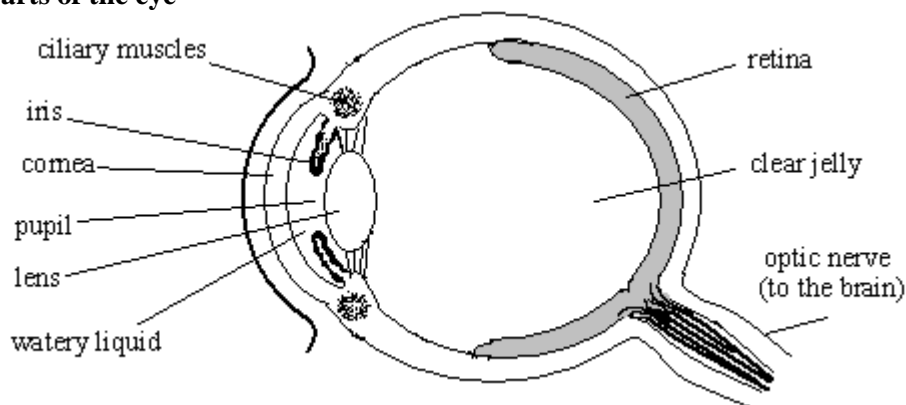


Figure 1.56

a. The cornea and the watery liquid;

The cornea is the curved window over the front of the eye.

The cornea and the watery liquid converge the light rays entering the eye.

b. The lens;

The lens is used to make focusing adjustments. It focuses the image on the retina by using the ciliary muscles around it to change its shape. The process of focussing the image on the lens is called accommodation. When the object moves closer to the eye, the lens becomes thick. This shortens its focal length and the image stays in focus on the retina. When the object moves away from the lens the lens becomes flattened to make its focal length, f longer.

c. Iris and the pupil:

The iris controls the amount of light entering the eye by making the pupil bigger or smaller.

When light is not enough, the pupil becomes bigger, and when light is too bright it becomes narrow.

d. The retina;

Retina is the screen at the back of the eye where the image is formed.

2.2 The nature of the image formed on the Retina:

The image formed on the retina is:

- real
- inverted.
- smaller than the object.

e. The optical nerve:

This is the nerve connected to the back of the eye.

The optical nerve passes the image formed on the retina to the brain.

The brain interprets the image formed on the retina and makes us see the object the right way up.

Similarities between the eye and the camera

1. In both of them the image is formed on a light sensitive screen, on the retina in the eye and on the film in the camera.
2. Both use converging lenses.
3. Both are black inside.
4. Light entering in both of them is controlled; in the eye by the iris and by the aperture diaphragm in the camera and the shutter.

Differences between the camera and the eye

The Eye	The Camera
The focal length in the eye changes	the focal length of the lens in the camera is fixed
The eye has a fixed image distance (v)	the image distance for the camera changes
The eye is normally open	the camera is normally closed, except when a picture is taken

Table 1.20

3. The Projector:

A projector is an instrument that is used to enlarge an object and focus a real, upright image on a screen.

3.1 Slide Projector

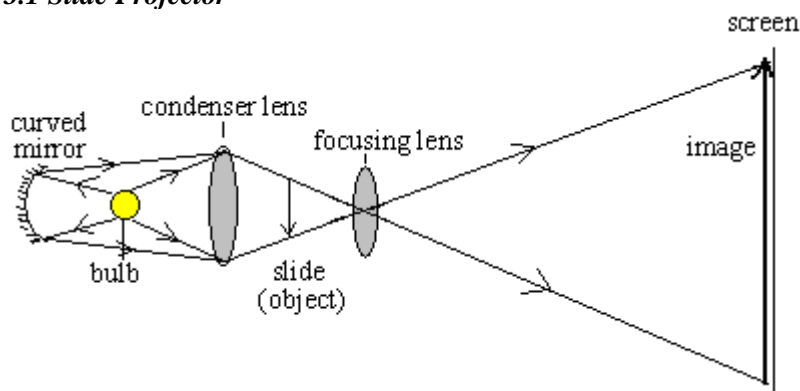


Figure 1.57

a. Object, O .

The object is the slide. It is placed upside down in the projector. In this way the image is seen upright on the screen after being inverted by the focusing lens.

b. Focusing / projector lens.

This is a lens of long focal length. It focuses the image on the screen. The image is; real, larger than the object and inverted.

c. Bulb;

The bulb is used to illuminate the film.

d. Curved mirror;

This is situated at the back of the projector. Its function is to reflect the light rays that are directed away back to the film.

e. Condenser lens:

This is a convex lens of short focal length. Its function is to converge and condense light rays from the bulb and the reflected rays from the mirror on to the film.

3. 2. The Overhead projector

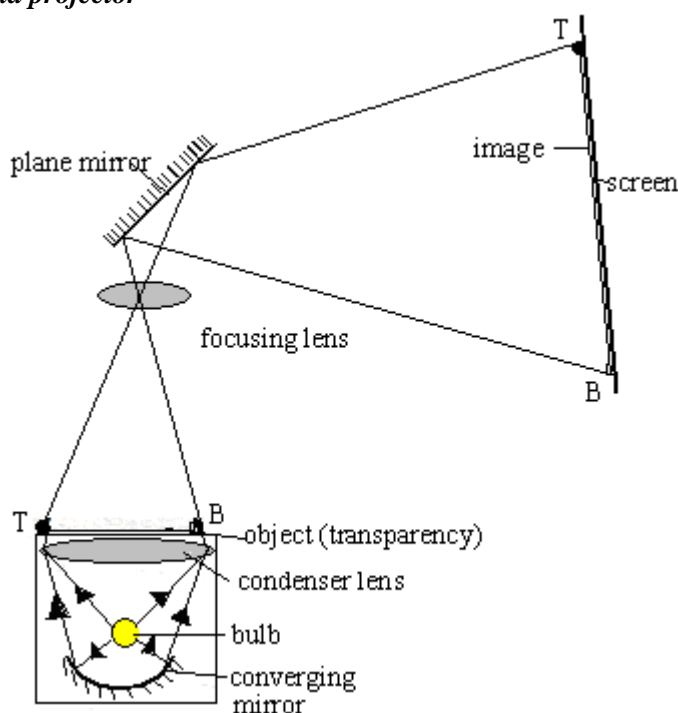


Figure 1.58

a. The bulb:

The bulb illuminates the film (the transparency).

b. Curved mirror:

The curved mirror reflects lost light rays back onto the film.

c. Condenser lens:

The condensing lens converges and condenses light rays onto the transparency

d. Focusing lens:

The focusing lens focuses an image onto the plane mirror. The image formed on the mirror is real, magnified and inverted.

e. The plane mirror:

The plane mirror reflects the image onto a screen. The image reflected by the mirror onto the screen is real, upright and larger than the object.

Review questions;

1. a. What equation links speed, frequency and the wavelength of a wave?
- b. The wave crests seen in a ripple tank are 10 mm apart and the frequency of the vibrator is 20 Hz. What is the wave speed?
2. a.(i) How can waves in a ripple tank be made to move more slowly?
(ii) When the waves are made to move slowly, what is the effect on;

- (1) Frequency
(2) Wavelength.
- b. One side of a ripple tank ABCD is raised slightly and a ripple is started at S by a pencil. One second later the shape of the of the ripple is as shown below;

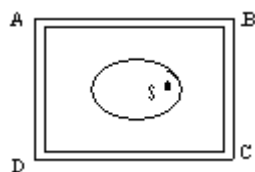


Figure 1.59

- (i) Why is the ripple not circular?
(ii) Which side of the ripple tank is raised?
3. The straight lines in the figure below are crests of straight ripples (waves)

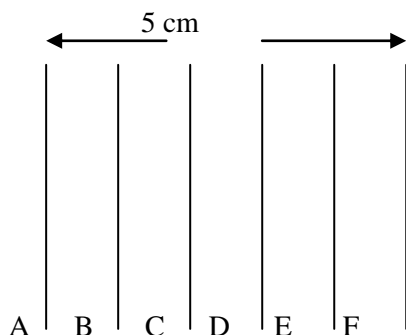


Figure 1.60

- (a) What is the wavelength of the waves?
(b) If ripple A occupied, 5 seconds ago, the position now occupied by ripple F, What is the frequency of the waves?
(c) What is the speed of the wave?
4. Waves are set across a pond and a small floating object goes up and down 5 times in 10 seconds. If the wave crests are 30 cm apart, calculate the speed of the wave.
5. Copy the figure below and show on it what happens to the waves as they pass through the gap, if the water is much shallower on the right than on the left.

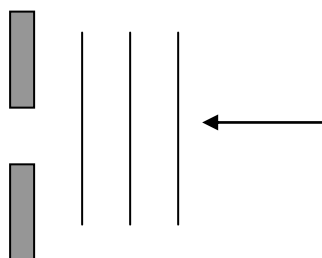


Figure 1.62

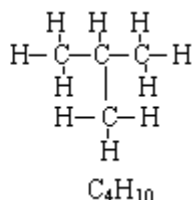
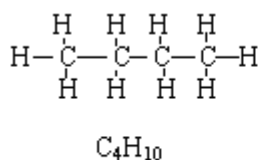
10. A small upright object is placed well outside the focal point of a convex lens:
(a) Draw a ray diagram to show how the image is formed and say whether the image is real or virtual.
(b) What is the effect on the size of the image if the object is moved towards the lens?
11. Describe how you could find the focal length of a convex lens more accurately.
12. A lens of focal length 20 cm is used to magnify an object 10 times. How far must the object be placed from the lens?
13. A convex lens of focal length 6 cm is held 4 cm from a newspaper which has a print of 0.5 cm high. Determine the size and the nature of the image produced by: (i) calculation
(ii) scale drawing
14. a. Where is the image formed in; (i) the eye.
(ii) the camera
b. An object is moved closer to eye and to the camera, what changes must take place in
(i) The camera (ii) the human eye, so that the image is sharp in focus.
c. How is the amount of light entering the eye controlled?
d. Give two similarities and two differences between a camera and the human eye.
15. A camera has a lens of focal length 4 cm. How far from the film must it be positioned if it is to form a sharply focused image of a distant object?

2. ORGANIC CHEMISTRY II

Isomerism

Definition

Isomerism means the existence of compounds with the same formula but different structures. The compounds with the same chemical formula but different structures are known as isomers. For example the following are isomers;



Types of formulas

The following three types of formulas are used in the study of organic chemistry.

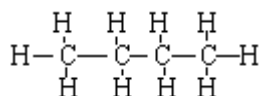
a. Molecular Formula:

This is a formula which shows the number of atoms in a molecule. E.g. C_4H_{10}

b. Structural formula

The formula which shows how atoms are joined in a molecule is known as a structural formula or just the structure.

E. g



c. Condensed structural formula.

This is the formula in which the separate bonds in each unit are not written. Eg.



Isomers and Conformations:

Conformations are molecules with the same molecular formulae and structural formulae. All molecules with the same molecular formula but appear to have different structures due to turning, bending, or twisting of the carbon-carbon (C – C) bonds in the same molecule are called conformations of each other.

Identifying Isomers and Conformations:

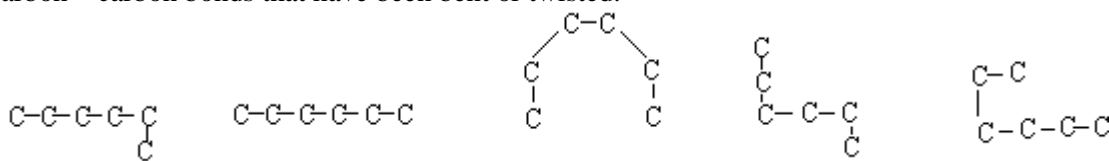
Sometimes it is not easy to tell whether structures are isomers or conformations when the structure is drawn in full and when the structure is large. In such situations the following methods may assist in identifying isomers and conformations.

a. Working out the carbon skeleton first.

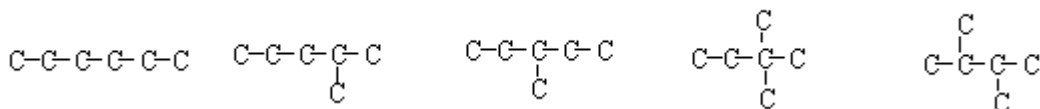
The carbon skeleton is the basic structure of a molecule which shows the carbon atoms only.

The carbon skeleton enables us to see the important points about the structure of the molecule.

For example, the following carbon structures represent conformations, because in all of them it is only the carbon-carbon bonds that have been bent or twisted.

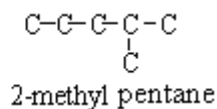
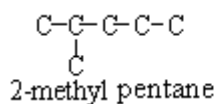


However, the following are isomers because the carbon chains have branches:



b. Naming the compounds.

Isomers have the same molecular formula but different names while conformations have the same molecular formulae and names. For example, the following are conformations of a compound with the molecular formula C_6H_{12} ;

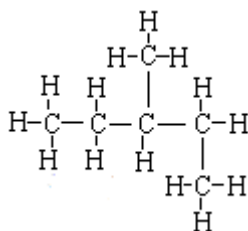


How to name isomers

Knowing how to name isomers is very important because it's one which can help us to tell whether two compounds are isomers or conformations. The isomers are named systematically as follows

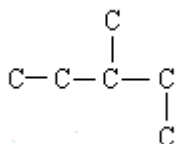
i. Naming isomers due to the existence branches in the carbon chains

Consider the following;



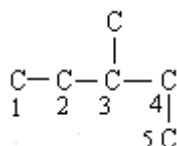
To come up with the name of this isomer;

a. Write down the carbon skeleton for each molecule.



b. Number the longest carbon chain (the parent chain);

Numbering starts from the end of the longest chain nearest the first branch.



The longest chain is named after the unbranched organic compound with the same number of carbon atoms.

For example, the longest chain in the compound above is pentane.

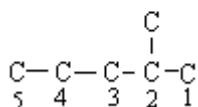
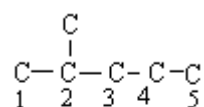
c. Name the group that is attached to the longest chain. These groups are called alkyl groups.

Some of the alkyl groups are shown in table 2.1 below:

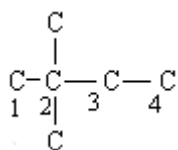
Number of carbon atoms in the branch	Structure	Formula	Name of the alkyl group
1	$\begin{array}{c} \text{H} \\ \\ -\text{C}-\text{H} \\ \\ \text{H} \end{array}$	$-\text{CH}_3$	Methyl-
2	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ -\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$	$-\text{CH}_2\text{CH}_3$	Ethyl-
3	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ -\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$	$-\text{CH}_2\text{CH}_2\text{CH}_3$	Propyl-
4	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \\ -\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	$-\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	Butyl-

Table 2.1

d. Give the positions on the carbon chain of any group attached. The numbering of the carbon atoms in the parent chain can start from any end of the chain provided the number given to the carbon atom to which the alkyl group is attached is the lowest possible. For example, the name for the following compounds is 2-methyl pentane



If more than one alkyl group is attached to the parent chain, the numbers indicating the positions of the branches are written before the alkyl group. The numbers of the alkyl groups with the same number of carbon atoms which are attached to the same carbon atom in the parent chain are indicated by prefixes di-, tri or tetra to mean two, three or four alkyl groups respectively. For example, the name for the following isomer is 2, 2 – dimethyl butane.



Properties of branched isomers:

- They have lower melting and boiling points than the straight chain isomers. This is because the branches make it difficult for the molecules to get close and attract each other more strongly.
- They burn less easily.

Example

Draw and name the structures of all the isomers of the organic compound with the molecular formula C_7H_{16} .

Working out

Refer table 2.2 below

Structure	Name
<pre> H H H H H H H H - C - C - C - C - C - C - C - H H H H H H H H </pre>	n-heptane
<pre> H H H H H H H - C - C - C - C - C - C - H H H - C - H H H H H </pre>	2-methyl hexane
<pre> H H H H H H H - C - C - C - C - C - C - H H H H - C - H H H H </pre>	3-methyl hexane
<pre> H H H H - C - H H H H - C - C - C - C - C - C - H H H H - C - H H H H </pre>	2,2-dimethyl pentane
<pre> H H H - C - H H H H H - C - C - C - C - C - C - H H H H - C - H H H H </pre>	3,3-dimethyl pentane,
<pre> H H H H H H H - C - C - C - C - C - C - H H H - C - H H - C - H H H H H </pre>	2,3-dimethyl pentane,
<pre> H H H H H H - C - C - C - C - C - H H H - C - H H - C - H H H H </pre>	2,4-dimethyl pentane
<pre> H H H H H H - C - C - C - C - C - H H H H - C - H H H H - C - H H </pre>	3-ethyl pentane

Table 2.2

Straight single bonded carbon – carbon isomers

The straight chain isomers are referred to as normal isomers. The names of these straight chain isomers start with the prefix 'n -' which stands for normal.

E. g. $\text{C} - \text{C} - \text{C} - \text{C} - \text{C}$
n - pentane

Exercise

1. Draw and name all the isomers of the organic compounds with the formula

(a) C_5H_{12}

(b) C_4H_{10}

(c) C_9H_{20}

2. The following are the names of the organic compounds with the molecular formula C_8H_{18} . Draw the structure for each name given.

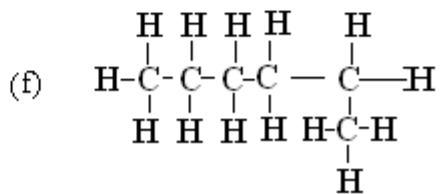
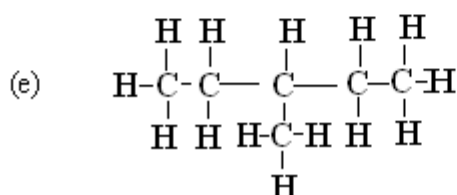
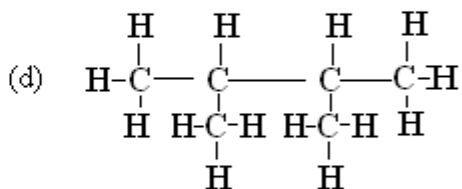
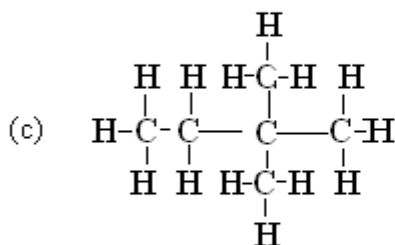
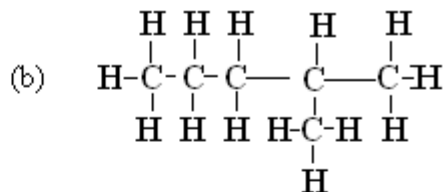
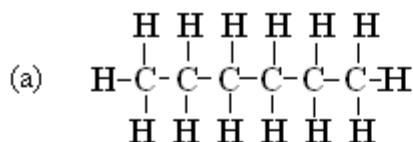
(a) n- octane

(b) 2- methyl heptane

- (c) 3 - methyl heptanes
- (d) 2, 2- dimethyl hexane
- (e) 3, 3- dimethyl hexane
- (f) 2,3 - dimethyl hexane
- (g) 2,4dimethyl hexane
- (h) 3- ethyl hexane
- (i) 3- ethyl,3-methyl pentane

3. The following are structures of the compounds with the molecular formula C_6H_{14} .

- (i) Name the compounds.
- (ii) Identify any compounds that are conformations of each other



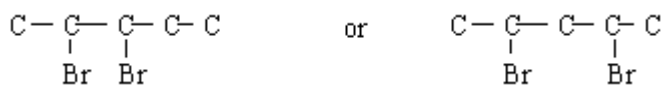
ii. Positional isomers

Isomerism can also occur due to the position of hetero atoms or the position of the functional groups such as the double bond or the -OH group.

a. Isomerism due to the position of hetero atoms

Hetero atom is any atom apart from the carbon, the hydrogen or oxygen atoms in an organic compound molecule. The hetero atoms are usually the halogen atoms.

E. g.



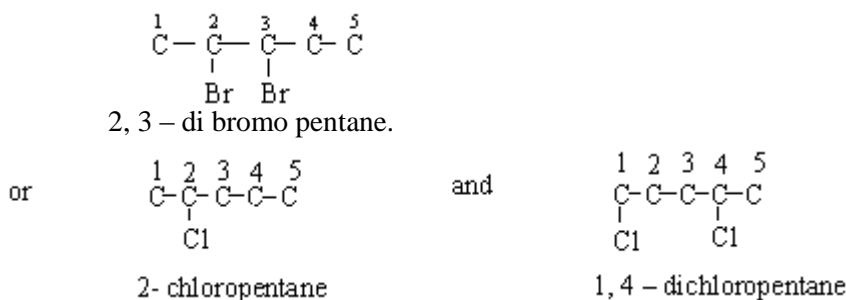
To name the isomers with hetero atoms,

- (a) Number the longest carbon chain,
- (b) Identify the halogen atom attached to the longest chain.
- (c) Name the hetero atom attached as follows:

The Halogen atom	Name
Chlorine	Chloro -
Fluorine	Fluoro -
Bromine	Bromo -
Iodine	Iodo -

Table 2.3

(d) Write down the name with the number indicating the carbon to which the hetero atom attached in front of the name as follows;

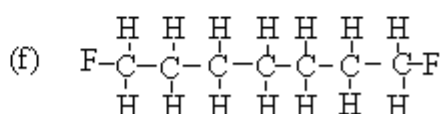
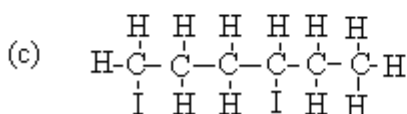
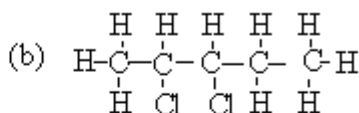
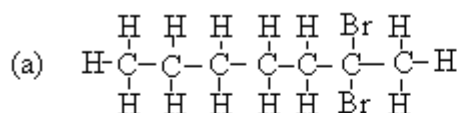


Exercise

1. Draw the structures of

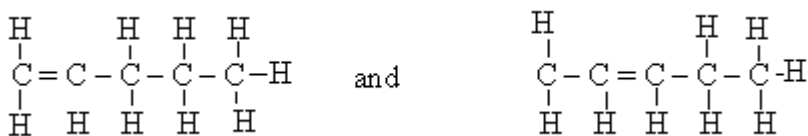
- 1-chlorohexane
- 3, 4-dichloropentane

2. Name the following organic compounds



b. Isomerism due to the position of a double bond

Organic compounds with a carbon-carbon double bond ($\text{C} = \text{C}$) belong to the alkene family. The alkenes with the same molecular formulae but different positions of the double bonds in the molecules have different names and therefore are isomers. For example, the following compounds are isomers.



To name the isomers with double bonds;

a. Write down the carbon skeleton for each structure and number the longest carbon chain that contains the double bond, starting from the end that will give the smallest number to the first carbon atom attached to the double bond as follows $\begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 \\ \text{C} & - & \text{C} = & \text{C} & - & \text{C} & - & \text{C} \end{array}$

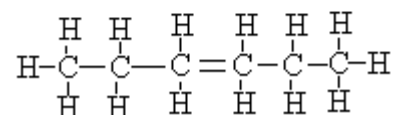
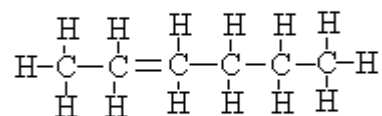
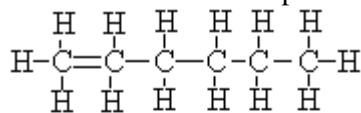
b. Write down the name of the compound with the position of the double bond written before the suffix – ene. Therefore, the name of this isomer $\text{C} - \text{C} = \text{C} - \text{C} - \text{C}$ is but – 2 – ene.

Example

Draw and name all the isomers of compounds with the formula C_6H_{12} .

Working out

The isomers of the compounds with the formula C_6H_{12} are as follows;



Exercise:

1. Draw the structures and write down the names of all the isomers of the alkenes with the following molecular formulas;

(a) C_7H_{14}

(b) C_9H_{18}

c. Isomers due different positions of an -OH group

The position of the -OH group in organic compounds significant as it affects the physical properties of the compounds. The compounds with the same molecular formula but different positions of the -OH are, therefore, isomers. To name the isomers due to positions of the -OH groups the following procedure is followed.

a. The position of the -OH group is indicated by a number. The numbering of the longest carbon chain which contains the -OH group is done in such a way that the carbon atom to which the -OH group is attached has the lowest number possible.

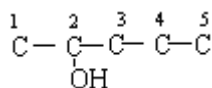
c. Write down the name of the compound, considering the total number of the carbon atoms in the molecule, with the number of the carbon atom to which the -OH group is attached written in front of the name before the suffix - ol.

Example

Name the organic compound, whose formula is $C_5H_{11}OH$.

Working out

The carbon skeleton with numbered carbon atoms is as follows;



The name of this compound is butan - 2 - ol.

Exercise

1. Draw the structures and name all the isomers of the alkanols with the following molecular formulas;

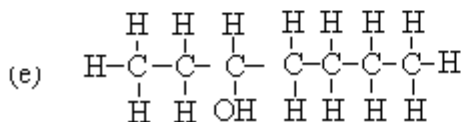
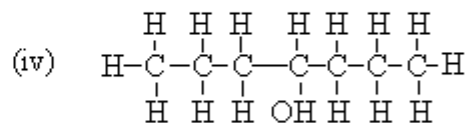
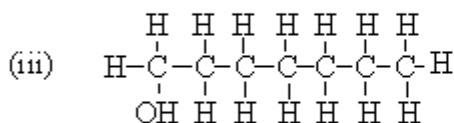
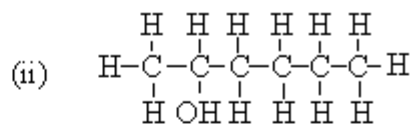
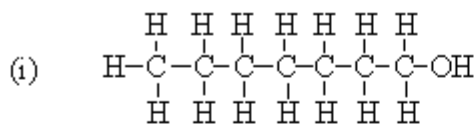
(a) C_3H_7OH

(b) C_4H_9OH

(c) $C_8H_{17}OH$

(d) $C_5H_{11}OH$.

2. a. Name the following compounds;



b. Which two structures represent conformations in question 2.a above?

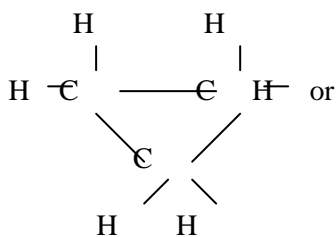
iii. Isomers due to different functional groups;

Isomerism can also take place when organic compounds with different functional groups have the same molecular formula as follows;

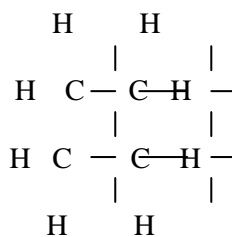
a. Cycloalkanes and alkenes

Cycloalkanes are organic compounds with rings of carbon atoms that are bonded to each other by single bonds.

e. g.



cyclopropane



cyclobutane

The names of cycloalkanes start with the prefix 'Cyclo -' followed by the name of an alkane with the same number of carbon atoms.

The examples of the isomers of alkenes and cycloalkanes are as shown in the following table:

Formula	Isomer/ Name
C_3H_6	$\text{CH}_2 = \text{CH} - \text{CH}_3$ Propene <div style="display: inline-block; vertical-align: middle; margin-left: 20px;"> $\begin{array}{c} \text{CH}_2 \quad \text{---} \quad \text{CH}_2 \\ \quad \quad \diagdown \quad \diagup \\ \quad \quad \text{CH}_2 \end{array}$ cyclopropane </div>
C_4H_8	$\text{CH}_2 = \text{CH} - \text{CH}_2 - \text{CH}_3$ butan -1 - ene <div style="display: inline-block; vertical-align: middle; margin-left: 20px;"> $\begin{array}{c} \text{CH}_2 \quad \text{---} \quad \text{CH}_2 \\ \qquad \qquad \\ \text{CH}_2 \quad \text{---} \quad \text{CH}_2 \end{array}$ cyclobutane </div> $\text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_3$ butan -2 - ene

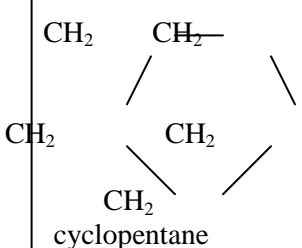
C ₅ H ₁₀	$\begin{array}{c} \text{CH}_2 = \text{CH} - \text{CH}_2 - \text{CH}_2 - \text{CH}_3 \\ \text{pentan - 1 - ene} \end{array}$	$\begin{array}{c} \text{CH}_2 = \text{C} - \text{CH}_2 - \text{CH}_3 \\ \\ \text{CH}_3 \\ \text{2-methyl butan - 2 - ene} \end{array}$	
	$\begin{array}{c} \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 \\ \text{pentan - 2 - ene} \end{array}$	$\begin{array}{c} \text{CH}_2 = \text{CH} - \text{CH} - \text{CH}_3 \\ \\ \text{CH}_3 \\ \text{3-methyl butan - 1 - ene} \end{array}$	
	$\begin{array}{c} \text{CH}_3 - \text{C} = \text{CH}_2 - \text{CH}_3 \\ \\ \text{CH}_3 \\ \text{2-methyl butan - 2 - ene.} \end{array}$		

Table 2.4

Exercise;

1. Write down and name 6 isomers of an organic compound with the molecular formula C₅H₁₀

b. Alkanols and ethers

An ether is an organic compound that contains an oxygen atom bonded to two hydrocarbon groups as follows; CH₃ – O – CH₃

To name an ether, the hydrocarbon, before the oxygen atom is regarded as an alkoxy group and is added to the alkane after the oxygen atom. Consider the following table of some ethers and their names;

Ether	Name
$\begin{array}{c} \overset{1}{\text{C}} - \overset{2}{\underset{\text{OH}}{\text{C}}} - \overset{3}{\text{C}} - \overset{4}{\text{C}} - \overset{5}{\text{C}} \\ \text{CH}_3 - \text{O} - \text{CH}_3 \end{array}$	methoxymethane
CH ₃ –CH ₂ – O– CH ₂ –CH ₃	Ethoxyethane
CH ₃ – O– CH ₂ –CH ₃	methoxyethane
CH ₃ –CH ₂ – O–CH ₃	ethoxymethane
CH ₃ –CH ₂ – O– CH ₂ –CH ₂ –CH ₃	ethoxypropane

Table 2.5

Some of the isomers of alkanols and ethers are as follows;

Formula	Isomers/ Name
C ₂ H ₅ OH or C ₂ H ₆ O	$\begin{array}{c} \text{CH}_3 - \text{CH}_2 - \text{OH} \\ \text{ethanol} \end{array} \qquad \begin{array}{c} \text{CH}_3 - \text{O} - \text{CH}_3 \\ \text{methoxymethane} \end{array}$
C ₃ H ₈ O	$\begin{array}{c} \text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{OH} \\ \text{propan - 1 - ol} \end{array} \qquad \begin{array}{c} \text{CH}_3 - \text{CH}_2 - \text{O} - \text{CH}_3 \\ \text{ethoxymethane} \end{array}$ $\begin{array}{c} \text{CH}_3 - \text{CH} - \text{CH}_3 \\ \\ \text{OH} \\ \text{propan - 2 - ol} \end{array} \qquad \begin{array}{c} \text{CH}_3 - \text{O} - \text{CH}_2 - \text{CH}_3 \\ \text{methoxyethane} \end{array}$

Table 2.5

Exercise

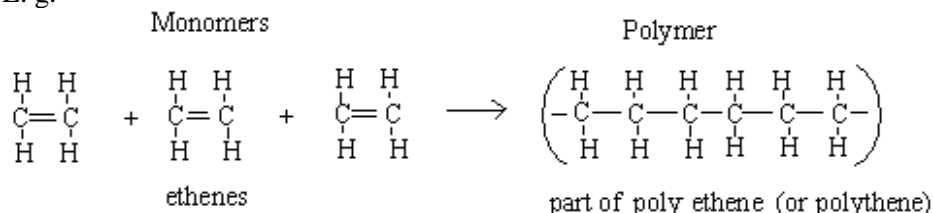
1. Draw and name seven isomers with the molecular formula $C_4H_{10}O$ or C_4H_9OH
2. Draw and name eleven isomers with the molecular formula $C_5H_{12}O$ or $C_5H_{11}OH$

Polymerisation

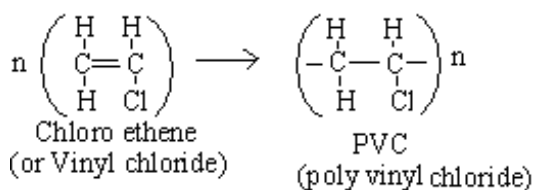
Definition

Polymerisation is the process of joining small molecules to form long-chain molecules called polymers. The small molecules which join together to form the long-chain molecules are called monomers.

E. g.



or



n stands for a large number of the monomers.

Types of Polymerisation reactions

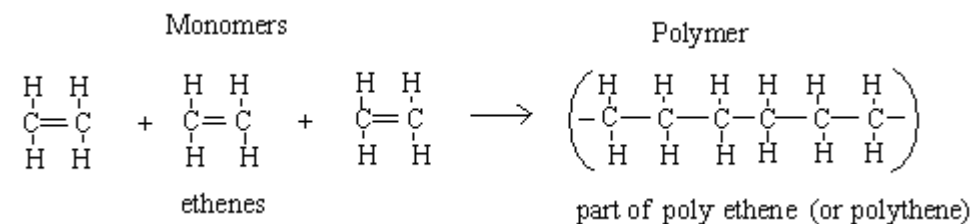
There are two types of polymerisation reactions; addition polymerisation and condensation polymerisation.

(i.) The Addition polymerisation:

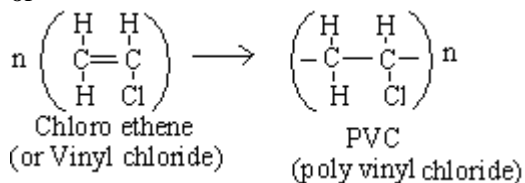
This is the polymerisation which involves repeated addition reactions of similar monomers.

The monomers used in addition polymerisation are unsaturated ones, (with double bonds) usually alkenes such as ethene or derivatives of alkenes such as chloroethene.

Examples of addition polymerisation;



or



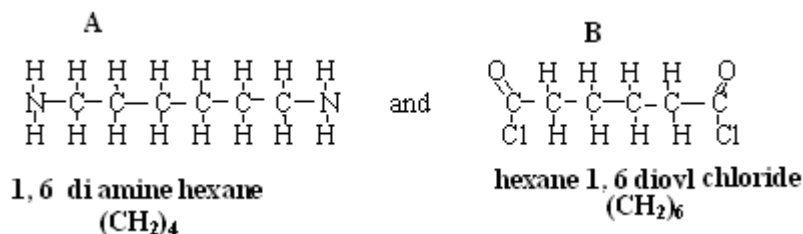
Most addition polymerisation reactions are synthetic (artificial) and are used in industries to produce the plastics.

(ii). Condensation polymerisation.

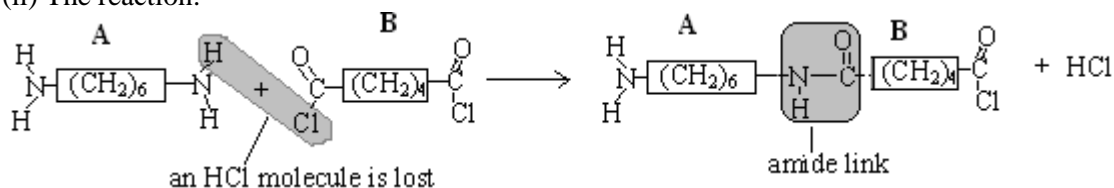
This is the polymerisation where a small molecule is released during the reaction. Condensation polymerisation usually involves two different monomers, each of which contains *two* similar functional groups. Examples of condensation polymerisation reactions:

a. Formation of nylon;

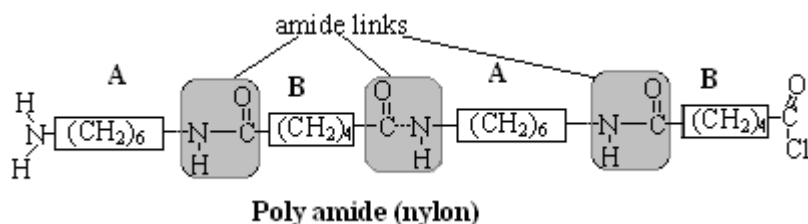
(i) The two monomers involved;



(ii) The reaction:



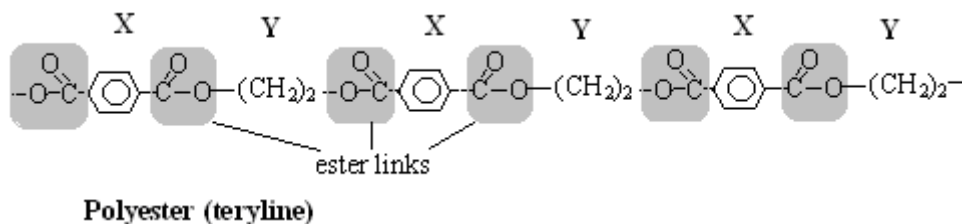
Part of the final polymer s as follows;



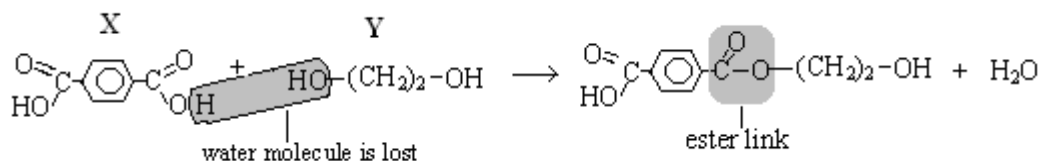
The linking groups of atoms are called 'amide link' because the -CONH is also present in the functional group of the amides which is -CONH₂. Therefore nylon is a polyamide because the linking groups of atoms in the polymer are amides.

b. Formation of terylene

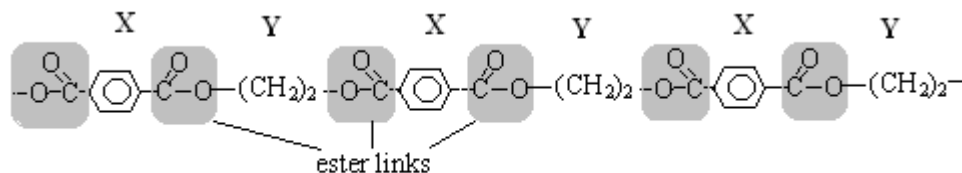
(i) The two monomers involved;



(ii) The reaction;



(iii) Part of the final polymer:



(iv) Terylene is polyester because the linking groups of atoms in the polymer are esters.

3. The Natural polymers:

Polymer	Monomer	Where it is found	Use
Protein	amino acids	Wool, silk, muscles	-To store amino acids, -To build body tissues and hair
Starch (carbohydrate)	Glucose	Potatoes, wheat, wood	To store glucose
DNA (Deoxyribonucleic acid)	Nucleotides	Chromosomes, genes	-To control protein synthesis in the body, -To control characteristics of individuals
Fats (poly esters)	Fatty acids and glycerol	Animal tissues	-To store fatty acids and glycerol .
Rubber	2 – methyl but-1,3 – diene.	Tree's sap	For making car tyres.
Cellulose	Glucose	Walls of plant cells	Cellulose from wood is used to make paper, cotton is used to make clothing.

Table 2.6

Advantage of the natural Polymers:

They are all biodegradable, so they do not cause disposal problems.

The disadvantage

They cannot be produced synthetically.

Synthetic polymers:

Synthetic polymers are normally referred to as plastics. Synthetic polymers are the polymers that are produced artificially.

Properties and uses of some Plastics:

Polymer	monomer	Properties	Uses
Poly ethene	Ethene $\text{CH}_2=\text{CH}_2$	Tough , durable	Carrier bags,

			buckets, bowls
Poly propene	$\text{CH}_3\text{C}=\text{CH}_2$	Tough, durable	Ropes, Packaging
PVC	CHloroethene, $(\text{CH}_2=\text{CHCl})$	Strong, hard, Less flexible than polythene	Pipes, electrical insulation
Poly tetrafluoroethane (PTFE)	$\text{CH}_2=\text{CF}_2$ (Tetrafluoroethene)	Non stick surface, Withstands high temperatures	Non stick frying pans, Soles of iron.
Polystyrene	$\text{CH}_2=\text{CHC}_6\text{H}_5$ (Styrene)	Light poor conductor of heat.	Insulation, packaging, Radio cabinets, pot handles.
Perspex	$\text{CH}_2=\text{C}(\text{COCH}_3)\text{CH}_3$	Transparent	Used as a glass substitute, lenses.

Table 2.7

Advantages of plastics:

- Cheap to produce.
- Resistant to acids, alkalis (i.e. bases), air and water.
- They adaptable i. e they can be varied according to what they are used for.

Disadvantages of plastics:

- They cause disposal problems because most of them are not readily biodegradable.
- They are expensive to recycle.
- Some give toxic gases when they burn. For example, some plastics on burning give off hydrogen cyanide gas which can kill human beings.

Types of plastics:

Activity: 2.1

Aim: To identify types of plastics

Materials:

- a piece of formica (or a piece of broken electric switch or socket),
- plastic ball point pen case,
- fire
- tongs.

Procedure:

1. Hold the piece of formica with the tongs over the fire.
2. Record your observations in a table like the one shown in table.
3. Repeat steps 1 and 2 with a ball point pen case.

Object being heated	Observation
Formica	
Plastic ballpoint pen case	

Table 2.8

Discussion

What happened to each of the objects when heated?

Observation

The formica does not become soft when heated while the plastic ball point pen becomes soft when heated. This is because there are two types of plastics depending on how they respond to heat. There are those that become soft and melt on being heated and those that do not melt on being heated. These two types of the plastics are;

- (a) thermoplastic polymers
- (b) thermosetting plastics.

(a) *Thermoplastic polymers.*

Thermoplastics are plastics which melt or soften when heated and harden into new shape when cooling. This is because the forces of attraction between the thermosetting plastic polymer chains are weak and there are no cross links between them.



Figure 2.1

Examples of thermoplastics are; polythene, PVC, polystyrene, e t c. Thermoplastics are also called thermo softening plastics

Properties and characteristics of thermoplastics

Properties	characteristics
They are flexible	They do not break easily.
They have no cross links	-They stretch under tension because the molecules are sliding over one another - They can be moulded into new shapes after they are made.
They melt at low temperatures	They are soft

Table 2.9

(b) *Thermosetting plastics (or thermo sets);*

These are plastics which set hard and cannot be melted again once they are made. This is because the polymers are held together very strongly due the presence of cross links between the polymer chains in the thermosetting plastics as shown in figure 2.3 below.

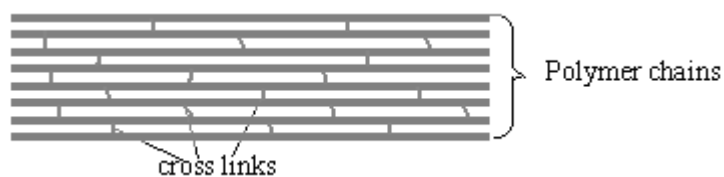


Figure 2.3

Examples of the thermosetting plastics are; electric plugs, ash trays, melamine plates, formica etc.

Properties and characteristics of thermosetting plastics

Properties	characteristics
They are rigid	They break other than stretch when under tension.
They do have cross links	- They cannot be moulded into new shapes after they are made.
They do not melt	They break down at high temperatures

Table 2.10

Waste Management of polymers

Paper and plastics can be disposed off by in following ways;

1. Recycling
2. Burning
3. Incineration
4. Burying in the soil
5. Paper can also be disposed off by making fire briquettes
6. Photodegradable plastics can be disposed off by exposing them to sunlight.
7. Plastics which dissolve in water such as persil capsules can be disposed off by exposing them to water.

Importance of recycling polymers

Recycling is the best way of disposing off polymers because of the following reasons;

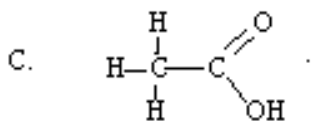
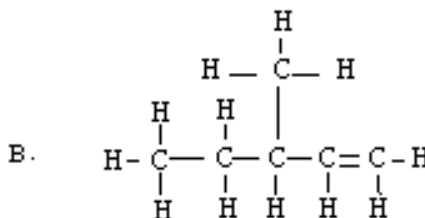
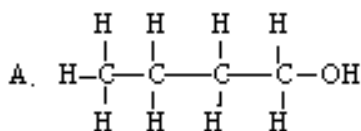
- (i) It serves as raw materials for making new products hence it reduces expenses.
- (ii) It cuts down need for mining and further extraction of raw materials hence there is less damage to the environment

Review questions

1. Draw the structure of the organic compounds with the following names:

- (i) 3 propyl octan – 3 – ol.
- (ii) 2 ethyl hex -2 - ene.

2. Study the structures of organic compounds A, B and C.



(a) Name compound B.

(b) To which family does C belong?

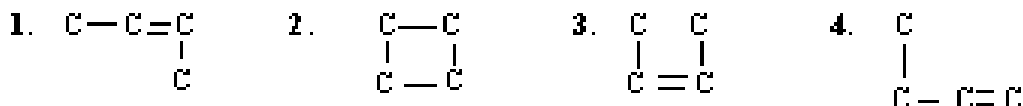
- (c) Write two isomers of compound A.
 (d) Briefly explain how you could distinguish a sample C from A.

3. a. Name one use of each of the following polymers;

- (i) Plastic
 (ii) Carbohydrate
 (iii) Polystyrene (polystyrene)

b. State two ways of disposing plastics to avoid polluting the environment.

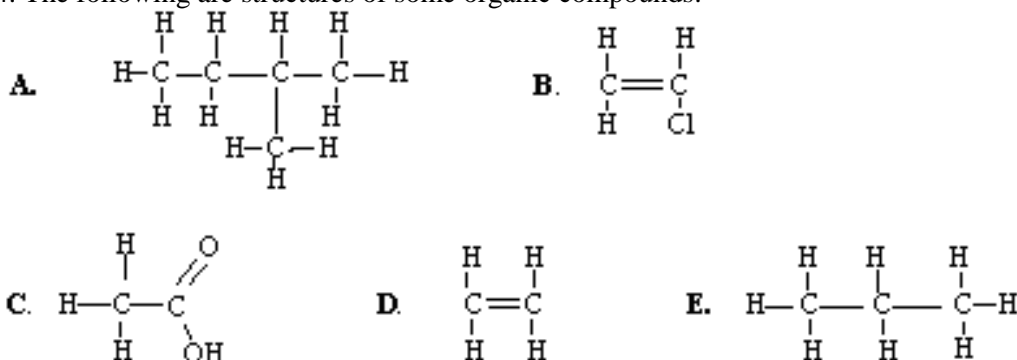
c. The following are structural formulae of four molecules with the molecular formula C_4H_8



(i) Name molecules 1 and 2.

(ii) Which two structures are isomers if each other?

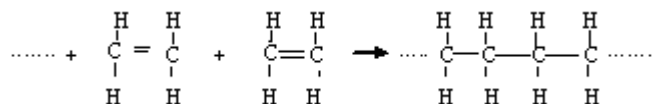
4. The following are structures of some organic compounds:



- (a) Name compound A.
 (b) Which one of the compounds A and E would have lower boiling point? Give a reason.
 (c) Compound D is a monomer. Write an equation to show its polymerisation.
 (d) Give one use of the substance formed in the polymerisation of compound B.
 (e) What is the state of D at room temperature?
 (f) Describe the test that could be done to distinguish the compounds D and E.
 (g) Write the isomers of substance A.
 (j) Give two advantages of thermoplastics.

5. a. Draw all the structural isomers of a compound with the formula C_6H_{12} .

b. Polymerization of ethene can be represented by the following equation:



- (i) Name the polymerization represented by the equation.
 (ii) Describe how the polymer is formed from the ethene molecules.
 (iii) Give three examples of artificial polymers.
- c. (i) Give three differences between thermosetting and thermoplastic polymers.
 (ii) Give three advantages of plastic polymers materials over metallic materials.

3. ELECTRICITY, MAGNETISM AND ELECTROMAGNETIC INDUCTION II

Electronics

Definition

Electronics is the branch of science which is concerned with the development of tiny electrical circuits and the devices that use these circuits.

Band Theory

In a single atom each electron occupies a specific energy level. But in blocks of solids, such as metals, the atoms are very close together and the energy levels fuse into bands which are shared by all the atoms. Each band contains allowed energy levels. The outermost band is called the conduction band. The band next to the conduction band is the valence band. The bands have gaps between them that represent energies which the electrons cannot have. These gaps are called forbidden bands. All the energies below the conduction band are full.

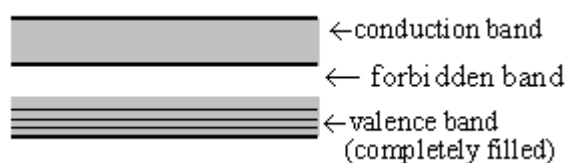


Figure 3.1

Electrical conduction by solids

Solids are grouped into three groups depending on their conductivities for electricity or heat. These groups are conductors, semiconductors and insulators (or non conductors)

(i) Conductors

In conductors such as metals, the gap between the conduction band and the valence band is very small. As such, electrons are able to move freely between valence band and the conduction band.

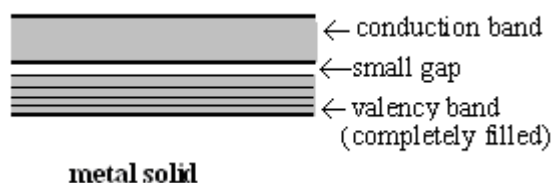


Figure 3.2

Any Pd (voltage) across the metal makes the electrons flow in one direction (causing an electric current).

(ii) Semiconductors;

In semiconductors, such as silicon, there is a bigger energy gap between the valence band and the conduction band.

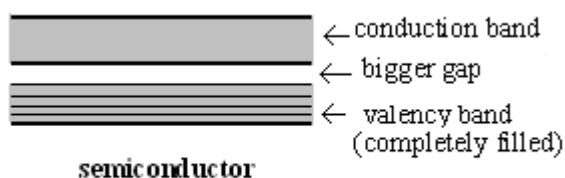


Figure 3.3

In the semiconductors, electrons must receive extra energy to be able to jump into the conduction band. The electrons may get this energy from heat or from an electric field. When the temperature of the semiconductor increases, more electrons from the valence band get enough energy and can jump into the conduction band, leaving holes (gaps) in the valence band. When a Pd is applied across the semiconductor, the electrons in the conduction band and the gaps in the valence band contribute to the flow of an electric current. The gaps behave as positive charge carriers. The semiconductors are not good conductors of electricity and heat because it needs extra energy to move the electrons from the valence band into the conduction band. When the temperature of a semiconductor is low, its conductivity decreases and the resistance increases. At low temperatures semiconductors behave as insulators.

(iii) Insulators:

In the insulators, the gaps between the valence band and the conduction band are too big as shown in figure below.

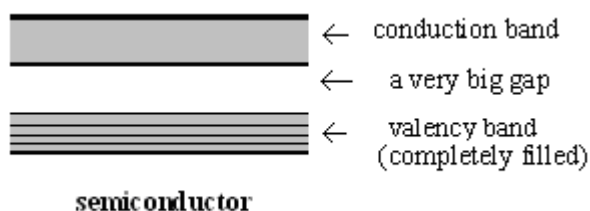


Figure 3.4

In the insulators, the electrons in the valence band cannot get enough energy to jump across the forbidden gap into the conduction band. As such no current can flow through the insulators.

The Semiconductors:

Semiconductors are materials which partially conduct electricity. In the semiconductors electricity is conducted by;

- flow of the electrons (negative charges)
- motion of the gaps (positive charges)

Types of semiconductors;

(a) Intrinsic semiconductors:

The materials which are naturally semiconductors are called intrinsic semiconductors. Examples of intrinsic semiconductors include silicon and germanium. The conductivity of intrinsic semiconductors can be improved by adding to them small, controlled amounts of atoms of other substances known as impurities. The process of adding the small but controlled amounts of impurities into intrinsic semiconductors is called 'doping'.

(b) Extrinsic semiconductors;

These are semiconductors that are made by doping intrinsic semiconductors. There are two kinds of extrinsic semiconductors depending on whether the atoms of the doping impurities had more electrons in the valence bands or had less number of electrons in the valence band than the intrinsic semiconductor. These extrinsic semiconductors are;

- n – type semiconductors
- p – type semiconductors.

(i) The n – type semiconductor:

This is an extrinsic semiconductor made by doping an intrinsic semiconductor with atoms which have more electrons in the valence band than in the valence band of the intrinsic semiconductor. This adds some electrons, (negative charge carriers) in the valence band. For example, doping silicon, which is an intrinsic semiconductor with 4 valence electrons, with phosphorus which has 5 valence electrons;

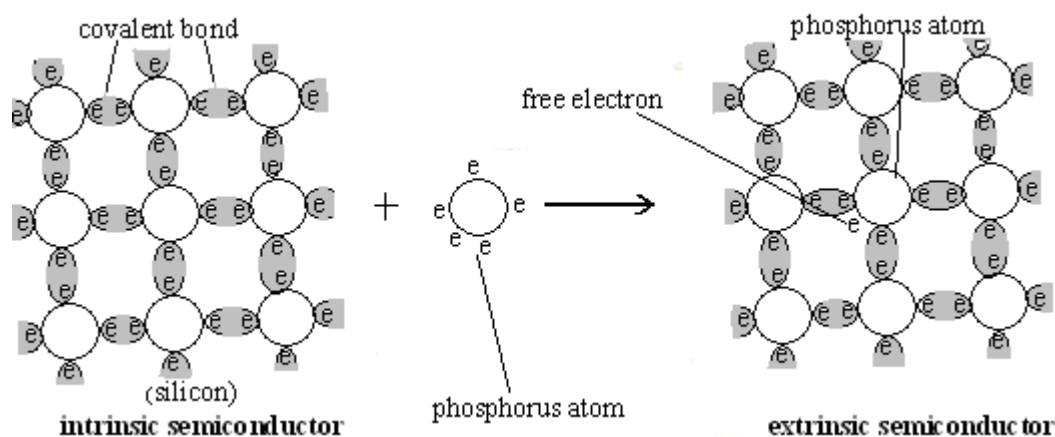


Figure 3.5

The extra electrons go into the conduction band and they are free to move through the material.

In the extrinsic semiconductors the conductivity is improved;

- because there are now more electrons in the conduction band.
- because of the gaps in the valence band.

(ii) The p- type semiconductors;

A p – type semiconductor is a semiconductor made by doping an intrinsic semiconductor with an atom which has less number of electrons in the valence shell than in the valence shell of the intrinsic semiconductor.

For example, doping silicon, which has 4 valence electrons, with boron, which has 3 valence electrons;

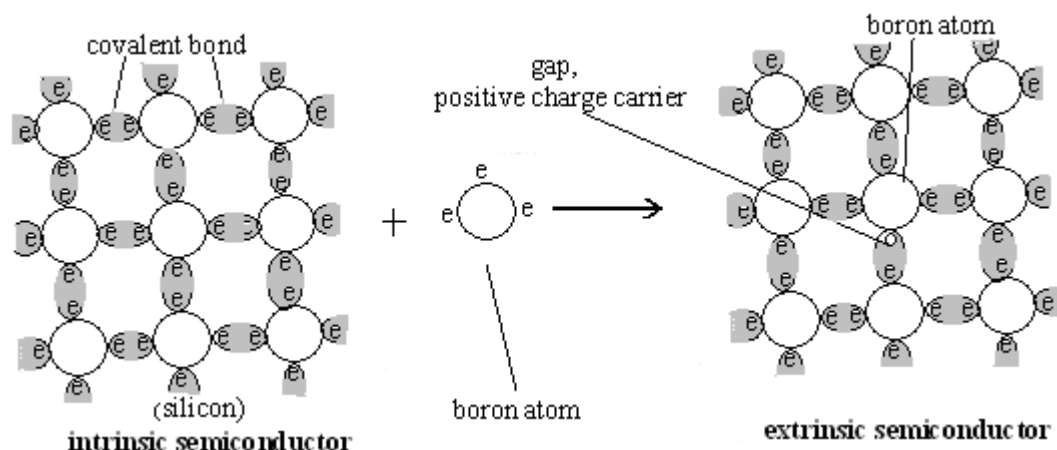


Figure 3.6

This increases the number of gaps in the valence band. Electricity flows;

(a) - when the gaps move or

(b) - when the electrons which have jumped into the conduction band flow.

P – n junction semiconductor:

This is the semiconductor made by doping an intrinsic semiconductor in such a way that one end is p – type and the other end is n – type. At the junction, electrons from the n – type side move to fill the gaps in the p type side.

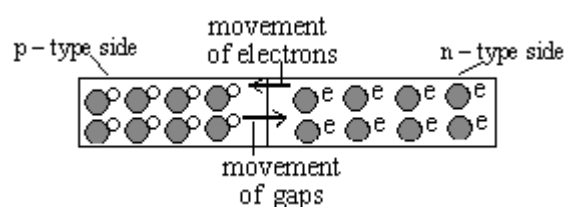


Figure 3.7

The movement of the electrons from the n – type side to the p – type side makes the p-type side to become negatively charged and the n – type side to be positively charged. The charge movement takes place within a small layer at the junction. This layer is known as a depletion layer. In this layer all the free electrons on the n – type side and the holes on the p – type side have been lost and the negative charges and the positive charges have been built on the opposite ends.

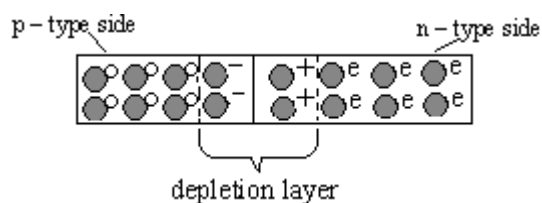


Figure 3.8

The depletion layer behaves like pure silicon with high resistance. Once the charges have built on the opposite sides of the layer, any further movement of the electrons across the boundary from the n – type side is repelled by the electrons already in the p – type side. Similarly the positive charge carriers (the holes) will be repelled by the holes already in the n – type side.

How the p – n junction semiconductor works

Activity: 3.1

Aim: To investigate how a p-n junction diode works.

Materials:

- a diode (from an old radio)
- connecting wires
- a torch bulb,
- bulb holder,
- cells
- a switch.

Procedure: (i) Connect a circuit as shown below;

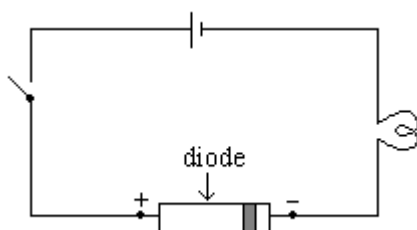


Figure 3.9

- (ii) Close the switch and observe the bulb.
- (iii) Switch off and reverse the diode so that the terminal near the band is connected to the positive terminal.
- (iv) Close the switch and observe the bulb.
- (v) Repeat steps (i) to (iv) three or four times.

Discussion:

In which connection of the diode does the bulb give light?

Observation

The diode is a p-n junction semiconductor. The side with the band is the n – type side and the terminal near the band is the negative (-) terminal. The other end of the diode is p – type and it is the positive (+) terminal. The bulb gives light, only when, the negative terminal of the diode is connected to the negative terminal of the cell. The diode can be operated in one of the following two ways;

- reverse biased or
- forward biased.

(a) Reverse Biased:

The p – n junction semiconductor is said to be reverse biased when it is connected to a battery or a cell in such a way that no current can flow through it as shown below.

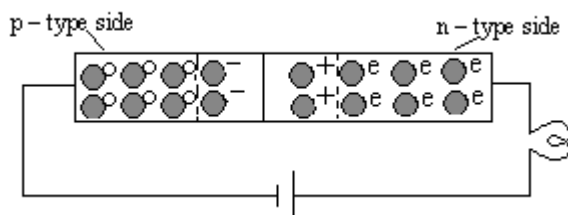


Figure 3.10

When the negative terminal of the battery is connected to the p – type side of the semiconductor, the layer of the negative charges in the p – type side in the depletion layer, repels the electrons from the negative terminal of the battery. This prevents the electrons from flowing and no current flows.

(b) Forward Biased:

The p – n junction semiconductor is said to be forward biased when its p – type end is connected to the positive terminal of the battery so that current flows through it as shown below;

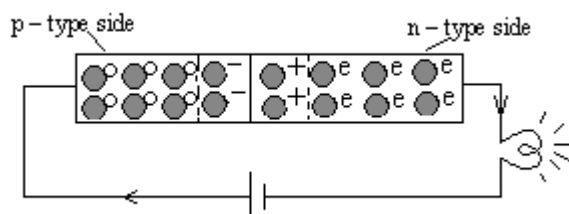
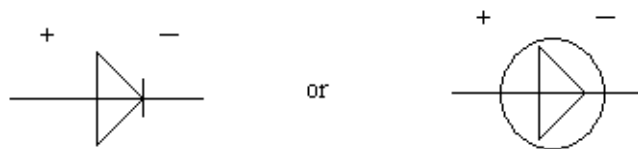


Figure 3.11

When the positive terminal of the power supply is connected to the p type end of the of the p – n junction semiconductor, the extra electrons in the p – type end attracted by the positive terminal of the power supply and so more electrons from the n – type side are able to move across the boundary into the p – type side and so the current flows.

Diodes:

A diode is a device that allows current to pass through it in one direction only. Its symbol is as follows:



Figure

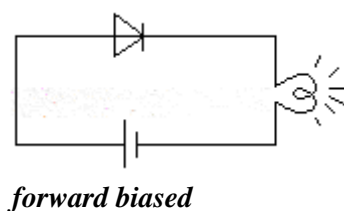
3.12

And its diagram is as follows;



Figure 3.13

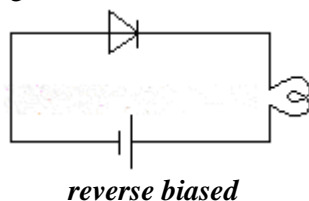
A diode is forward biased when its negative terminal is connected to the negative terminal of the battery as follows;



forward biased

Figure 3.14

It is reverse biased when its negative terminal is connected to the positive terminal of the battery as follows:



reverse biased

Figure 3.15

Uses of Diodes

Diodes are used to change current from an a c to d c. The process of changing ac to dc is known as rectification. The devices that change ac to dc are called rectifiers and the circuit that is used to change ac to dc is known as rectifier circuit. So the diodes are used as rectifiers.

Rectification:

There are two ways of rectifying currents;

- (a) Half wave rectification.
- (b) Full wave rectification

(a) The half wave rectification

An ac voltage supply changes terminals periodically (from + to – to + to – and so on) and so the current direction also changes in the same way and its graph is as follows;

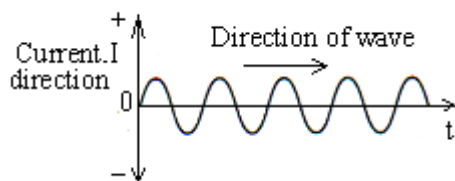


Figure 3.16

If a diode is connected in a circuit in series as shown below;

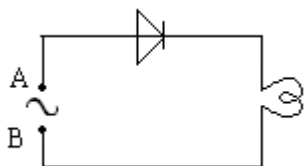
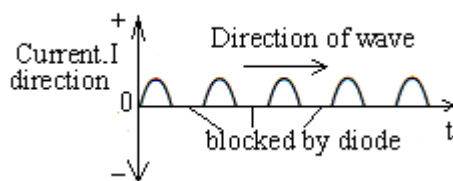


Figure 3.17

When A is positive, the diode is forward biased and current will flow through it. When B becomes positive, the diode is reverse biased and current will not flow through it. This means the current flows in the circuit for only one half of the cycle and it is zero for the other half as shown below;



Rectification with one diode.

Figure 3.18

Half wave rectification is, therefore, the process of changing a c to d c which results in current flowing through the circuit for only one half of the cycle. The circuit that is used to bring about half wave rectification is known as a half wave circuit.

(b) Full wave rectification

Full wave rectification is the process of changing ac to dc where current flows through the circuit in both halves of the cycle. There are two ways of achieving full wave rectification;

- (i) centre-tap full wave rectification and
- (ii) bridge rectification.

(i) centre-tap full wave rectification.

The centre – tap full wave rectification uses two diodes and a transformer with centre tap secondary coil.

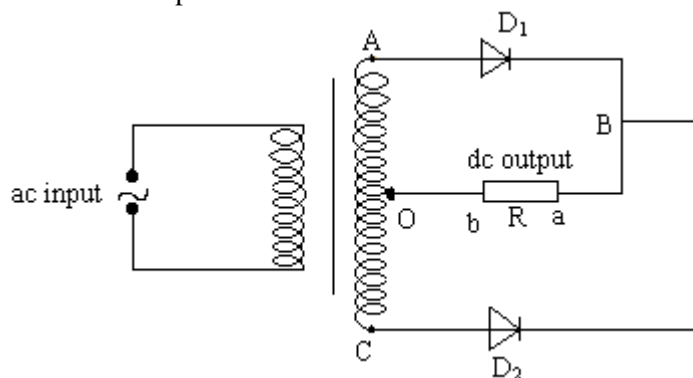


Figure 3.19

When A is positive, with respect to O, and C is negative, D_1 is forward biased and D_2 is reverse biased. Current flows in the circuit A, D_1 , B, R (entering at a , and leaving at b), O, A. When C is positive with respect to O, A is negative and D_2 is forward-biased. Current flows through C, D_2 , B, R (entering at a , and leaving at b), O, C. D_1 is now reverse-biased. In both halves of the cycle, current flows in the same direction through the load R and a fluctuating direct output current flows through R as follows:

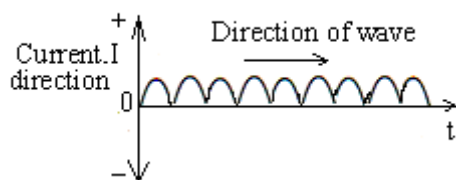


Figure 3.20

The disadvantage of the centre tap rectification is that the output power is half of the input power because it uses half of the transformer.

(ii) The bridge Rectifier:

In the bridge rectifier, the four diodes are arranged in a bridge network as follows:

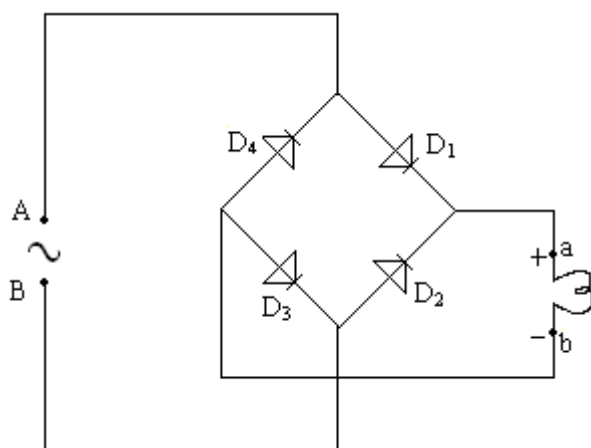


Figure 3.21

When A is positive, D_1 and D_3 are forward biased while D_2 and D_4 are reverse-biased. Current will flow from A, to D_1 , to the bulb (entering at a and leaving at b), to D_3 , and to B.

When B is positive, D_2 and D_4 are forward biased while D_1 and D_3 are reverse-biased. This time the current will flow from B, to D_2 , to the bulb (entering at a and leaving at b), to D_4 , and to A.

In both halves of the cycle, a fluctuating direct output current flows through the bulb in the same direction. The current through the bulb will be as follows;

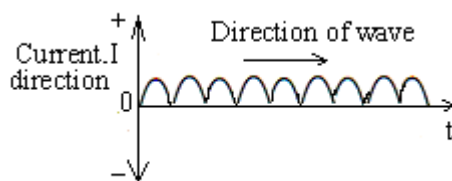


Figure 3.22

Smoothing the Rectified current

To make the fluctuating direct output current smooth, a large capacitor, called a reservoir capacitor, C , is connected in parallel with the appliance, such as the bulb, in this case as shown below.

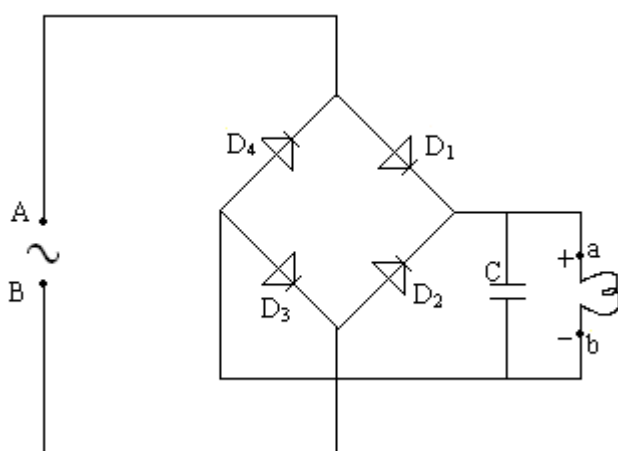


Figure 3.23

The rectified input p.d. causes the current to flow through the bulb and at the same time the capacitor, C , becomes charged to the maximum value of the input p.d. When the input p.d. begins to fall, as the terminals **A** and **B** are exchanging polarities, from positive to negative and from negative to positive respectively, the capacitor, C , starts to discharge. It cannot do so through the rectifier since the diodes are reverse biased, but it does through the bulb and thus maintains current flow. The total output current through the bulb will be as follows;

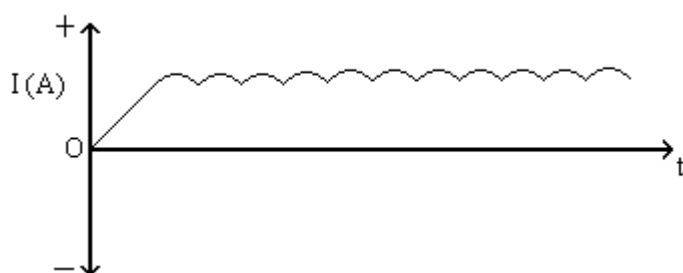


Figure 3.24

The effect of the bridge rectifier and the capacitor is that the current through the appliance is direct and it does not fall to zero.

Application of Rectifiers

Rectifiers are used in radio receivers if the radio is connected to an a.c. power source.

Transistors:

A transistor is a small semiconductor made by joining three semiconductors together.

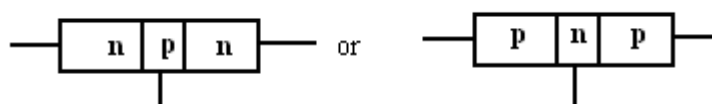


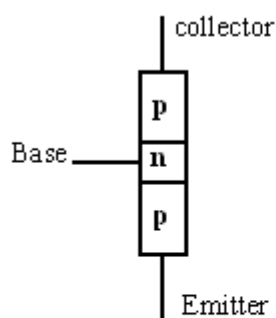
Figure 3.25

There are two types of transistors; the p-n-p transistor and the n-p-n transistor. Each transistor has three terminals (connections); the collector, **c**, the base, **b**, and the emitter, **e**. The base is the connection to the central slice and the emitter is the connection with an arrow. The symbols for the two types of the transistors are similar but the arrows point in different directions. In a *p-n-p transistor*, the arrow points towards the emitter while in an *n-p-n transistor* the arrow points away from the emitter.

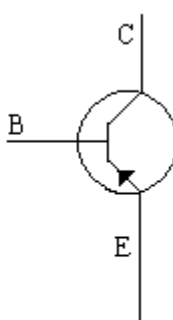
The arrows point in the direction of the flow of current. They always point to the n-type semiconductor. The two types of the transistors are as follows:

a. The p-n-p transistor:

In the p-n-p transistor, the n – type semiconductor is in between two p– type semiconductors as follows:



Diagram

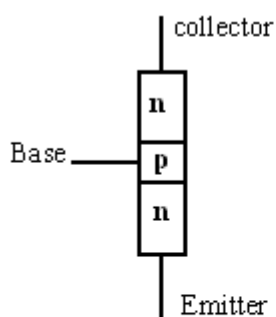


Symbol

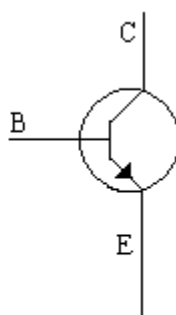
Figure 3.26

b. The n-p-n transistor:

In the n-p-n transistor the p – type semiconductor is sandwiched between two n –type semiconductors as shown below:



Diagram



Symbol

Figure 3.27

How transistors work:

Activity: 3.2

Aim: To investigate how transistors work.

Materials:

- 3 ammeters
- a $1000\ \Omega$ resistors
- a transistor (from an old radio)
- 8 connecting wires
- 2 dry cells

Procedure:

(i) Set up the apparatus as shown in figure 3.28 below

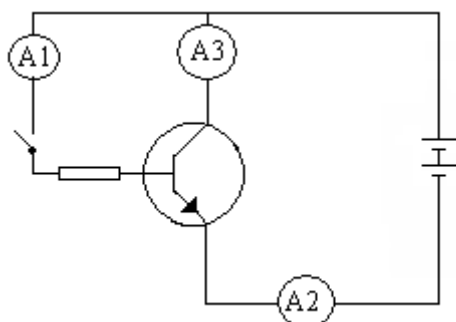


Figure 3.28

- (ii) Close the switch and record the ammeter readings.
(iii) Open the switch so that there is a break in the circuit to the base.
(iv) Note and record the readings of A2 and A3.
(v) Repeat steps (i) to (iv) and record your observations in a table as the one shown in table 3.1.

Switch (open/ closed)	Reading of A1 (A)	Reading of A2 (A)	Reading of A3 (A)
closed			
open			

Table 3.1

Discussion

How do the reading of A1, A2 and A3 compare when the switch is closed?

What happens to bulb A2 and A3 when the switch is open?

Explain the observations made above.

Observations

Ammeters A1, A2 and A3 show some readings when the switch is closed. But the when the switch is open all the ammeters do not show any reading, which means that no current is flowing through the ammeters A2 and A3 although their circuit is complete. We also observe that the reading of A1 is smaller is smaller than that of A2 and A3 and the reading of A1 + the reading of A2 = the reading of A3.

These observations show that a small current through ammeter A1 causes a large currents to flow through A2 and A3. The ammeters A1 and A2 are connected in two different circuits which are connected to the same transistor. These two circuits are;

- (i) base emitter circuit I_B .
(ii) emitter collector (via base) circuit, I_C .

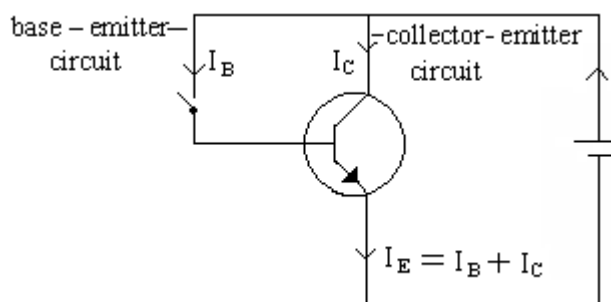


Figure 3.29

The current through the base emitter path (I_B) switches on the current through the emitter collector path (I_C). If I_B is switched off current cannot flow through the emitter collector path and so $I_C = 0$. This is because one of the p-n junction diodes becomes reverse biased as shown in figure 3.30 below.

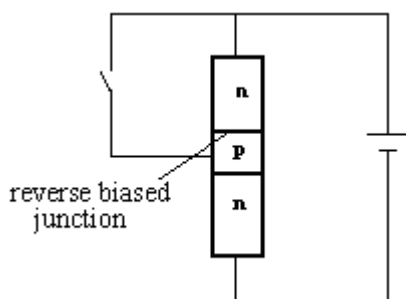


Figure 3.30

When a small current flows through the base-emitter path, current begins to flow in the collector-emitter path. This means a small current in the base-emitter path causes a large current in the collector-emitter path and the emitter current, I_E is greatly increased since $I_E = I_B + I_C$. To operate the transistor the base emitter junction must be connected so that the base emitter junction is forward biased, i. e. p-type end of the diode is connected to the positive terminal of the power supply. There are two ways of connecting circuits to a transistor:

i. Common emitter circuits:

This is a connection where both the base emitter and the collector emitter circuits are joined to the emitter.

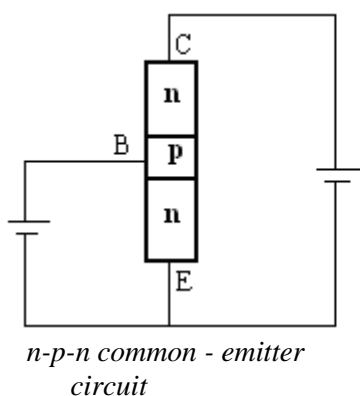


Figure 3.31(a)

or

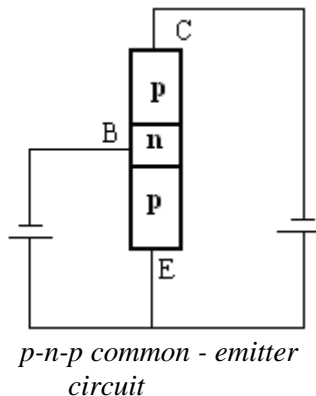
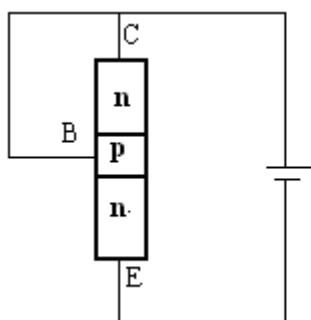


Figure 3.31 (b)

In the common-emitter circuit, a small power supply is needed in the base emitter path so that the base emitter junction is forward biased and current flows through it.

ii. Common collector circuits:

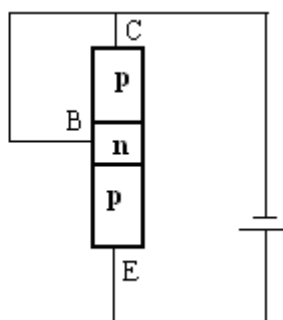
The common collector circuit connection is the connection where both base – emitter and the collector – emitter circuits are joined to the collector. In the common collector circuits, the same power supply which is in the collector- emitter path provides the small current in the base-collector path which switches on the current in the collector – emitter path.



n-p-n common collector circuit

Figure 3.32(a)

or .



p-n-p common collector circuit

Figure 3.32 (b)

Exercise

Draw the diagrams in figures 3.31 (a) and 3.31(b) using the appropriate symbols for the transistors.

Uses of transistors:

(i) As a switch:

The changes in the base current can turn on and off the current in the collector emitter path.

(ii) As an amplifier:

A small change in the base current produces large changes in the collector current.

Review questions:

1. In the figure below is a bridge rectifier;

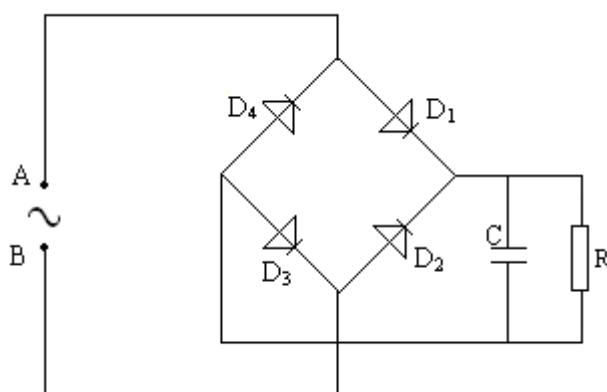


Figure 3.33

- The four diodes D1 to D4 make up a bridge rectifier. By considering one complete cycle of an alternating voltage explain how the bridge rectifier performs its task. You may begin as follows 'During the first half of the cycle, current flows through....'
- What is the purpose of the capacitor, C?
- Draw a graph representing the flow of current through the resistor, R;
 - When the capacitor is removed.
 - When the capacitor is connected.

2. a. Draw a circuit showing the use of a diode in a half –wave rectifier circuit.
b. Sketch graphs representing the input and the output currents.
3. The figure below shows a p-n junction diode in series with a small bulb.

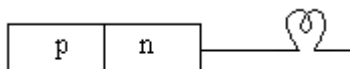


Figure 3.34

- a. (i) Copy and complete the diagram to show how a battery should be connected so that the diode is forward biased.
(ii) What would be the effect on the light bulb?
 - b. Redraw the diagram using the appropriate circuit for the diode.
 - c. What would be the effect of reversing the battery connection?
3. a. Draw a graph to show the effect of half wave rectification of an alternating current.
b. Draw a circuit which could be used to produce a half wave rectification.
c. What would be the effect of connecting a large capacitor across the load?
 4. Study the figure below:

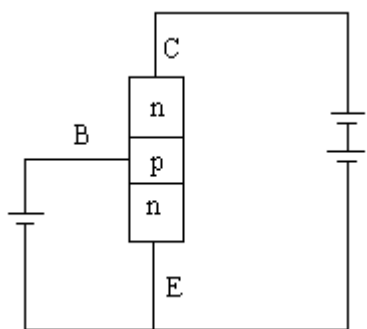
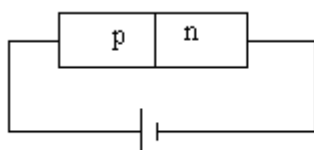


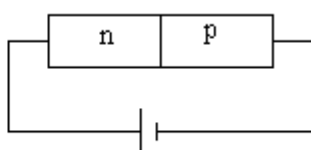
Figure 3.35

- a. Redraw the figure using the appropriate symbol for the n-p-n junction transistor. Mark on your diagram the emitter, E, the base, B, and the collector, C of the transistor.
 - b. What does the arrow on the transistor symbol represent?
5. The figure below shows two ways of connecting a p-n junction diode



X

Figure 3.36a



Y

Figure 3.36 b

In which circuit will the current not flow? Why?

6. The figure below shows an n-p-n transistor;

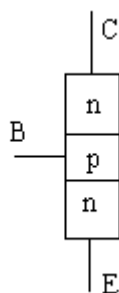


Figure 3.37

Complete the diagram by showing the connections of two batteries suitable for connecting the transistor in the common-emitter mode.

7. The figure below shows an incomplete circuit diagram for full wave rectification of an ac current.

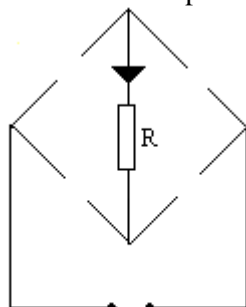


Figure 3.38

Complete the diagram by inserting the diode symbols so that the rectified current passes through R in the direction shown by the arrow.

8. a. Draw a circuit diagram of a p-n-p transistor operating in the common emitter mode. Indicate on the diagram the directions of collector current, I_C , the base current I_B and the emitter current, I_E .

b. Write the equation connecting the quantities I_C , I_B and the I_E

4. CHEMICAL REACTIONS II

Electron transfer reactions

Activity: 4.1

Aim: To find out what happens when an iron nail is dipped into a copper sulphate solution.

Materials:

- a clean 2 inch iron nail,
- copper sulphate solution
- a 25 ml beaker

Procedure:

- Pour the copper sulphate solution into the beaker.
- Dip one the iron nail into a copper sulphate solution and leave it there for about 3 minutes.
- After 3 minutes remove the nail from the solution and observe it.

Discussion

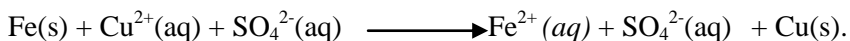
What happened to the nail when it was dipped into the solution?
Explain your observations

Observation

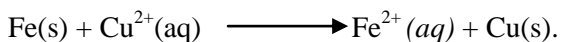
The iron nail was coated with copper metal. The copper metal came from the solution. This shows that a chemical equation has taken place between the iron, Fe and the copper sulphate (CuSO_4) solution. The equation is as follows;



Writing the equation using the ions present in the solution we have;



This type of equation in which the ions which were involved in a reaction are shown is known as an ionic equation. In this equation, the sulphate ion is found on both sides of the equation. This means that the SO_4^{2-} ion did not take part in the reaction nothing has changed on it. It is a spectator ion and should not be included in the equation. The equation should then be written as;



This equation is called the net ionic equation.

Oxidation numbers

All chemical reactions involve transfer of electrons. The number assigned to an atom or an ion to show how many electrons it loses or gains during chemical reactions is known as the oxidation number.

When working out oxidation numbers of elements, all compounds including the covalent (molecular) compounds are treated as if they either gain or lose electrons during the reactions. Sharing of electrons is ignored when working out oxidation numbers. In the covalent compounds the bonding (i.e. the shared) electrons are imagined to be owned by the more electronegative atom. (Electronegative means electron attraction power).

Rules for Calculating Oxidation Numbers:

- (a) The oxidation numbers of uncombined element is equal to zero. For example, the oxidation number of; carbon, $\text{C} = 0$, $\text{Cl}_2 = 0$, $\text{O}_2 = 0$, $\text{H}_2 = 0$
(b) The oxidation numbers of monoatomic ions are equal the charges on the ions.
eg the oxidation number of $\text{Al}^{3+} = +3$ and the oxidation number of $\text{Cl}^- = -1$
(c) The oxidation number of each hydrogen atom, H is $+1$
(d) The oxidation number of each oxygen atom, O is -2
2. The algebraic sum of oxidation numbers of the elements in a compound (ionic or covalent) is equal to zero.
3. For oxy anions such as SO_4^{2-} , the oxidation number of the other element in the ion is found by; charge on the ion – (minus) ($-2 \times$ the number of oxygen atoms)
4. In any substance the more electronegative atom has a negative oxidation number while the less electronegative atom has a positive oxidation number.

Example

1. What is the oxidation number of sulphur, S in the ion SO_4^{2-}

Working out;

$$\begin{aligned}\text{Oxidation number of S} &= -2 - (-2 \times 4) \\ &= -2 - (-8) \\ &= +6\end{aligned}$$

2. Work out the oxidation number of H_2SO_4 .

Working out

The oxidation number of H = +1, O = -2

let the oxidation of S = y,

Therefore; $y + (2 \times +1) + (4 \times -2) = 0$

$$\rightarrow y + 2 + -8 = 0$$

$$\rightarrow y = -2 + 8$$

$$\rightarrow y = +6$$

the oxidation number of S = 6

Exercise

1. Work out the oxidation number of;

(a) Mn in MnO_4^- .

(b) S in SO_4^{2-}

(c) S in SO_2

(d) C in carbonate CO_3^-

2. Find the oxidation number sodium, Na, Chlorine, Cl, potassium, K and Manganese, Mn in the following compounds

(a) NaCl

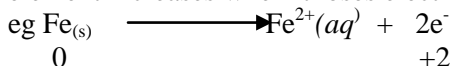
(b) KMnO_4

Oxidation and Reduction;

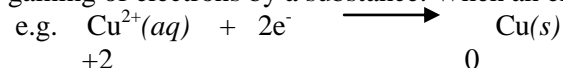
During the reaction between copper sulphate solution CuSO_4 and the iron, the iron atom, Fe has lost 2 electrons and become an iron ion as Fe^{2+} follows;



The loss of electrons the atoms of an element is called oxidation reaction. The oxidation number of the element increases when it loses electrons:

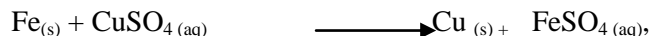


The element is said to have been oxidized when its oxidation number has increased. Reduction means the gaining of electrons by a substance. When an element gains electrons, its oxidation number decreases:



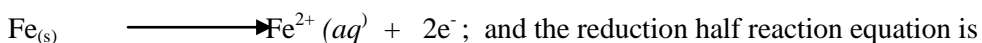
When the oxidation number of an element decreases, it is said to have been reduced. Reduction and oxidation reactions take place simultaneously. When one substance is oxidized another substance is reduced at the same time. The two reactions are, therefore, just known as **redox** reactions

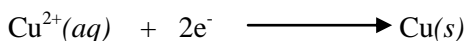
For example, when the iron, Fe is mixed with an aqueous solution of copper sulphate, $\text{CuSO}_4(\text{aq})$, the Fe is oxidized to become Fe^{2+} while the copper ion, Cu^{2+} , in the CuSO_4 is reduced to become copper atom, Cu at the same time as follows;



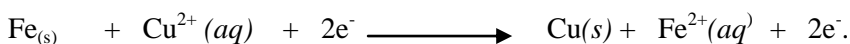
Half reaction equations:

The two equations representing oxidation and reduction reactions are known as half reaction equations. For example, in the net ionic equation,

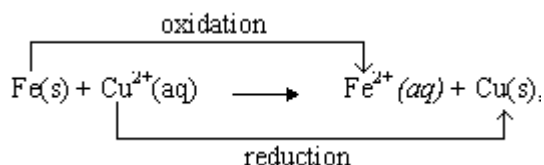




Combined the two half reaction equations we have the equation as follows;



The electrons are found on both sides of the equation and must be excluded in the final net ionic equation;



Exercise:

Write down the oxidation and reduction half equation for each of the following redox reactions:

- $\text{Zn}(\text{s}) + \text{Pb}^{2+}(\text{aq}) \longrightarrow \text{Zn}^{2+}(\text{aq}) + \text{Pb}(\text{s})$
- $\text{Cl}_2(\text{aq}) + 2\text{Br}^{-}(\text{aq}) \longrightarrow 2\text{Cl}^{-}(\text{aq}) + \text{Br}_2(\text{aq})$
- $\text{Mg}(\text{s}) + 2\text{H}^{+}(\text{aq}) \longrightarrow \text{Mg}^{2+}(\text{aq}) + \text{H}_2(\text{g})$
- $2\text{Na}(\text{s}) + \text{Cl}_2(\text{g}) \longrightarrow 2\text{NaCl}$

Balancing Redox Equations:

There are two rules for writing redox equations as follows;

(i) In any ionic equation the charges must balance:

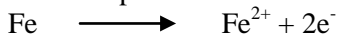
This means that the sum of the charges on the left-hand side, LHS must be equal to the sum of the charges on the right-hand side, RHS. This rule applies to ionic equation for both overall reactions and half reactions.

Examples

Charges on	Charges on	Equation	
		left hand side	right hand side
a. $\text{Mg}(\text{s}) + 2\text{H}^{+} \longrightarrow$	$\text{Mg}^{2+}(\text{aq}) + \text{H}_2(\text{g})$	2+	2+
b. $2\text{Br}^{-}(\text{aq}) \longrightarrow$	$\text{Br}_2(\text{aq}) + 2\text{e}^{-}$	2-	2-
$2\text{Na}(\text{s}) \longrightarrow$	$2\text{Na}^{+}(\text{aq}) + 2\text{e}^{-}$	0	$(2+) + (2-) = 0$

(2) The number of electrons lost in the oxidation half reaction must be equal to the number of electrons gained in the reduction half reaction.

For example in the reaction the number of electrons lost in the oxidation half reaction is two;



Therefore the number of electrons gained in the reduction half reaction must also be two;



Writing Redox Equations from two Half Reaction Equations;

1 (a) Balance the two half equations separately by adding electrons to either the LHS or the RHS (*rule one above*)

(b) Balance the two half equations with respect to each other so that the number of electrons lost is equal to the number of electrons gained (*rule 2 above*)

2 Combine the two half equations to give the redox equation. For example adding the two half reaction equations above and cancelling the electrons we obtain the following equation;

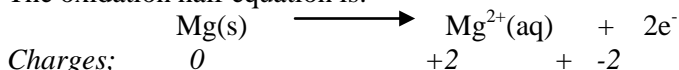


Examples

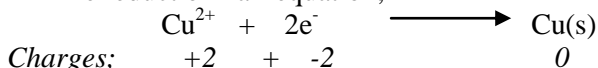
Write the balanced redox equations from the following reactions;

(i) The reaction between magnesium and copper (II) sulphate solution;

The oxidation half equation is:



The reduction half equation;



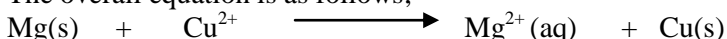
The two half equations are balanced;

Each side has zero charge (**rule 1**).

Magnesium, Mg(s) loses two electrons which are subsequently gained by the copper (II) ions, Cu²⁺, so the number of electrons lost is equal to the number of electrons gained (**rule 2**).

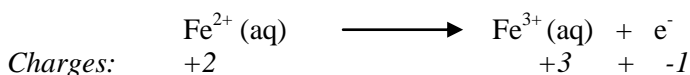
The two half equations are combined to give an overall redox equation. The electrons cancel each other out and so do not appear in the overall equation.

The overall equation is as follows;

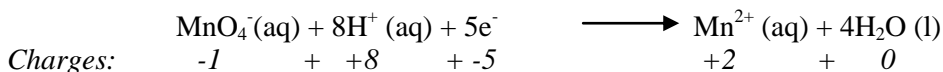


(ii) The oxidation of iron (II) ions, Fe²⁺ to iron (III) ions, Fe³⁺ by potassium manganate (VII) in acidic solution.

The oxidation half reaction equation is;



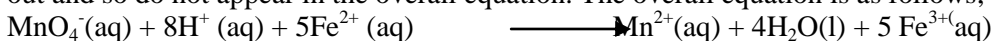
The reduction half reaction equation is



The Two half reaction equations are balanced in terms of charges (**rule 1**). The reduction reaction involves the transfer of five electrons whereas the oxidation half equation involves the transfer of one electron. To balance the equations with respect to each other, the oxidation half reaction must be multiplied by five (**rule 2**), as follows;



The two ionic half equations can be combined to give a redox equation. The electrons cancel in each other out and so do not appear in the overall equation. The overall equation is as follows;



Oxidizing Agents and Reducing Agents

a. Oxidizing Agents;

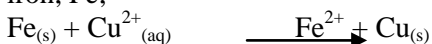
An oxidizing agent is a substance that oxidizes another substance by accepting electrons from it. When oxidizing the other substance the oxidizing agent is itself reduced.

b. Reducing Agents

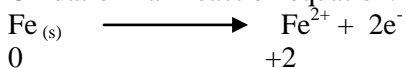
A reducing agent is a substance that reduces another substance by donating electrons to it. While donating the electrons the reducing agent is itself oxidized.

Example;

Consider the ionic equation below for the reaction between copper (II) sulphate solution and iron, Fe;

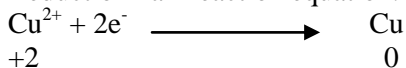


Oxidation half reaction equation:



In this equation iron is oxidized since its oxidation number increases from 0 to +2, so iron is a reducing agent

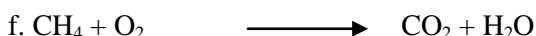
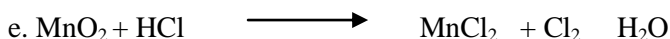
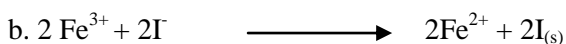
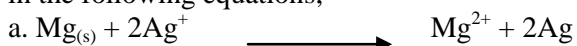
Reduction half reaction equation:



In this equation copper is reduced because its oxidation number decreases from +2 to 0, so it is an oxidizing agent.

Exercise:

Write the oxidation and reduction half reaction equations and identify the oxidizing and the reducing agents in the following equations;



Applications of Redox Reactions:

a. Displacement of metals.

Activity: 4.2

Aim: To investigate if some metals are more reactive than others.

Materials:

- zinc metal,
- copper metal
- iron nail,
- tin metal,
- 2 droppers,
- copper sulphate solution
- zinc sulphate solution
- a white tile.

Procedure:

- Place each piece of metal on the tile separately.
- To each piece of metal, add 3 drops of the copper sulphate solution.
- Observe for 5 minutes
- Compare the rates of the reactions and record your observations as fast reaction, slow reaction, moderate reaction or no reaction in a table as follows;

Substances together	added	Rate of reaction
Zn + CuSO ₄		

Sn + CuSO ₄	
Fe + CuSO ₄	
Cu + CuSO ₄	

Table 4.1

(v) Repeat steps 1 – 4 with zinc sulphate solution.

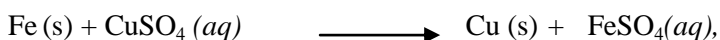
Discussion

Which metal is more reactive than the others.

Arrange the metals in order of their reactivity.

Observations

During reactions between metals and the solutions of metal compounds, the metal component in the compound may be displaced by the other metal. For example, during the reaction between iron and the copper sulphate solution, copper is displaced from its compound by iron as follows;



The metals that are displaced from their compounds are less reactive than those that displace them.

From the results of the experiment above, it can be observed that;

- copper is displaced from its compound by zinc, iron, and tin. Therefore, copper is the least reactive of the four metals.
- the reaction between zinc and copper sulphate solution is the fastest of all the reactions and zinc is not displaced by any of the three metals. This means zinc is the most reactive metal of the four metals.
- the reaction between iron and the copper sulphate solution is faster than the reaction between tin and the copper sulphate solution. Therefore, iron is more reactive than tin.

Arranging the metals in order of their reactivity we have;

Zinc
 Iron *increasing reactivity*
 Tin
 Copper

Less reactive metals cannot displace more reactive metals from the solutions of their compounds.

The reaction in which a more reactive metal displaces a less reactive metal from a solution of its compound is called a displacement reaction.

Displacement Series;

This is the arrangement of the metals in the order of their relative chemical reactivity.

It is also known as reactivity series or activity series.

The series is as follows;

Most reducing ↑ increasing activity	(or most reactive) Lithium, Li Potassium, K Calcium, Ca Sodium, Na Magnesium, Mg Aluminium, Al Zinc, Zn Iron, Fe Tin, Sn Lead, Pb Hydrogen, H Copper, Cu Silver, Ag	↓ Decreasing activity
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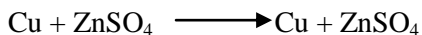
Gold, Au
Least reducing (or the least reactive)

The series is also called the redox series because the metal high in the series reduces the metal which is lower in the series and the metal which is lower in the series will oxidize the metal which is higher in the series.

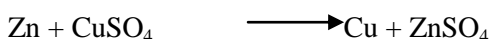
The positions of the metals in the series tell us the following;

(i) Whether a reaction will take place or not.

If the ion is of an element below and the atom is of an element above, reaction will take place. But if the ion is of an element above and the atom is of an element below in the series, reaction will not take place. For example, reaction cannot take place when copper metal is mixed with a solution of zinc sulphate;



However, a reaction takes place when zinc metal is mixed with a solution of copper sulphate solution;

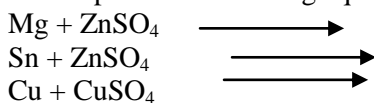


(ii) The rate of the reaction.

The reaction between the atoms of an element and the ions of an element just below it will be slower than that between the atoms of an element and the ions of an element far below it. For example, the reaction between zinc and a solution of copper sulphate is faster than the reaction between tin and a solution of copper sulphate.


Exercise:

1. Complete the following equations to show whether the reaction will take place or not;



2. a. The following is part of an activity series:

Lithium (Li)
Sodium (Na)
Magnesium (mg)
Lead (Pb)
Hydrogen (H)
Copper (Cu)
Silver (Ag)

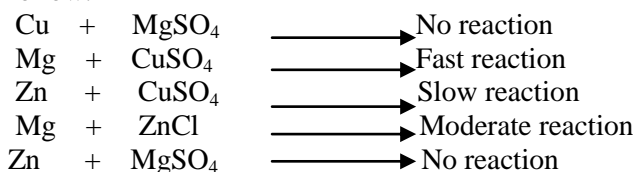


(i) State whether copper (Cu) will react with a solution of magnesium sulphate, MgSO_4 . Give a reason to your answer.

(ii) Which element is the most reactive in the activity series? Why?

Write half equations for the reaction between silver nitrate, AgNO_3 and sodium, Na.

3. Below are results of a set of experiments carried out by a pupil. Study them and answer the questions that follow.



(i) Write a balanced chemical equation for the reaction between magnesium, Mg, and copper sulphate CuSO_4 solution.

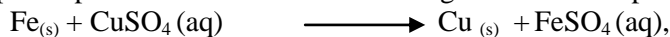
(ii) Name the oxidizing agent and the reducing agent in the reaction you have written in (i) above.

(iii) Arrange the metals in order of reactivity, starting with the most reactive.

Uses of Displacement Reactions of Metals

(i) Extracting metals.

Displacement reactions can be used to **extract metals** from their ores. Metals naturally exist as in the form of compounds such as oxides or sulphides. Such compounds are called ores. Less reactive metals such as copper can be extracted from their ores by the spontaneous redox reactions. The metal is extracted by dipping the more reactive metal into the aqueous solution of the metal to be extracted. For example, to extract copper from its compound, an iron metal can be dipped into the aqueous solution of a compound of copper such as a copper sulphate solution and the following reaction takes place;



The copper metal is reduced during the reaction and is deposited on the iron metal.

b. Electroplating.

Activity: 4.2

Aim: To demonstrating electroplating copper wire with zinc.

Materials:

- 2 cells
- connecting wires,
- switch,
- zinc metal,
- zinc chloride solution,
- copper wire
- a beaker.

Procedure:

(i) Arrange the apparatus as follows;

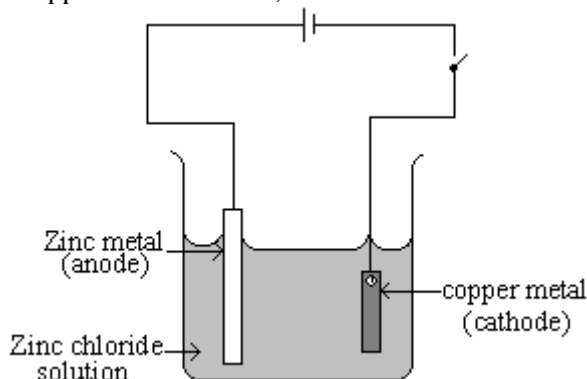


Figure 4.1

(ii) Close the switch and leave the apparatus for about 5 minutes.

(iii) Open the switch and remove the copper metal and the zinc metal from the solution.

Discussion

Look at the copper metal, what has happened to it?

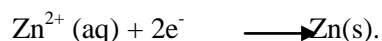
What has happened to the zinc metal?

Observation

The copper metal has been coated with zinc metal while the zinc metal is eaten up. When the switch is closed, the zinc metal at the anode is oxidized as follows;



The zinc ions are attracted to the cathode. At the cathode, the zinc ions are reduced to zinc atoms.



The zinc metal coats (covers) the copper metal. The process of coating (or plating) one metal with another metal using electricity is what is known as electroplating.

To electroplate an object with metal X, the object to be electroplated should be connected to the cathode. Metal X must be the anode. The electrolyte should be the solution of the compound of metal X.

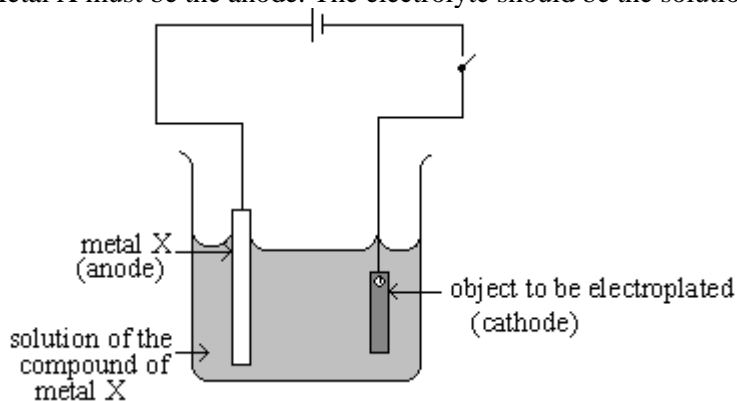


Figure 4.2

Uses of electroplating

- i- to make metals more attractive. For example, cheap metal jewellery can be coated with silver to make it beautiful.
- ii- to protect metals from corrosion . For example, steel car bumpers are coated with chromium and steel cans are coated with tin.

c. Rusting:

Activity: 4.3

Aim: To investigate conditions for rusting.

Materials:

- three test tubes,
- test tube rack,
- cotton wool,
- three iron nails
- cooking oil,
- anhydrous
- calcium chloride
- distilled water.

Procedure

- (i). Set up the three boiling tubes as shown in the figure below;

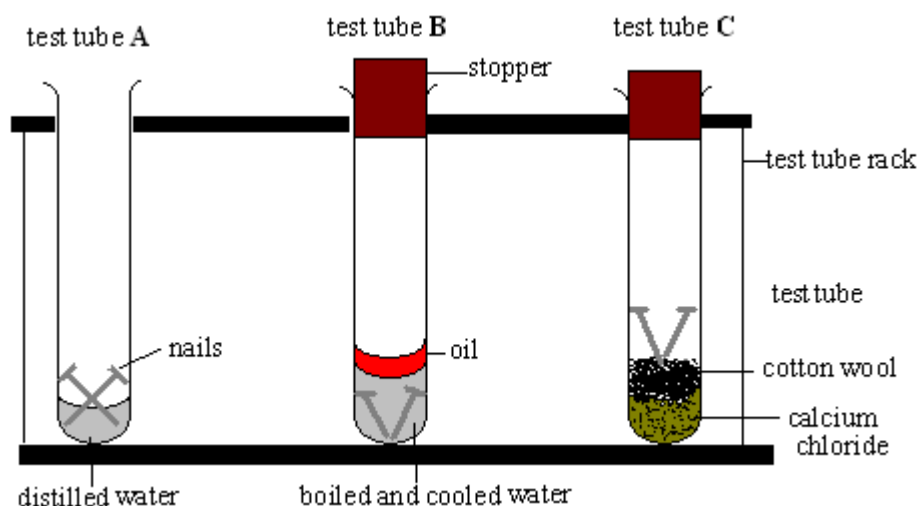


Figure 4.3

(ii). Leave the test tubes for one week.

Discussion

In which test tubes did the nails rust?

What causes rust?

Observations

We might have observed that the nails in test tube A rusted while those in test tubes B and C did not. The boiled and cooled water does not contain dissolved oxygen in it.

In test tube B there was no oxygen in the water and the stopper and the oil prevented any oxygen in the air from entering the water. The nails in this test tube did not rust.

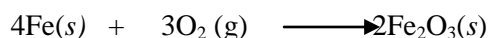
In test tube C, there was no water. The calcium chloride removed any water in the air enclosed in the tube. The nails in this tube did not rust.

In test tube A, both water and oxygen were allowed to come into contact with the nails. The nails in this test tube rusted.

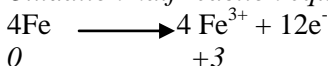
Therefore, the conditions necessary for rusting are water and oxygen.

The meaning of rusting

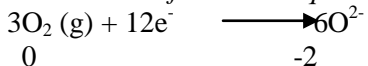
Rusting means the oxidation of iron. During rusting, iron reacts with oxygen to form brown iron (III) oxide.



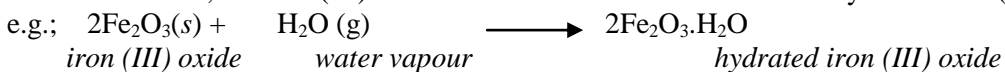
Oxidation half reaction equation;



Reduction half reaction equation;



At the same time, the iron (III) oxide reacts with water to form brown hydrated iron (III) oxide,



The hydrated iron oxide is known as rust. Rust is soft, crumbly brown solid.

Ways of Preventing Rust:

Rusting can be prevented by keeping the iron away from oxygen and water.

The methods are as follows;

1. Painting.
2. Oiling or greasing.
3. Alloying.

Alloy is a mixture of metals. For example, stainless steel is made by mixing iron with chromium, nickel and manganese.

4. Galvanizing.

Galvanizing means covering iron with a layer of zinc. Even if the zinc is scratched to expose iron, the iron does not rust. This is so because zinc is higher in the reactivity series and it reacts with oxygen and water in preference to iron. This type of protection is known as *sacrificial protection* since zinc is being sacrificed for the iron. Zinc-coated iron is called *galvanized iron*.

5. Coating iron with plastic.

d. Purification of metals;

The electron transfer reactions can be used to purify metals such as copper and zinc.

To purify a metal, electricity is used; the impure metal is connected to the anode and the cathode is the pure metal. The electrolyte is the solution of the compound of the metal.

For example, copper can be purified as follows;

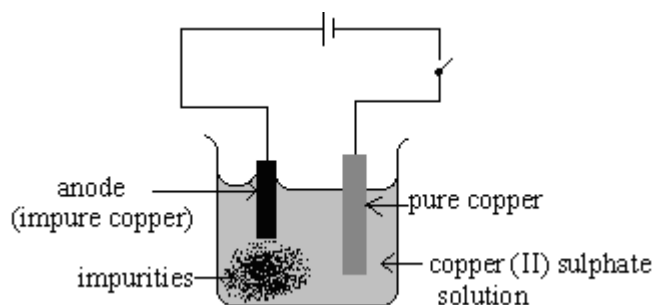
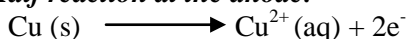


Figure 4.4

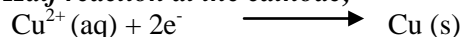
Half reaction at the anode:



The impurities drop to the bottom of the vessel.

The copper ions are reduced and deposited on the pure copper cathode.

Half reaction at the cathode;



Proton Transfer Reactions

A hydrogen atom consists of one electron and one proton;



Figure 4.5

When the atom loses the electron to become hydrogen ions, H^{+} it is the proton only that remains;

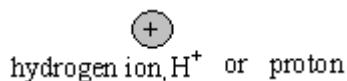


Figure 4.6

Therefore, the hydrogen ion is also called a proton. Proton transfer reactions are the reactions which involve the transfer of hydrogen ions, H^+ from one substance to another.

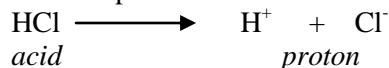
Acids and Bases

A Danish chemist Johannes Bronsted and an English chemist Thomas Lowry, having studied acids and bases, proposed what is known as a Bronsted – Lowry theory of acids and bases. According to the Bronsted – Lowry theory;

An acid is a proton donor (or giver)

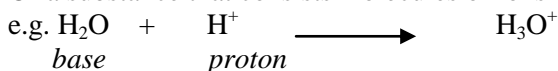
Or a substance that contains molecules or ions which donate protons

For example when HCl dissolves in water it gives hydrogen ions, H^+ to the solution as follows;

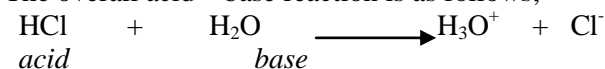


A base is a proton acceptor.

Or a substance that consists molecules or ions which accept protons.



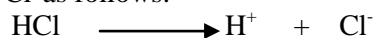
The overall acid – base reaction is as follows;



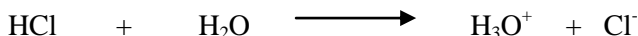
The pH scale measures the concentration of the hydrogen ions, H^+ in solutions; 1 means very acidic, 7 is neutral and 14 is very basic. The base that dissolves in water is called *an alkali*.

Formation of a Hydronium Ion, H_3O^+

When an acid dissolves in water protons, H^+ are donated by the acid to the water to form an ion known as a hydronium ion, H_3O^+ . For example when HCl dissolves in water, it dissociates into the ions H^+ and Cl^- as follows:

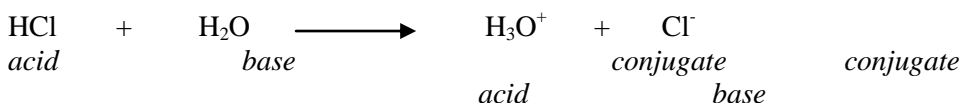


The protons are then accepted by the water to form a hydronium ion, H_3O^+ as follows:



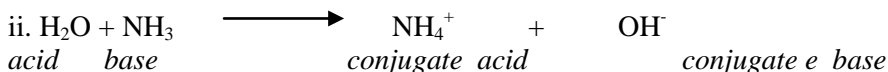
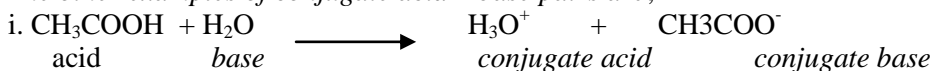
Conjugate Acid - Base Pairs

A conjugate acid is the ion that is formed when a base has accepted a proton, H^+ . A conjugate base is the ion that is formed when an acid has donated a proton. For example, in the equation below;



The conjugate base of the acid, HCl is the ion Cl^- and the conjugate acid of the base H_2O is the ion H_3O^+

The other examples of conjugate acid – base pairs are;



NB: Water, H_2O can behave as a base in one condition and as an acid in another depending on the substances present.

The nature of a substance to behave as an acid in one condition and as a base in another is called *amphoteric nature*.

Water is, therefore, an amphoteric substance.

Strong and Weak Acids

Activity: 4.4

Aim: To Compare strengths of acids using pH values.

Materials:

- universal indicator,
- pH scale,
- test tubes,
- hydrochloric acid, HCl,
- ethanoic acid,
- droppers.

Procedure:

- Pour 3 ml of HCl into a test tube.
- Add 3 drops of the universal indicator into the test tube.
- Find the pH value of the acid on the scale.
- Record the results in the table as follows;

Acid	pH
HCl	
Ethanoic acid	

Table 4.2

- Repeat steps (1) to (4) with ethanoic acid in the test tube.

Discussion:

Which acid has lower pH value?

Which acid is more acidic?

Observation

A substance is classified as an acid if it can produce hydrogen ions, H^+ when dissolved in water.

The acid that produces more hydrogen ions when dissolved in water is known as a stronger acid.

The universal indicator measures the strength of an acid and the value of its acidity can be found using the pH scale. On the pH scale, strong acids have lower the pH numbers. HCl is strong acid is a strong acid because it ionizes completely (its molecules completely separate into ions) when dissolved in water;

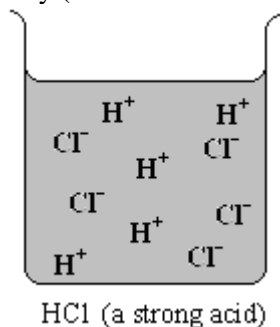
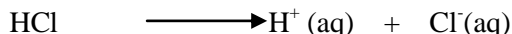


Figure 4.7

The equation is;



Other examples of strong acids are sulphuric acid, H_2SO_4 , Nitric acid etc. A weak acid is the acid which partially ionizes in water and produces few hydrogen ions when dissolved in water. For example, ionization of hydrogen fluoride HF in water is partial as shown below

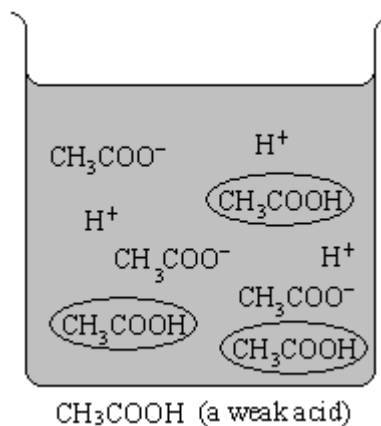
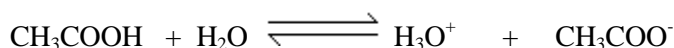
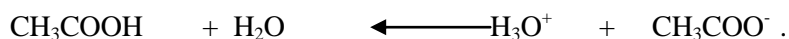
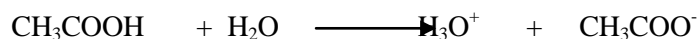


Figure 4.8

Weak acids are partially ionized in water. Therefore, CH₃COOH is a weak acid and its dissolution in water is represented as follows;



The double arrow means that as the reaction in the forward direction is happening, another reaction in the reverse direction is also happening at the same time as follows;



This means that when the ethanoic acid molecule breaks down to release the hydrogen ions, H⁺ and the ethanoate ions, CH₃COO⁻, these ions react together to form the ethanoic acid molecules again. In the forward reaction the ethanoic acid is acting as an acid and in the reverse reaction its conjugate base, CH₃COO⁻ is acting as the base. This type of reaction is called *reversible reaction*. It is also known as *equilibrium reaction*. Equilibrium reaction is a reaction in which products are produced on both sides and the result is a mixture of all four substances in a state of balance.

Strong and Weak Bases;

Activity: 4.5

Aim: To Compare strengths of bases using pH values.

Materials:

- universal indicator,
- pH scale,
- test tubes,
- NaOH,
- NH₃,
- droppers.

Procedure:

- (i) Put 3 ml of NaOH into a test tube.
- (ii) Add 3 drops of the universal indicator into the test tube.
- (iii) Find the pH value of the base on the scale.
- (iv) Record the results in a table as shown in table 4.3 below;
- (v) Repeat steps (1) to (4) with NH₃ in the test tube.

Acid	pH
NaOH	
NH ₃	

Table 4.3

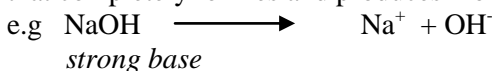
Discussion

Which base has lower pH value?

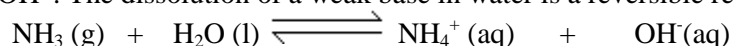
Which base is more basic?

Observation

A base is a substance that produces hydroxide ions, OH^- when dissolved in water. A strong base is the base that completely ionizes and produces more hydroxide ions, OH^- in water.



Stronger bases have higher pH values on the pH scale. Examples of strong bases include all alkali metal hydroxides such as NaOH and KOH. A weak base is the base that partially ionizes in water and produces fewer hydroxide ions, OH^- . The dissolution of a weak base in water is a reversible reaction as follows;



Activity: 4.6

Aim: To determine the strengths of acids and bases using conductivity measurements.

Materials:

- 4 connecting wires,
- 2 cells,
- 2 carbon electrodes,
- an ammeter,
- hydrochloric acid HCl,
- ethanoic acid,
- 4 beakers,
- a switch,
- NaOH solution
- NH_3 solution.

Procedure:

(i) Arrange the apparatus as follows;

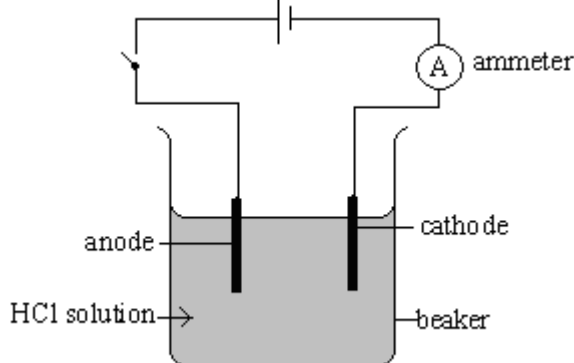


Figure 4.9

- (ii) Close the switch and read the ammeter.
- (iii) Record the reading in a table as shown in table 4.4 below.
- (iv) Repeat steps (i) – (iii) with ethanoic acid in the beaker.
- (v) Repeat steps (i)-(ii) with NaOH solution in the beaker.
- (vi) Record the ammeter reading in a table as shown in table 4.4 below.
- (vii) Repeat steps (i), (ii) and (vi) with NH_3 in the beaker.

Acid	Ammeter reading (A)
------	------------------------

HCl	
Ethanoic acid	

Table 4.4

Base	Ammeter reading (A)
NaOH	
NH ₃	

Table 4.5

Discussion

Through which acid was the ammeter reading higher? Suggest a reason.

Through which base was the ammeter reading higher? Why?

Observation

Through one of acids the ammeter reading was higher than through the other. The same observation was also made when the current was passed through the bases.

An electric current flows through a solution in form of ions. The aqueous solutions of acids or bases conduct electricity when they ionize in water.

The acids and bases that give higher ammeter readings are strong acids and bases respectively. Therefore strong acids and bases are good conductors of electricity because they ionize completely; hence produce more ions in water.

The electric current is lower through the solutions of weak acids or bases. This is because they do not ionize completely in water.

Increasing the concentration of a weak acid or base does not increase the electric current through it, and diluting a strong acid does decrease the current through it.

A strong acid is still strong even when it is less concentrated, and a weak acid is still weak even if it is more concentrated. The same also happens with bases.

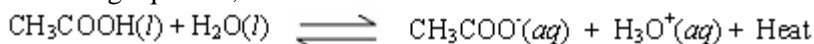
Variables that must be kept constant during the conductivity measurements

The following variables must be kept constant when conducting conductivity measurements to avoid affecting the results of the experiments;

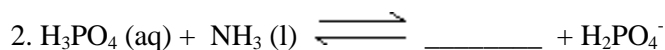
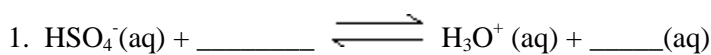
- temperature of the solution,
- electrode surface area
- electrode spacing.

Review questions;

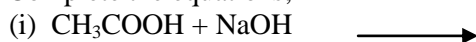
1. Ethanoic acid, CH₃COOH, ionizes in water. The ionization is reversible and can be represented by the following equation;



- What is a reversible reaction?
 - Write the conjugate acid- base pairs in the equation.
 - In the equation above, the equilibrium lies to the left. What do you understand by this statement?
2. a. (i) Name the ion responsible for the acidic properties of a substance.
(ii) What special property do bases have?
(iii) Why is carbonic acid a weak acid while hydrochloric acid a strong acid?
- What does the symbol, \rightleftharpoons mean in a chemical equation?
 - Complete the equations;



3. a. Complete the equations;



b. Write the ionic equations for the reactions above.

4. a. Explain the terms 'concentration' and 'strength' as applied to acids.

b. Hydrochloric acid is a strong acid while ethanoic acid is a weak acid. Explain the terms strong and weak acid using equations.

c. Sodium hydroxide is a strong base and ammonia is a weak one. Explain the terms strong and weak base with the use of equations.

5. a. Name the acid that is present in your stomach.

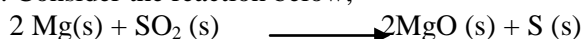
b. (i) A girl takes magnesium oxide to cure indigestion. Write down word equation for the reaction that takes place in the stomach.

(ii) Write down a balanced chemical equation for the reaction.

6. a. What is meant by displacement reaction?

b. Explain, in terms of displacement reactions, why gold occurs in an uncombined state as a free metal

c. Consider the reaction below;



(i) In this reaction, which substance is;

1. oxidized? 2. the oxidizing agent?

3. reduced ? 4. the reducing agent?

7. When 6.5 g of zinc, Zn, were added to a solution of copper (II) sulphate, CuSO_4 , 6.4 g of copper, Cu, were obtained. (RAMs; Zn = 65, Cu = 64)

a. What type of chemical reaction is this?

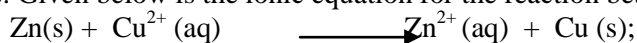
b. How many moles of zinc were used?

c. How many moles of copper were obtained?

d. Write a word equation for the reaction.

e. Use the information from b and c to write a balanced equation for the reaction

8. Given below is the ionic equation for the reaction between Zinc, Zn, and copper (II) ions, Cu^{2+} ;



a. What is the oxidation number for; (i) Zn (s) (ii) $\text{Cu}^{2+}(\text{aq})$ (iii) $\text{Zn}^{2+}(\text{aq})$ (iv) Cu (s)

b. Which substance has been oxidized?

c. Which substance has been reduced?

d. Which substance is a reducing agent?

e. Is this a redox reaction? Explain your answer.

9. a. (i) What is rust?

(ii) Explain how rust forms on structures made up of iron or steel.

b. Rust is a redox reaction. Explain the process of rusting in terms of oxidation and reduction.

5. NUCLEAR PHYSICS

The Nuclear structure of the atom

An atom is made of the following sub – atomic particles; protons, neutrons and electrons. The protons and the neutrons are found inside the nucleus of the atom; hence they are called nuclear particles or nucleons. Electrons are found outside the nucleus in regions called shells or energy levels.

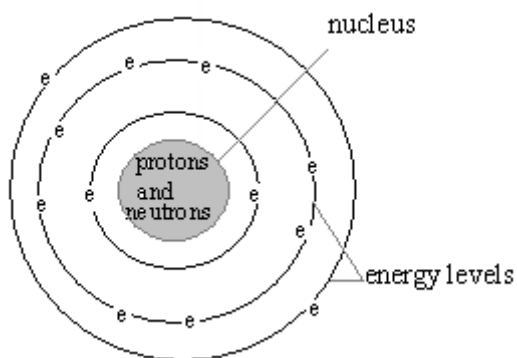


Figure5.1

The number of protons in an atom is very important because it identifies the element of the atom. For example, an oxygen atom, **O** has 8 protons; therefore there is no other element that has 8 protons in its atoms apart from oxygen only. Any element that has eight protons in its atoms is an oxygen atom. The number of protons in an atom is called atomic number and is represented by the symbol **Z**. The atomic number plus the number of neutrons in an atom is called the mass number. The symbol for the mass number is **A**.

The chemical symbol, the atomic number, **A**, and the mass number, **Z**, of an element are represented as follows; ${}^A_Z\text{X}$, where **X** is the chemical symbol. For example, an oxygen atom has 8 protons and 8 neutrons, it is therefore represented as ${}^{16}_8\text{O}$.

The arrangement of the protons and the neutrons in the nucleus is very delicate and it is the one that decides on the stability of the atoms.

Isotopes

Different atoms of the same element may have different numbers of neutrons, hence different mass numbers but they never have different numbers of protons.

For example, the elements ${}^{12}_6\text{X}$ and ${}^{14}_6\text{Y}$ are different atoms of the same element because they have the same atomic numbers.

The atoms that have the same atomic numbers, but different mass numbers are called isotopes. **Table 5.1** below shows isotopes of some elements.

Element	symbol	Particles present
Hydrogen	${}^1_1\text{H}$	1 proton, 0 neutrons
	${}^2_1\text{H}$	1 proton, 1 neutron
	${}^3_1\text{H}$	1 proton, 2 neutrons
Carbon	${}^{12}_6\text{C}$	6 protons, 6 protons
	${}^{13}_6\text{C}$	6 protons, 7 neutrons
	${}^{14}_6\text{C}$	6 protons 8 neutrons
Uranium	${}^{235}_{92}\text{U}$	92 protons, 143 neutrons
	${}^{238}_{92}\text{U}$	92 protons, 146 neutrons

Table 5.1

Radioactivity

When the numbers of the nuclear particles is not balanced, especially when an atom has more neutrons than protons the atom is not stable, and when the delicate arrangement of the particles in stable atoms is disturbed, the atom breaks up and emits particles rays of energy from the nucleus. In the process, the nucleus may change to an atom of another element which is more stable.

The breaking up and emission of the subatomic particles or rays of energy from the nucleus of an atom is called radioactivity. The subatomic particles and the rays of energy are called nuclear radiations because

they radiate from the nucleus.. Common examples of radioactive substances are Uranium ${}^{238}_{92}\text{U}$ and radium ${}^{226}_{83}\text{Ra}$.

Characteristics of Radioactive Substances

Radioactivity happens spontaneously (all by itself) and at random. It cannot be controlled and is not affected by chemical combination, pressure or temperature. During radioactivity, reactions, called nuclear

reactions, take place inside the nucleus of the substance. The nucleus loses one or more of its subatomic particles and energy; hence a new element is created from the existing one.

Types of nuclear Radiations

There are three types of radiations from radioactive substances:

- (i) alpha particles, α
- (ii) beta particles, β
- (iii) gamma rays,

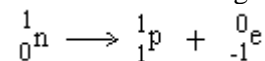
i. The Alpha particles, α

This is a helium nucleus emitted from the nucleus of a radioactive substance. An alpha particle is made up of 2 protons, 2 neutrons and zero electrons.

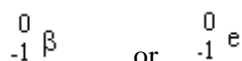
It is expressed as follows: ${}^4_2\text{He}^{2+}$ or ${}^4_2\alpha$.

ii. The beta particle, β :

This is an electron emitted from the nucleus of a radioactive element. This electron is created when a neutron in the nucleus changes into a proton and an electron as follows:



The proton remains in the nucleus while the electron is thrown out. A beta particle is expressed as follows:



iii. The Gamma Rays

Gamma rays are waves of high energy emitted from the nucleus of a radioactive substance.

Properties of the Nuclear Radiations

	Alpha particle	Beta particle	Gamma rays
<i>Nature</i>	- Its a helium nucleus - Has a charge of +2	- It is an electron, - Has a charge of -1	- It is an electromagnetic wave. - Has no charge.
<i>Mass</i>	- Has a greater mass	- Has low mass	Has no mass
<i>Ionising effect</i>	- Very strong	- low	- very weak
<i>Penetrating power</i>	- Not very penetrating, can be stopped by a sheet of paper, skin or few mm of air. This is because they are heavy.	- More penetrating, but can be stopped by few mm of aluminium or other metal	- Very penetrating, cannot be stopped fully. But thick lead or concrete can only reduce their speed.
<i>Deflection effect in an electric field.</i>	- Deflected less – because they are heavy. Deflected towards the negative plate.	- Deflected much - Deflected towards the positive plate.	- Never deflected because they are not charged.
<i>Deflection in a magnetic field.</i>	- Deflected less –because they are heavy. Direction of deflection is given by the *Fleming's left hand rule.	Deflected much – they are light. Direction of deflection is given by Fleming's left hand rule.	Never deflected – they are not charged.

Table 5.2

* The Fleming's left hand rule state that if you hold the thumb and the first two fingers of the left hand, with the First finger pointing in the direction of field and the seCond finger in the direction of current, then the Thumb points in the direction of Thrust (force). Current flows in the direction opposite to the direction of electrons of in the direction of the flow of positively charged particles.

The alpha particles are positively charged and the beta particles are negatively charged, hence their flow creates an electric current.

The effects of Magnetic and Electric fields on the three Radiations are as follows:

(a) *Magnetic field;*

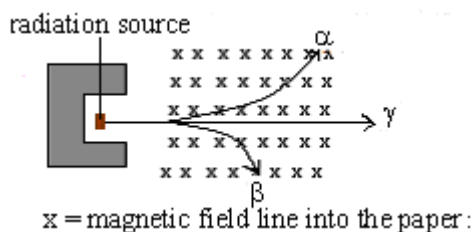


Figure 5.1

(b) *Electric field;*

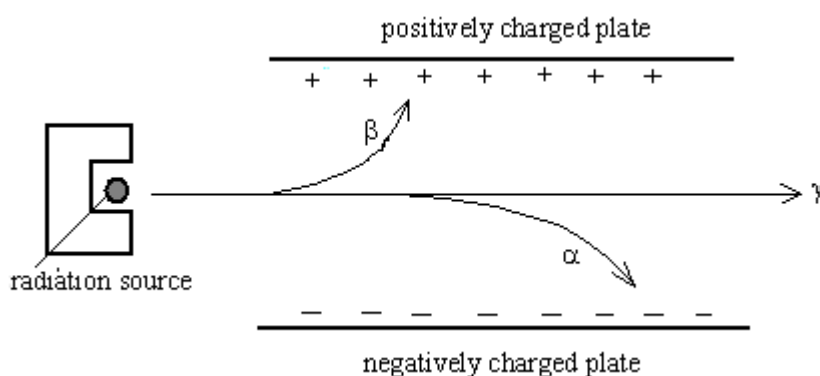


Figure 5.2

4. Radiation Detectors

The radiations can be detected by the following;

a. Photographic film (plates).

The film is blackened by the rays.

The amount of blackening indicates the level of exposure.

b. Scintillation counters:

When the radiations strike some substances, such as zinc sulphate, scintillations are produced. Scintillations mean light spots. In the scintillation counter, the light spots are converted into electric currents. A digital counter, then, records the current as number of strikes per second.

c. Spark counter:

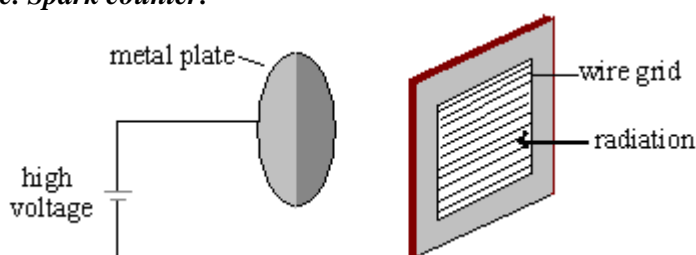


Figure 5.3

When radiations pass between the positively charged wire grids and the negatively charged metal plate, ionization of the air takes place. The ions and the electrons produced enable a large current to suddenly pass through the air under high voltage between the grid and the metal plate. A spark is seen or heard and it may be registered by an electronic device.

d. Cloud chamber

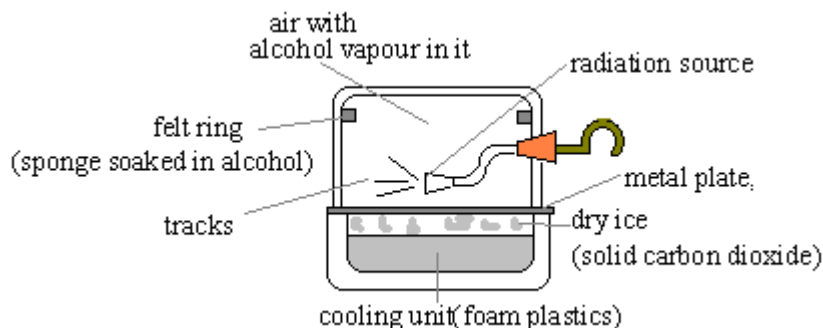


Figure 5.4

The base of the chamber is cooled by dry ice. The felt ring is moistened with alcohol. The alcohol vapour diffuses downwards becoming cool and ready to condense. When a radiation passes in the chamber it produces ions along its path and the alcohol vapour condenses around these ions. The condensed alcohol droplets reflect light and can be seen as narrow white lines (tracks of light). The cloud chamber is best for studying the alpha radiations because of its high ionization.

e. GM tube (Geiger – Muller tube)

The GM consists of a cylindrical metal cathode containing argon gas and a central wire anode as shown in figure 5.5 below.

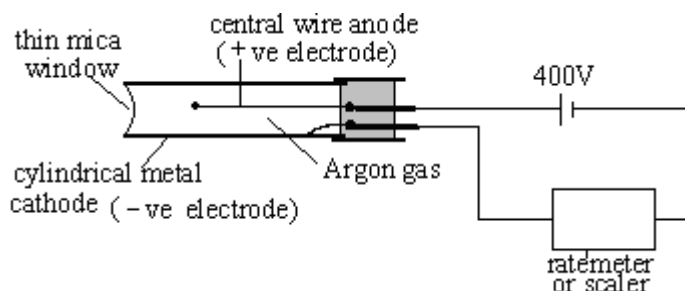


Figure 5.5

The mica window is thin enough to allow even alpha particles to pass through. When radiation enters the tube it ionizes the gas inside it. This causes a high voltage spark across the gas and sudden large current flows in the tube. A scalar or a rate meter connected to the GM tube can detect this current. The rate meter records the number of radiations per second while the scalar counts the total number of alpha or beta particles detected by the tube.

f. Electroscope:

In an electroscope ionized air molecules discharge a charged electroscope.

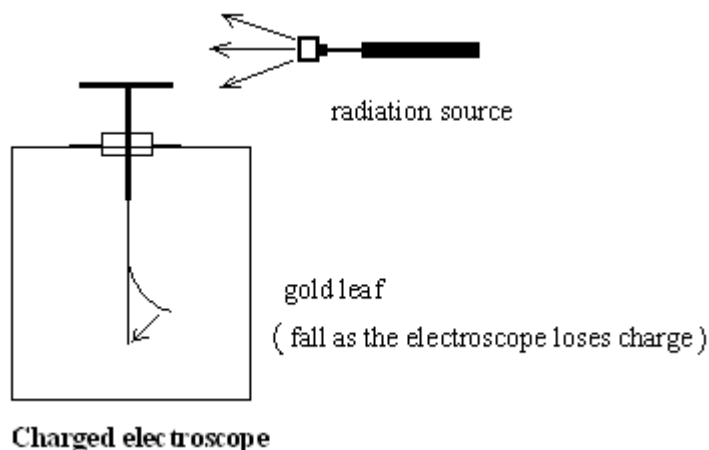


Figure 5.6

The radiations from a radiation source ionize the surrounding air molecules by knocking off electrons and leaving them positively charged. The ions are attracted to the cap if it is negatively charged. If it is positively charged, it is the electrons that are attracted to it. The charge on the electroscope is then neutralized (discharged) in either case. This method is suitable for detecting alpha particles only, but not the beta radiation or the gamma rays because they cause insufficient ionization.

Radioactive decay

This is the change in the energy and numbers of the particles in the nucleus of an atom as a result of radioactivity. There are three types of the radioactive decay.

- Alpha decay,
- Beta decay and
- Gamma emission

(a) Alpha decay:

This is an emission of an alpha particle from the nucleus during a radioactive decay.

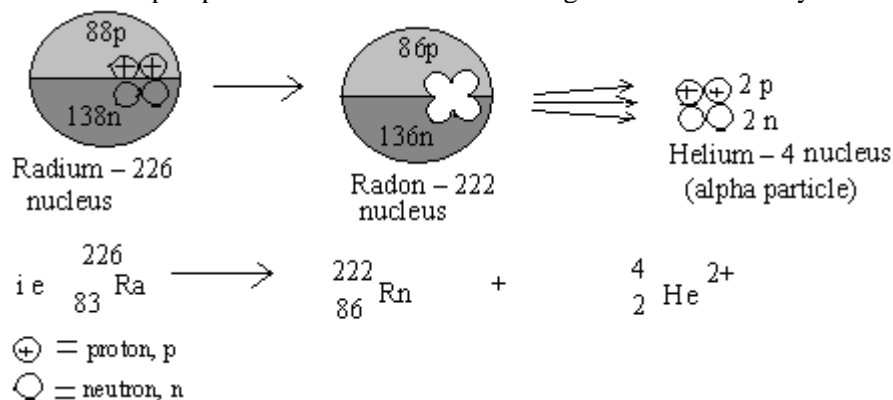


Figure 5.7

During an alpha decay;

- The mass number of the substance that has decayed decreases by 4 and its atomic number decreases by 2 and a new element is formed.
- The numbers on top balance on both sides of the equation. E. g. $226 = 222 + 4$.
- The numbers at the bottom balance on both sides of the equation E. g. $88 = 86 + 2$.

(b) Beta decay:

This is an emission of an electron from the nucleus of an atom as follows;

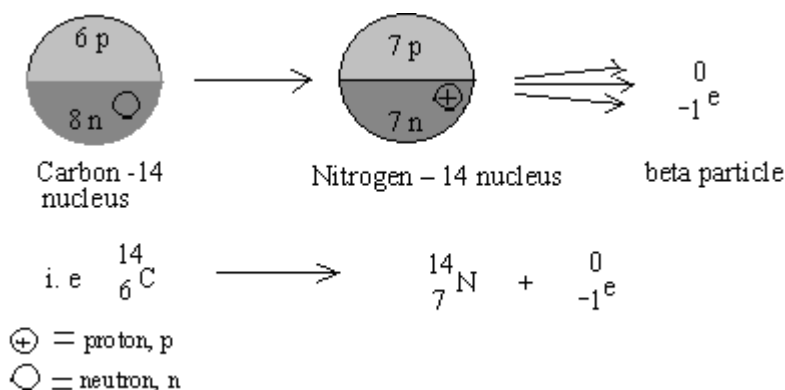


Figure 5.8

During a beta decay;

- (i) A new element is formed which has 1 atomic number greater than the one that has decayed. The mass number does not change during the beta decay.
- (ii) The top numbers on both sides of the equation balance; e. g. $14 = 14 + 0$.
- (iii) The bottom numbers on both sides of the equation balance; e. g. $6 = 7 + (-1)$.

(c) Gamma emission

This is the emission of rays of energy from the nucleus during a radioactive decay. During the gamma emission there is no change in the mass number or the atomic number of the substance. Gamma radiation mainly carries away the excess energy from the excited nucleus. It can be detected on a photographic film, in a cloud chamber, and by a GM counter.

Exercise

Table 5.3 shows atomic numbers and mass numbers for some elements.

Element	Atomic number	Mass number
Carbon, C	6	12
Nitrogen, N	7	14
Oxygen, O,	8	16
Fluorine, F	9	19
Neon, Ne	10	20
Magnesium, Mg	11	24
Aluminium, Al	12	27
Silicon, Si	13	28

Table 5.3

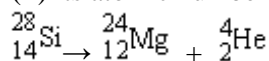
Write a nuclear equation to show the changes that will take place in the nucleus of a silicon atom if it undergoes;

- (a) alpha decay (b) gamma emission

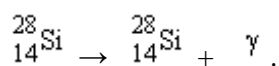
Working out

- (a) An alpha particle is represented as ${}^4_2\text{He}$, therefore, if an element undergoes an alpha decay;

- (i) its mass number decreases by 4 while
- (ii) its atomic number decreases by 2, the equation for the nuclear reaction is



- (b) There are no changes in the numbers of the particles in the nucleus of an atom. Therefore the reaction is



Exercise

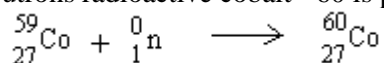
Use **table 5.3** to answer the following question.

Write a nuclear equation to show the changes that will take place in the nucleus of an oxygen atom if it undergoes

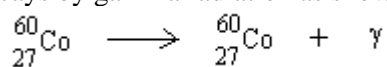
(a) an alpha decay (b) beta decay (c) gamma decay

Induced Radioactivity

Radioactivity can be induced by striking stable nuclei with neutrons. Some of the nuclei absorb an extra neutron and become unstable because the delicate balance of the neutrons and the protons in the nucleus is disturbed. The element then undergoes radioactive decay. For example, when the stable Cobalt - 59 is bombarded with neutrons radioactive cobalt - 60 is produced as follows:



Cobalt - 60 then decays by gamma radiation as shown below:



The induced radioactive substances are called radioisotopes (i.e. radioactive isotopes) because they are isotopes of their stable elements.

Differences between natural and induced radioactivity

	Induced radioactivity	Natural radioactivity
<i>How radioactivity is induced</i>	striking nuclei with subatomic particles such as neutrons	spontaneous
<i>Types of atoms used</i>	with stable nuclei and lower proton numbers.	with unstable nuclei and proton numbers above 83.
<i>Circumstances where they can be used.</i>	in agriculture, industries and medicine	as source of energy in nuclear power stations and in atomic bombs
<i>Type of radiations</i>	alpha, beta, gamma and sometimes positrons (positrons are positive electrons, ${}_1^0\text{e}$)	alpha, beta and gamma but never positive electrons.

Table 5.4

Activity: 5.1

Aim: To demonstrate how atom of radioactive substances decay.

Materials:

- 100 bottle tops (or 100 dice with one face painted)

Procedure:

- Shake and throw all the bottle tops
- Remove all the bottle tops that land with the open side up (or dice that land with the marked faces up)
- Count the number of the bottle tops remaining and record it in the table of results like the one shown in table 5.4 below.
- Repeat the process with the surviving bottle tops until all of them are finished.

Throw number	Number of bottle tops surviving

Table 5.5

(iv) Plot a graph of number of bottle tops surviving against the throw number.

Discussion

Discuss the shape of the graph.

Observation

The numbers of the bottle tops that were landing with faces up were at random. The graph of number of bottle tops surviving against the throw number plotted takes the shape like the one shown in **figure 5.9** below.

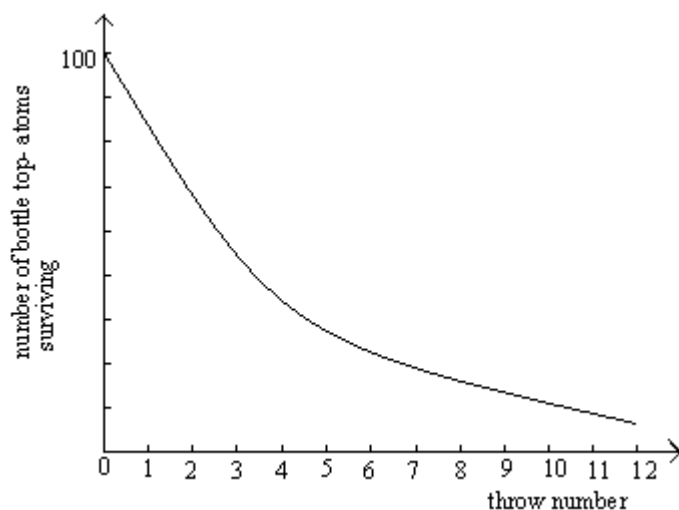


Figure 5.9

Real atoms behave in the same way. Each unstable atom decays in a random way.

Half life

The rate of decay of a radioactive element is expressed by its half life. Half life of an element is the time taken for half of its atoms in a given sample to decay. For example if there are 8 atoms of a certain element and it takes 3 days for four of them to decay, 2 of the remaining four will take another 3 days to decay and one of the remaining 2 atoms will also take 3 days to decay. And so the half life of that element is 3 days.

Half lives for some radioactive elements

Radioactive element	Half life
carbon - 14	5730 years
iodine - 131	8 days
Iodine – 128	25 min
uranium - 238	4.5×10^9 years
uranium - 235	7.1×10^8
strontium - 90	28 days
cobalt - 60	5.24 years
radon - 220	54 sec
hydrogen – 3	12.26 years

boron -12	0.62 sec
-----------	----------

Table 5.6

Activity

The average number of atoms of a radioactive element that decay per second is called its activity. The activity of a radioactive element is always proportional to the number of the undecayed atoms. If the half life of the element is 28 days, its activity also halves every 28 days. Half life can therefore also be defined as the time taken for the activity of any given sample of a radioactive sample to fall to half of its original value. The unit of activity is Becquerel (Bq). For example the activity of 100 Bq means that 100 atoms decay per second. It is difficult to know when all the atoms of a radioactive substance have decayed since atoms are very small particles. But it is easy to find the time for its activity to fall to half of its original value by using the GM tube and the rate meter.

Decay Curve

This is a graph which shows the decrease in an activity of a radioactive substance against time.

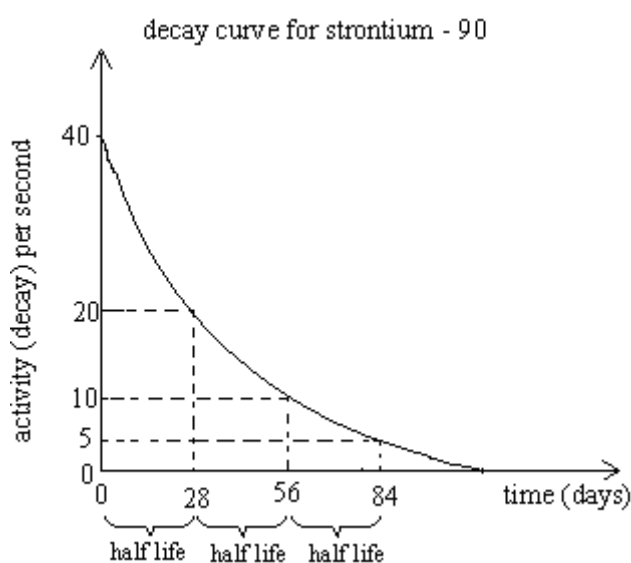


Figure 5.10

In a decay curve, the activity decreases by the half ($\frac{1}{2}$) in each time interval. For example in the decay curve above, the activity decreases from 40 decays per second to 20 decays per second in 28 days and from 20 to 10 decays per second in the next 28 days and so on.

Examples

1. An element has a half life of 15 years. How long will it take for $\frac{1}{32}$ of its sample to decay.

Working out

Since half ($\frac{1}{2}$) of the atoms of the element decays after every 15 years then we have to find how many halves ($\frac{1}{2}$) are there in $\frac{1}{32}$. The number of the halves in $\frac{1}{32}$ will tell us the number of the half lives that have gone for $\frac{1}{32}$ of its atoms to decay.

$$\therefore \left(\frac{1}{2}\right)^n = \frac{1}{32}$$

$$\rightarrow \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^5$$

Hence $n = 5$

5 half live have gone for the $\frac{1}{32}$ of the atoms to decay

Total time taken = 5 x half life

$$= 5 \times 15 \text{ years}$$

$$= 75 \text{ years}$$

2. Find the half life of an element, if $\frac{1}{16}$ of its atoms decay after 50 minutes.

SIMPLIFIES MSCE PHYSICAL SCIENCE

BY PETROS G JERE

Working out

The number of halves ($\frac{1}{2}$) in $\frac{1}{16}$;

$$\left(\frac{1}{2}\right)^n = \frac{1}{16}$$

$$\left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^4$$

$$\therefore n = 4$$

→ 4 x half life of the element = 50 minutes

Half life = $50/4$ minutes

$$= 12.5 \text{ minutes}$$

Hence the half life of the element is 12.5 minutes

Exercise

1. An element has a half life of 7 hours, how long will it take for $\frac{1}{64}$ of its atoms to decay?
2. Calculate the half life of an element if $\frac{1}{32}$ of its atoms decay after 45 days.

Hazards / Dangers of Radioactive Substances

Radiations are very dangerous because we can receive them in severe doses without being aware of them. Some of the effects of strong doses or accumulated small doses are as follows:

- a. Skin burns (blisters and sores on the skin).
- b. Loss of hair.
- c. Cancer
- d. Eye cataracts.
- e. Hereditary defects, which may also occur in succeeding generations due to genetic damage.
- f. Sterility i.e. inability to produce children.
- g. Low resistance to normal diseases.

Safety precautions when handling radioactive substances

- a. Handle radioactive substances with long tongs.
- b. Never point radioactive substances towards a person.
- c. Food should never be taken where the radioactive substances are being used.
- d. Never smoke near radioactive sources.
- e. Radioactive samples should be kept in lead castles built on lead bricks.

Uses of nuclear radiations

a. In agriculture;

In agriculture, radiations are used to study plants and animals.

For example;

- they can be used to study the uptake of fertilizers by plants from the roots to the leaves by adding a radioactive isotope (tracer) to the soil water and trace it flow by a detector.
- they can be used to control pests by exposing the males to gamma radiations and releasing them into the wild to mate with the females. The females lay sterile eggs and no new pests are born

b. In industries;

(i) Beta radiations are used to check the thickness of various flat objects. For example when paper is manufactured it has to be of a particular thickness. To achieve this beta radiation source is placed on one side of the source and a detector on the other side as shown below;

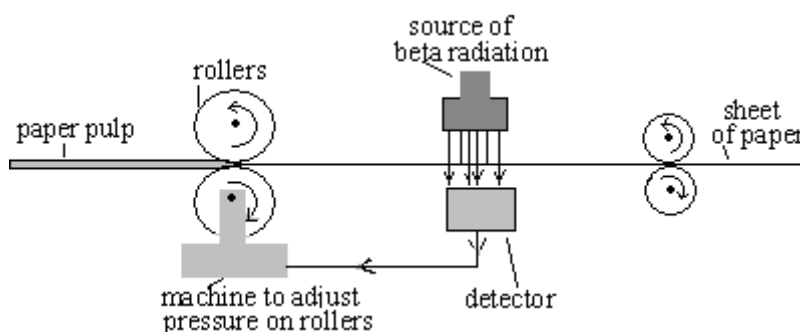


Figure 5.12

When the sheet is too thick, fewer beta radiations reach the detector. This sends signals to the machine, which adjusts the gap between the rollers. When the sheet is too thin, more radiation reaches the detector and necessary adjustments are also made on the rollers by the machine.

(ii) Gamma radiations are used to check faults in pipes and metal castings. A gamma radiation source is placed inside the pipe and a photographic film is wrapped around the outside of the pipe. The film is then developed and if there are faults the film is blackened on those parts where there are faults.

(iii) In textile industries irradiation with beta rays fixes various chemicals onto cotton fibres. This produces permanent press clothing.

(iv) They are used as tracers to detect leaks in underground pipes. A radioactive substance is added to the fluid in the pipe and a detector follows its flow.

c. Medical uses;

(i) *As biochemical tracers.*

A weak radioactive substance is injected into the person's body. It is then traced by a detector as it passes through the body tissues because it emits radiations. This can be used to detect blood clots, brain tumours or internal bleeding.

(ii) *As a radiotherapy.*

Gamma rays emitted from a strong source of cobalt – 60 can be used to kill cancer.

(iii) *Sterilising equipment;*

Medial instruments such as syringes and other operating instruments are sterilised by irradiating them with gamma rays.

d. Food preservation:

Different food types are irradiated with gamma rays to kill bacteria and other micro organisms that can spoil the food. The food, then, stays for long before going bad and without changing its taste or appearance. The irradiated food is safe to eat because no radioactive substance go into the food and so no radioactivity is produced in the food irradiated by the gamma rays.

e. Carbon dating

This is the process of estimating the age of dead plants and animals by measuring the activity of carbon - 14 present in them.

f. Power generation

In nuclear power stations, nuclear fission is used in a nuclear reactor to release heat energy that is used to boil water. The steam then turns turbines to produce electricity.

NB; The radioactive isotopes that are used as tracers must be those with short half life periods so that their half life must match the time needed for the experiment and their radioactivity is complete within a few day.

Nuclear Fission

This is the splitting of a large nucleus into two nuclei of similar sizes. During nuclear fission the nucleus of a radioactive substance is split by bombarding it with neutrons to it make more unstable so that it decays faster.

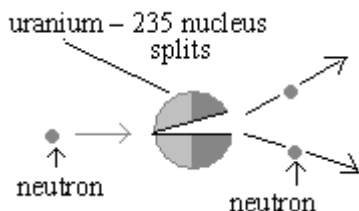


Figure 5.13

The nucleus that has split emits two or three neutrons and the fragments fly apart at high speeds.

The nucleus that has split emits two or three neutrons and the fragments fly apart at high speeds.

If the emitted neutrons go on to strike other nuclei chain reactions develop and very large amounts of energy is given off.

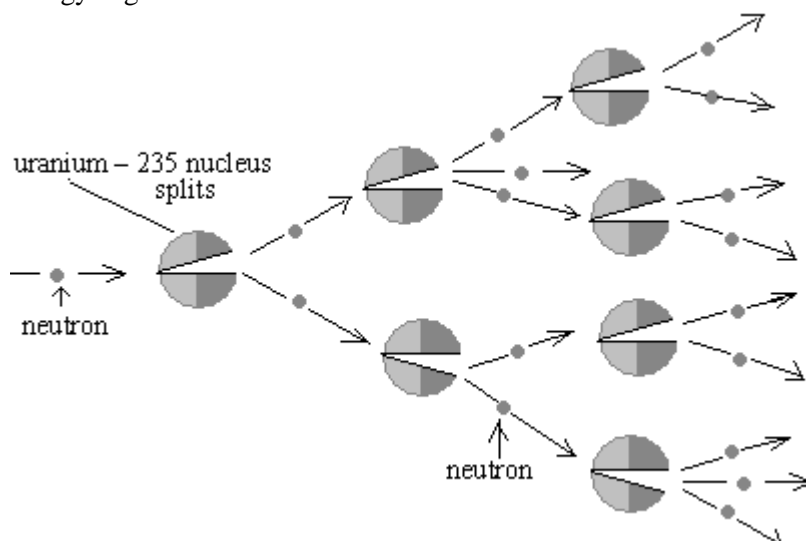
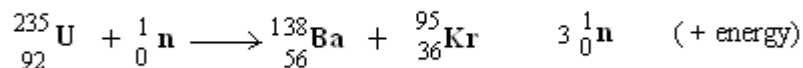


Figure 5.14

These chain nuclear reactions produce very large amounts of energy.

In nuclear fission;

- the nucleus is divided into two large fragments of roughly equal masses as shown below;



- Neutrons are emitted in the process.

- Much more energy than in the ordinary radioactive decay is produced.

Uses of nuclear fission

- i. atomic bombs
- ii. Nuclear power stations.

Differences between nuclear fission and radioactive decay

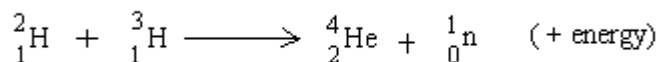
Decay	Fission
Spontaneous	Start when nuclei are hit with neutrons

The nucleus emits small particles	Nucleus splits into large fragments of roughly the same size
Particles emitted are alpha and/ or beta	Particles emitted are neutrons
Amount of energy released is less	Amount of energy released is very huge

Table 5.7

Nuclear fusion

Nuclear fusion means joining together of two light nuclei to form a heavier nucleus.



To start a nuclear fusion reaction, the nuclei are heated to extremely high temperature (e. g 10^8 K) so that they gain enough energy to overcome the repulsion forces between them. When the two nuclei fuse together, much more energy is released.

Uses of nuclear fusion

Nuclear fusion is used in the hydrogen bomb.

The hydrogen bomb releases much more energy than the atomic bomb.

Differences between nuclear fission and nuclear fusion

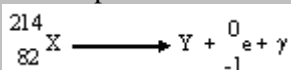
1. The energy obtained from the nuclear fission is as a result of the kinetic energy of the fragments flying apart while in the nuclear fusion the energy is released when a new nucleus is formed.
2. Total energy released per unit mass is greater in nuclear fusion than in the nuclear fission.

Review Questions

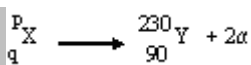
1. Which of the radioactivity is?

- the most penetrating,
- the most massive
- not a particle.

2. a. Complete the following radioactive decay equation:



b. What are the values of p and q in the nuclear equations given below?



3. A nuclide, F, has a half life of 2.5 hours. What percentage of the original number of atoms of the isotope would be left after 10 hours?

4. a. Copy and complete the figure below to show how the particles and the rays are deflected and at which material each of them is stopped.

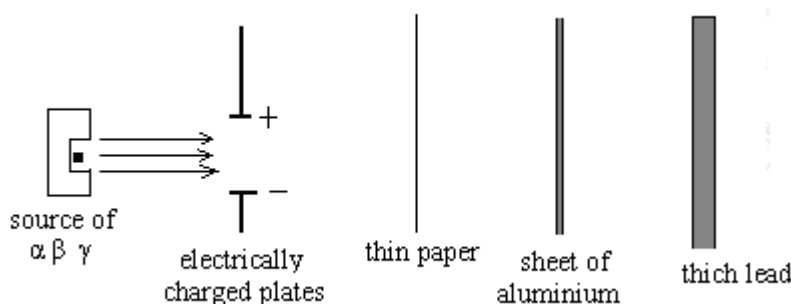


Figure 5.15

5. The figure below shows the deflection of radiations from a radioactive source by a uniform magnetic field.

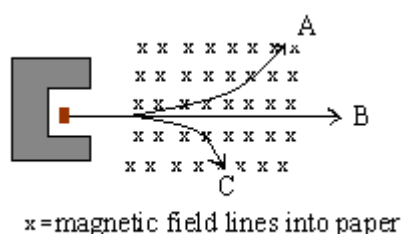
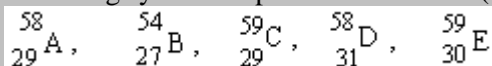


Figure 5.15

- a. Which type of radiation are A, B and C.
 - b. Explain two factors that bring about the differences in the in the deflections.
6. A sample of a certain nuclide which has a half life of 1500 years has an activity of 32 000 counts per hour at present time.
- a. Plot a graph of the activity of this sample against the period in which it will reduce to 1/16 of its present value.
 - b. If the sample of the nuclide could be left for 2000 years, what would be the activity then?
7. a. Name three types of radiations.
- b. State which radiation;
 - (i) is a form of an electromagnetic radiation.
 - (ii) carries positive charge
 - (iii) carries negative charge
 - (iv) is made up of high speed electrons
 - (v) is most highly ionizing.
 - (vi) is the most penetrating
 - (vii) can be stopped by skin or paper
 - (viii) is never completely absorbed.
8. a. Which type of radiation could be detected using a leaf electroscope? Describe how.
- b. Why is this method not suitable for detecting other forms of nuclear radiations?
9. You are told that a radioactive source has a half life of 24 hours.
- a. State what you understand by half life.
 - b. Assuming that you had a counter and could use it over a period of three days, describe how you would you would check that the half life was 24 hours
10. If the half life of thorium is 52 s, how long will it take for the activity of a thorium sample to be reduced to 1 / 32 pf its original value?

11. The following symbols represent five nuclei (nuclides)



- Which nuclei are isotopes of each other?
- Which nuclei could be produced from which other by emission of an alpha particle?
- Which nuclei could be produced from which other by emission of a beta particle?
- Which nuclide possesses most neutrons?

12. What changes in the mass and charge of an atom take place if it emits;

- an alpha particle?
- beta particle?
- a gamma ray?

13. a. The isotope ${}_{92}^{238}\text{U}$ decays by alpha emission to an isotope of thorium, Th. Compare the

${}_{92}^{238}\text{U}$ and thorium nuclei, explaining the changes that have occurred in the uranium nucleus.

b. The thorium nucleus decays by beta emission to an isotope of protactinium, Pa. Compare the thorium and protactinium nuclei accounting for the changes you describe.

- Give two uses of beta radiation
- Mention two industrial uses of radioisotopes.
- (i) Give two uses of radioactive tracers'
(ii) why is it important to use radioactive tracers with short half-lives.

15. The figure below shows a thickness monitoring system

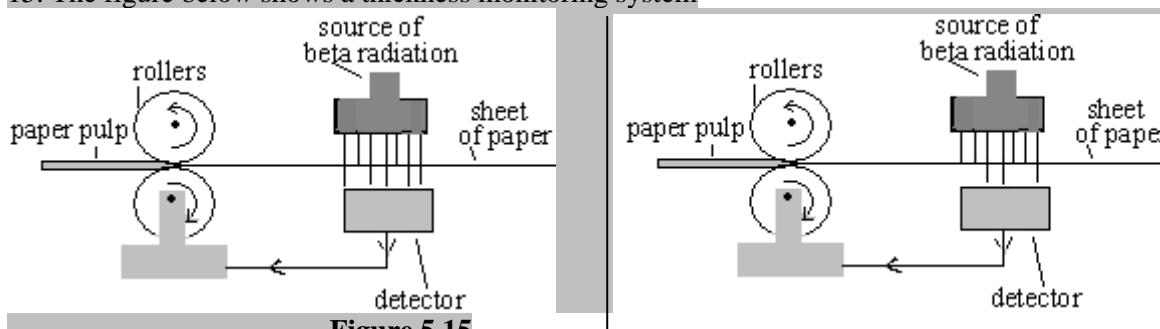


Figure 5.16(a)

Figure 5.15(b)

- Which sheet of paper in A or B is thicker? Give a reason for your answer.
- Why is beta radiation source used, rather than an alpha radiation.