SIMPLE CLASSIFICATION
OF
SUBSTANCES

Table of Contents

Objectives

By the end of this chapter, the learner should be able to:

- Define mixture, element, atom, molecule, compound, melting point, boiling point and sublimation.
- Write chemical symbols of common elements and identify the constituents of compounds.
- Determine purity of a substance and use separation techniques to obtain pure substances.
- Differentiate (i) permanent and non permanent changes (ii) physical and cchemical changes.
- Explain the arrangement of particles of matter in the three physical states in terms of the kinetic theory of matter

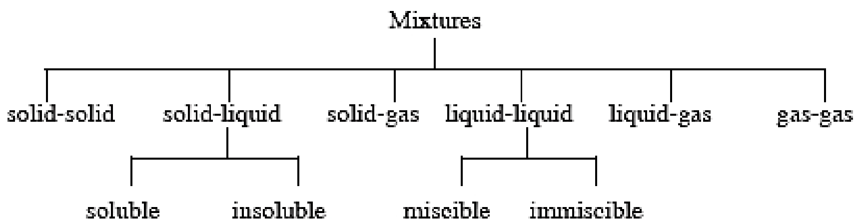
Organizer

SIMPLE CLASSIFICATION OF SUBSTANCES

The process of grouping together substances with similar properties is called **classification.** Knowledge about properties can be applied to obtain pure substances from mixtures.

1. Mixtures

A mixture is a material made up of two or more different substances which are physically combined. In nature, matter exists often as mixtures in various combinations as shown below.



The method chosen to separate a given mixture depends on the physical properties of the components of the mixture.

Separation of solid-solid mixtures

In this section, other methods of separating solid-solid mixtures will be studied.

Using a magnet.

A magnet can be used to separate a mixture such as that of iron fillings and sulphur.

Practically Speaking

Task: Place a mixture of iron fillings and sulphur on a piece of white paper and spread it out. Examine the mixture carefully and note its appearance. Hold a magnet above the mixture and observe what happens.
The mixture provided is grey-yellow in colour.
When a magnet is held above the mixture, the grey particles are attracted leaving a yellow powder on the paper. The grey substance attracted by the magnet is iron and the yellow substance left on the paper is sulphur.
A mixture of iron and sulphur can be separated by **use of a magnet** because **iron is magnetic** whereas **sulphur is not.**
This method is applied in **industries** such as **iron recycling, glass recycling and flour mills to remove iron particles.**

Sublimation

Sublimation is the process where a **substance changes from solid to vapour directly** without forming the liquid. The solid formed when the vapour cools is known as a **sublimate.**

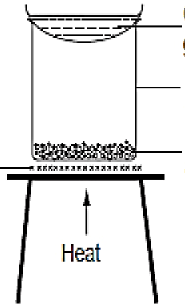
Deposition is the process by which a gas changes directly to solid (it gets deposited). It is the reverse of sublimation.

A mixture of iodine and sodium chloride can be separated by sublimation

Practically Speaking

Task: Place a spatula full of the mixture in a 100ml glass beaker. Place the beaker on a tripod stand. Cover the beaker with a watch glass containing cold water.

Heat the beaker gently until there is no further change. Carefully remove the watch glass from the beaker. Pour out the water from the watch glass and observe the lower surface. Examine the solid left in the beaker and record your observation.



Observation

The mixture contains white and shiny-black crystals.
As the beaker is heated, a purple vapour is observed. On cooling, the purple vapour forms shiny black crystals on the surface of the watch glass. White crystals remain in the beaker. The shiny black crystals are iodine crystals whereas the white crystals are sodium chloride.

Discussion

When solid iodine is heated, it changes directly into vapour (the purple vapour seen). The vapour cools to form solid iodine on the cold watch glass.
It is possible to separate a mixture of iodine and sodium chloride because iodine sublimes while **sodium chloride does not.**
Other substances that sublime are **anhydrous iron (III) chloride, aluminium chloride, benzoic acid and carbon (IV) oxide (dry ice).**

Application of sublimation

Dry ice is used in **cold boxes by ice cream vendors.** Dry ice is preferred over ordinary ice because:

(i) It sublimes leaving no wetness.
(ii) It is also a better coolant compared to ordinary ice.

Solid-liquid mixtures

Substances that dissolve in a liquid are said to be **soluble,** while substances that do not dissolve are **insoluble.**

When a substance dissolves in a liquid, the substance is called a **solute** and the liquid is called a **solvent.** The resulting mixture is called a **solution.** When the solution is stirred, it forms a **homogeneous** mixture.

A **Homogenous** mixture is a **mixture in which the solute and solvent particles are evenly distributed.**

Sodium chloride, sugar, potassium nitrate, and oxalic acid crystals dissolve in water. Naphthalene, sugar and oxalic acid dissolve in propanone. Oxalic acid and sugar dissolve in both water and propanone. Naphthalene, sand and sulphur do not dissolve in water. Sodium chloride, potassium nitrate, sand and sulphur do not dissolve in propanone. Sand and sulphur do not dissolve in both water and propanone.

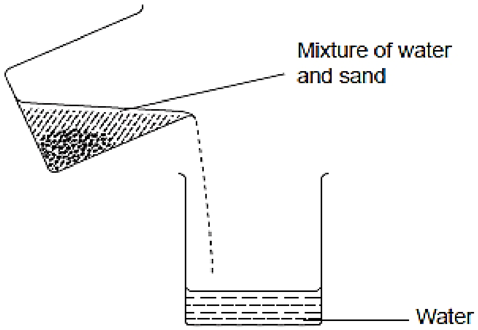
Separation of insoluble solid-liquid mixtures

Insoluble solid-liquid mixtures can be separated by decantation and filtration.

Decantation

Decantation is used to separate insoluble solid-liquid mixtures. In decantation, a solid-liquid mixture is allowed to stand such that the solid settles at the bottom. The liquid is then poured off carefully, leaving the solid behind.

Practically Speaking



A mixture of sand and water can be separated by decantation. To do this,

Transfer 10cm^3 of the mixture into 100ml beaker. Allow the mixture to settle and carefully pour the liquid into another beaker.

Discussion

Sand is insoluble in water. When a mixture of sand and water is allowed to stand, the sand settles at the bottom. The water can then be poured off carefully.

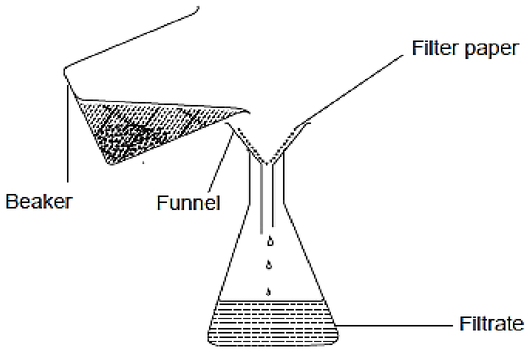
Side notes

The water collected in the second beaker is not clear. It still contains small suspended particles. **This method is not efficient** because some solids still pass into the liquid in the process of decanting. That is why the water collected in the second beaker is not **clear**. It still contains small suspended particles.

Filtration

In **Filtration**, an insoluble solid-liquid mixture is **poured down a funnel lined with a filter paper. The solid particles are trapped and collect on the filter paper** and are called the **residue.** The **liquid passes through** and is collected in the conical flask as the **filtrate.**

Practically Speaking



A mixture of sand and water can be separated by filtration. To do this,

Fold a filter paper into a cone shape. Place the filter paper in the funnel. Pour the mixture of sand and water carefully on the filter paper and collect the liquid in a conical flask

Observation

Fine sand particles are trapped and collect on the filter paper as the residue.

Side notes

The filtrate (water) collected in the conical flask is clear because the filter paper does not allow solid particles to pass through.

The advantage of this method over decantation is that the filtrate collected in the conical flask is clear because the filter paper does not allow solid particles to pass through.

Applications of Filtration

Filtration is used on a large scale in **water purification plants.** Dirty water is allowed to pass through a filter bed made of layers of gravel and sand. Suspended particles are trapped by the gravel and sand while the water passes through. Domestic water filters use the same principle.

Separation of soluble solid-liquid mixtures

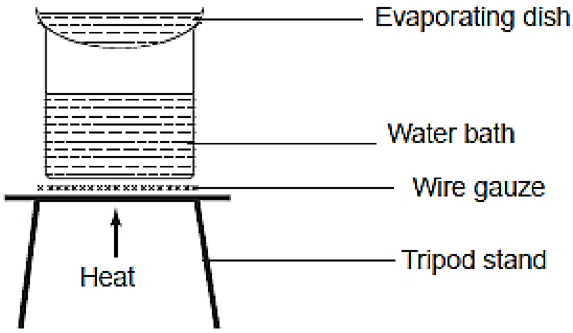
Soluble solid-liquid mixtures can be separated by evaporation, crystallization and simple distillation.

Evaporation

In evaporation, the mixture is heated to drive away the solvent in to the atmosphere. The solute remains behind.

Practically Speaking

A mixture of **sodium chloride and water** can be separated by evaporation. To do this;



Put 10 cm^3 of sodium chloride solution provided into an evaporating basin. Heat the evaporating basin until crystals start forming. Transfer the evaporating basin on to a water bath and continue heating to dry the crystals. Once dry, allow the crystals to cool. A sand bath may be used in place of a water bath but it takes long to be heated up. However, it retains heat much longer than the water bath.

Discussion

- The evaporating basin is heated to drive away water into the atmosphere.
- When crystals start forming the evaporating basin is transferred to a water bath so that the salt does not spit out of the basin as heating continues.
- This process is used to obtain salt from sea water.

Filtration and evaporation

Both filtration and evaporation can be used to separate a mixture of two solids with one of the solids being soluble in a particular solvent whereas the other is insoluble.

Practically Speaking

A mixture of **sand and sodium chloride** can be separated by filtration and evaporation. To do this;

Put a mixture of sand and sodium chloride in a beaker. Add water to it and warm while stirring. Allow the mixture to cool.

Filter the mixture using a filter paper and collect the filtrate on an evaporating basin. Evaporate the water until crystals start forming. Allow the solution to cool for more crystals to form.

Discussion

- Sand is insoluble in water and is separated by filtration. It is collected as the residue on the filter paper.
- Sodium chloride is soluble in water and is contained in the filtrate.
- To **recover the sodium chloride**, evaporation is carried out. The hot concentrated filtrate is then cooled to allow more crystals of sodium chloride to form.
- Both **filtration** and **evaporation** methods were used in this experiment to separate the mixture.

Crystallization

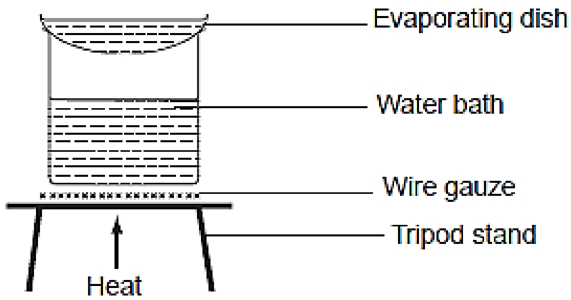
Crystallisation is the process of **obtaining crystals from a saturated solution.**
A saturated solution is one in which **no more solute can dissolve at a given temperature.**

This method can be used to separate most soluble substances from their solutions.

Practically Speaking

Crystals of various salts such as copper (II) sulphate can be obtained by crystallisation. To do this;

Put 10cm^3 of concentrated copper (II) sulphate solution into an evaporating basin. Arrange the apparatus as shown.



Using a water bath, heat the solution to evaporate excess water. As heating continues, dip a glass rod into the solution regularly and allow it to cool in the air.

When crystals start forming on the glass rod, remove the evaporating basin from the water bath and allow it to cool.

Discussion

The glass rod is dipped into the solution to find out whether the solution can form crystals on cooling. When crystals form on the glass rod, this is an indication that the solution is ready to form crystals. At this point the solution is said to be **saturated.**

Blue Crystals of copper(II) sulphate form.

Application of crystallisation

1. Extraction of salt from salty water e.g Lake Magadi and Ngomeni in Malindi.
2. Extraction of sugar from sugar cane.
3. Extraction of medicinal substances from plants.

Simple distillation.

Distillation is the process of evaporating a liquid from a solution and condensing the vapour produced back into liquid.

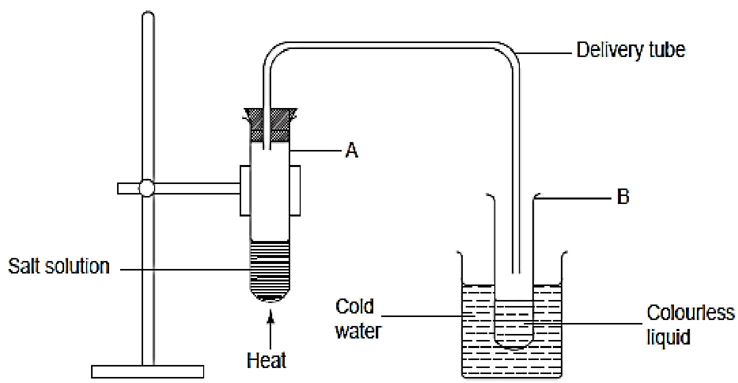
The liquid that is obtained after condensation is called the **distillate**.

Simple distillation can be used to obtain a solvent from a solution. In this method, both the solvent and the solute can be collected.

Practically Speaking

Water can be obtained from a solution of sodium chloride using simple distillation. To do this,

Place about 20cm^3 of sodium chloride solution in a boiling tube or a round-bottomed flask. Arrange the apparatus as shown.



Heat the solution until all the solvent has evaporated. Record your observation.

Place about 20cm^3 of the sodium chloride solution on a watch glass. Place the watch glass on a water bath. Heat the sodium chloride solution to dryness. Remove the watch glass from the water bath and allow it to cool. Record your observations.

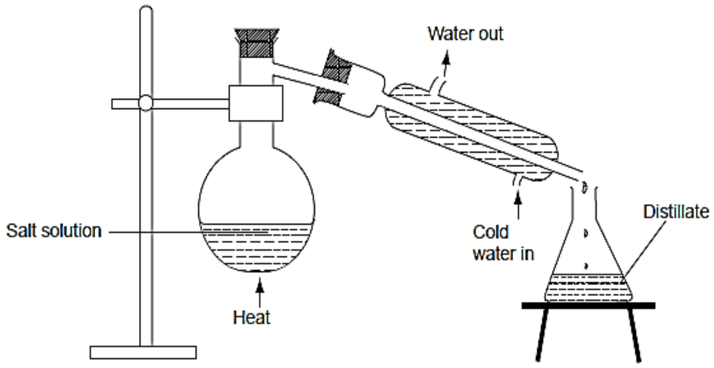
Place the liquid collected in tube B on another watch glass. Place the watch glass on the water bath. Heat the liquid to dryness. Allow the watch glass to cool. Record your observation.

Side note

- The cold water in the beaker acts as a coolant.

Discussion

- The steam passes through the delivery tube where some of it condenses on the cooler parts of the delivery tube to a colourless liquid. The steam is cooled and condenses to liquid water in test state tube B. The liquid collected in test tube B is called the **distillate.**
- A white solid remains in tube A. The white solid is sodium chloride. This method of separating a solute from a solvent is called **simple distillation.**
- When sodium chloride solution is placed on a watch glass and evaporated to dryness, a white residue is left behind.
- When the distillate is placed on a watch glass and evaporated, no residue remains. This shows that the distillate no longer contains dissolved sodium chloride.
- To improve the condensation process, a **Liebig condenser** is used as shown



Liquid-liquid mixtures

There are two types of liquid-liquid mixtures namely **immiscible** and **miscible** liquids.

Immiscible liquids do not mix but **form distinct layers.** Examples of such mixtures are **vegetable oil and water, kerosene and water.**

Miscible liquids mix to form a **homogenous mixture**. Examples are **water and ethanol, water and milk.**

Separating Immiscible Liquids

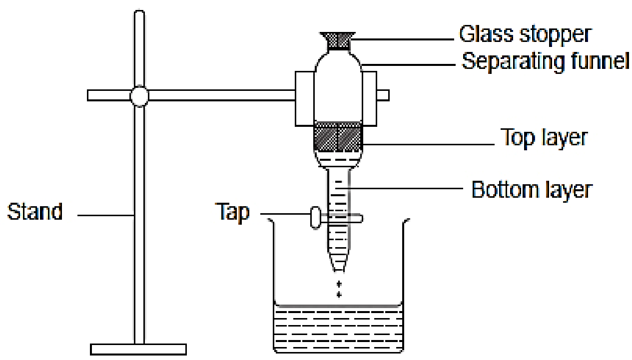
Immiscible liquids can be separated using a separating funnel, dropper or by decantation. A burette may also be used.

Using a separating funnel.

A mixture of kerosene and water can be separated using a separating funnel as shown in the experiment below.

Practically Speaking

Put 10cm^3 of coloured water in a conical flask. Add 10cm^3 of kerosene and shake well. Transfer the mixture into a separating funnel. Allow the mixture to stand for a while and observe. Remove the stopper. Open the tap of the separating funnel and allow the bottom layer to flow into a beaker. Discard the interphase (the boundary between water and kerosene) leaving the top layer in the separating funnel.



Side Notes

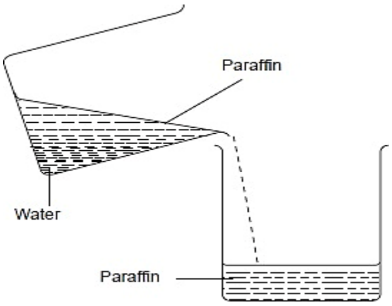
- The water is coloured to distinguish it from kerosene.
- The interphase contains both water and Kerosene. It is discarded because it is not easy to separate the two liquids at the interphase.

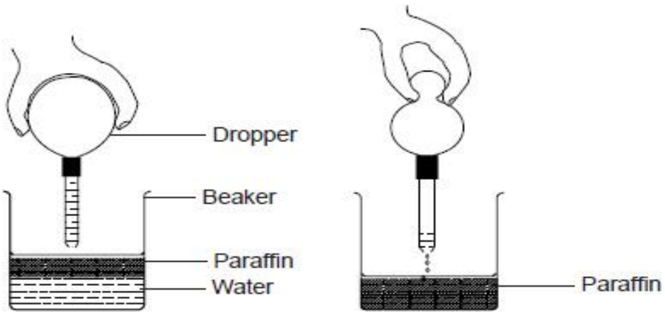
Discussion

Kerosene floats on water because it is lighter.
A mixture of water and kerosene is immiscible. The two liquids also have different densities.

Decantation

Decantation can also be used to separate immiscible liquids but it is not efficient.





A dropper can also be used to separate immiscible liquids by sucking the upper layer. The dropper is used to suck one layer transferring it to another beaker repeatedly. This method too is not accurate.

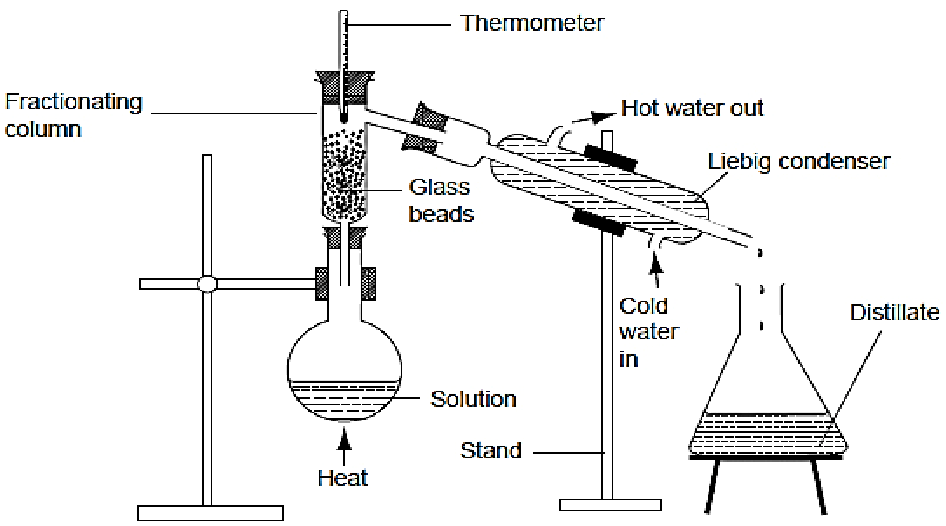
Separating Miscible Liquids

Miscible liquids can be separated using **fractional distillation.** The two liquids must be having different but close boiling points.

Practically Speaking

Separating a mixture of water and ethanol using fractional distillation.

Place $20cm^3$ of water in a round-bottomed flask. Add $20cm^3$ of ethanol and shake the mixture. Set up the apparatus as shown below.



Heat the mixture gently and note the temperature changes. Collect the distillate in the conical flask. Transfer a little distillate on a watch glass and light it. Record your observations.

Discussion

- Water and ethanol are miscible liquids. They are separated because they have different but close boiling points. Pure ethanol boils at 78.2°C while pure water boils at 100°C at sea level.
- When the mixture is heated, ethanol boils off first at about 78°C, and is collected as the first fraction of the mixture.
- The temperature remains fairly constant until the ethanol distils off. At this stage the temperature starts rising and the distillate collected thereafter is mainly water as a second fraction.

Side Notes

- The purpose of the **fractionating column** is to allow water vapour to condense into liquid and flow back into the flask before the boiling point of water is reached.
- The **thermometer** indicates when the boiling point of the medium being distilled has been reached.
- The **glass beads** increase the surface area for condensation.
- A **Liebig condenser** uses the counter flow principle to cool the vapour efficiently.
- If the **inlet and outlet were exchanged** in the Liebig condenser, condensation would still occur but less efficiently.

Applications of fractional distillation

1. (a) Distillation of crude oil to obtain fractions such as diesel, petroleum, cooking gas. (Kenya Petroleum Refinery in Changamwe, Mombasa),
   (b) Recycling of used oil (at Athi River and Kikuyu town).
2. Liquid air in the manufacture of nitrogen and oxygen. (British Oxygen Company, BOC).

Solvent extraction.

Solvent extraction, also known as **liquid-liquid extraction** is a process that allows the separation of two or more components due to their **unequal solubilities.** The **solvent**, also known as an **extractant** is chosen to **selectively extract a certain** component from a mixture.

Groundnuts, cashew nuts and coconuts contain oil which is useful. The oil can be extracted by solvent extraction using a suitable solvent such as propanone.

Practically Speaking

How to extract oil from groundnuts

Crush about 20 groundnut seeds in a mortar using a pestle. Continue crushing the nuts while adding propanone a little at a time. Decant the resulting solution into an evaporating basin. Leave the solution in the sun for some time.

Side Notes

- The nuts are first crushed to increase the surface area in contact with the solvent.
- Propanone is used as a solvent because it dissolves oil
- Water which is a common solvent cannot be used in this extraction because it will not dissolve oil.

Discussion

- Once the oil has dissolved in the propanone the solution is left in the sun for the **solvent to evaporate.** The oil having a higher boiling point than the solvent is left in the evaporating dish.

- Oil obtained this way can be made more pure by washing the product in water and separated from the water using a separating funnel.
- Oils leave a translucent patch on paper. This can be used as a simple test for their presence.

Applications of solvent extraction

1. Extraction of:
   (i) oil from nuts and seeds.
   (ii) natural dyes from plants.
   (iii) some herbal medicines from plants
   (iv) caffeine from tea and coffee
2. In dry-cleaning to remove dirt.

(d) Separation of Coloured substances

Naturally occurring substances may contain several pigments (colours). For example green grass has several pigments. The colours can be separated by chromatography.

Chromatography

Chromatography is derived from the terms *Chroma* which means **colour** and *chromatology* which means **study of colours**

Chromatography is a method of separating coloured substances. Each coloured substance has a **different solubility in a solvent** and a different extent of **adsorption** on the **adsorbent material.**

- **Adsorption** involves the binding of molecules or particles of a gas or liquid to the surface of a solid.
- A **chromatogram** is a final representation of the separated pigments.
- The furthest point where the solvent reaches on the adsorbent material is called the **solvent front.**

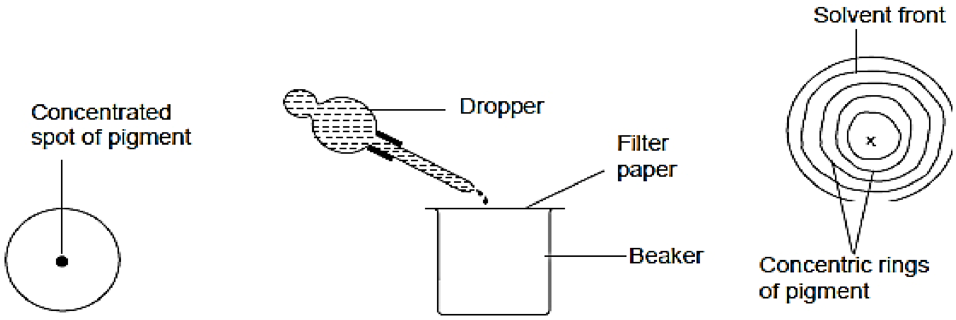
Practically Speaking

Using chromatography to separate a mixture of pigments.

Crush some green leaves or grass in a mortar using a pestle. Add propanone as you continue crushing the leaves.

Decant the extract into a beaker. Place a filter paper on top of an empty beaker. Using a dropper place one drop of the extract at the centre of the filter paper and allow it to spread as far as possible. Add a second and third drop at the same spot. Each time allow the extract to spread as far as possible.

Once the spot of the extract has stopped spreading, add the solvent drop-wise each time allowing the solvent to spread. Continue adding the solvent until it spreads out close to the edge of the filter paper. Draw the diagram of the filter paper showing the results obtained.



Chromatogram

Side Notes

The colouring matter in green leaves is composed of different substances. Propanone is used to dissolve the colouring matter.

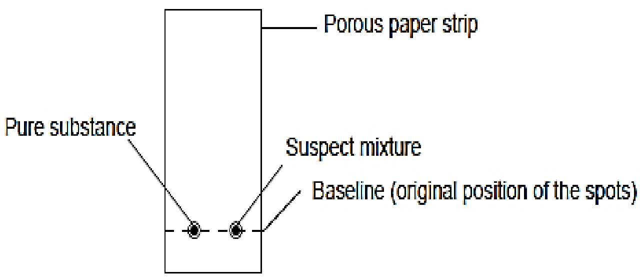
Discussion

- The coloured matter in leaves separates into two distinct pigments; a green colour due to a substance called **chlorophyll** and a yellow colour due to **xanthophylls.** The dry filter paper showing the separated pigments is called **chromatogram.** Xanthophyll is more soluble and less adsorbed.
- Each coloured substance has a different solubility in propanone and a different extent of **adsorption** on the filter paper **(adsorbent material).** As the propanone spreads, the pigments which are more soluble and less adsorbed are carried furthest while the less soluble and more adsorbed are left behind; as a result, separation takes place.

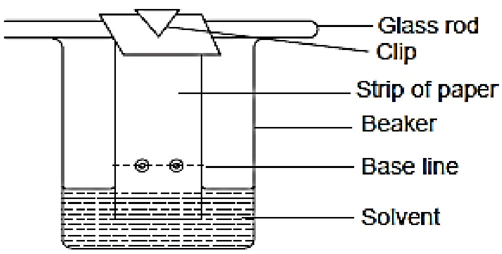
Using chromatography to determine the presence of a substance in a mixture

Chromatography can be used to determine the presence of a substance in a mixture by comparing it with a pure substance. The suspect mixture is placed on an adsorbent medium alongside the pure substance on the same **baseline**.

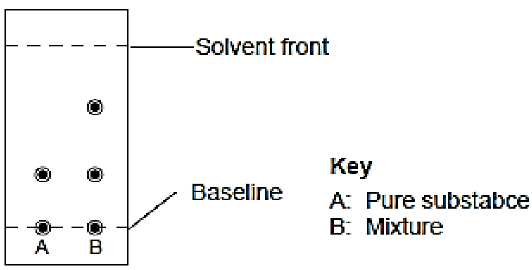
The paper strip is then placed in a beaker containing a solvent.



The solvent is allowed to ascend to the top **(solvent front)** and the paper is then removed and allowed to dry. The position of the spots from the mixture and the pure substance are noted and compared.



Set-up
(a)



Result
(b)

If **any** of the **spots in the mixture moves the same distance as the spot in the pure substance,** then the mixture **contains the pure substance** as one of the components.

This procedure is known as ascending paper chromatography.

Applications of chromatography

1. In sports, chromatography, is used to identify banned substances, for example steroids in urine or in blood samples.
2. In the pharmaceutical industry, to test purity of drugs.
3. In food industry, to identify contaminants in food and drinks.
4. In the cosmetics industry, to identify harmful substances.

2. Effect of Heat on Substances

States of Matter

Matter is anything that has mass and occupies space. Matter exists in three physical states namely solid, liquid and gas. A substance can exist in any of the three states depending on the prevailing temperature.

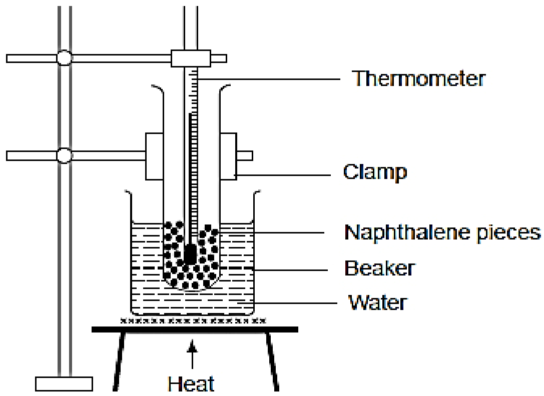
Practically Speaking

Heating and cooling curves of solid naphthalene

Place a spatulaful of naphthalene in a boiling tube. Note the temperature of the naphthalene.

Place the boiling tube in a beaker of water as shown below and heat the beaker. Record the temperature of the naphthalene every half a minute throughout the experiment until all the solid has melted.

Continue heating for about two more minutes. Record the temperature readings in a table and plot a graph of temperature against time.

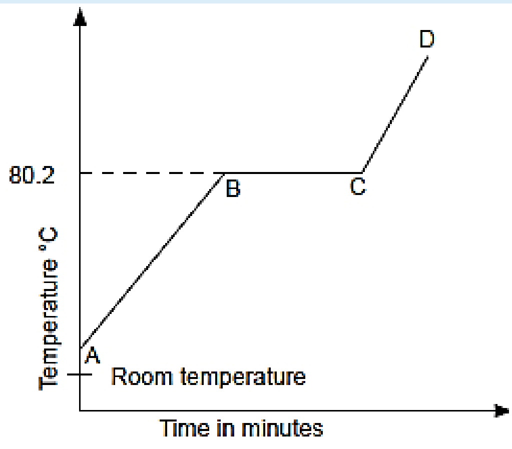


Side Note

- Heating in a water bath does not allow the boiling point of naphthalene (218°C) to be attained and therefore protects the thermometer from breaking.

Discussion

When naphthalene is heated, its temperature rises steadily until it starts to melt. At this point, the temperature remains constant until all the naphthalene has melted then the temperature starts rising again.
A sketch of the graph of temperature against time obtained when naphthalene is heated to melting is shown alongside. Such a graph is called a **heating curve.**



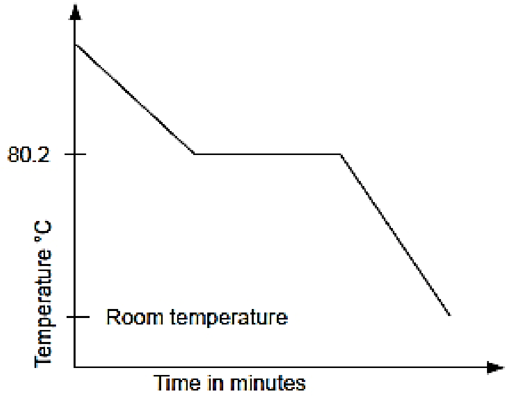
Heating curve

Region AB: The temperature increases steadily as the naphthalene absorbs heat energy. The heat absorbed increases the kinetic energy of the particles and they vibrate more vigorously.

Region BC: The temperature remains constant until all the naphthalene melts. Here, the heat supplied is used to weaken the forces of attraction holding the particles of naphthalene together. The particles therefore move far apart. As a result, the naphthalene changes its state from solid to liquid.

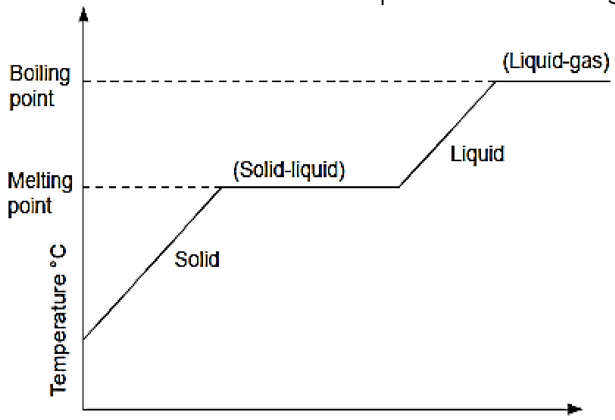
Region CD: Temperature rises steadily as the liquid naphthalene absorbs heat energy. The heat supplied increases further the kinetic energy of the particles causing them to move fast.

If liquid naphthalene is allowed to cool, the reverse can be obtained. It is then referred to as **cooling curve.**



Cooling curve

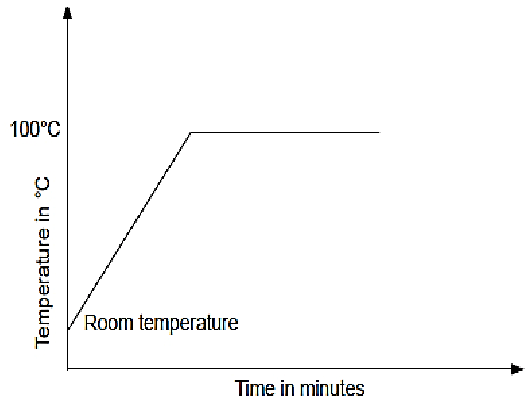
The figure below represents a heating curve of a solid which is heated from room temperature to boiling point.



Heating curve for a liquid: pure water

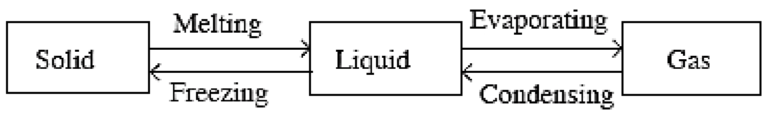
When water is heated, its temperature steadily increases as molecules absorb heat energy, which increases their kinetic energy. The temperature of the water continues to rise until the water starts to boil.

The temperature of the water **remains constant as it boils.** This is because **the heat energy supplied is used to break the forces of attraction holding the particles together.** As a result, some particles break free and the water changes from liquid to gaseous state.



The graph of temperature against time obtained when water is heated to boiling is given alongside.

Change of state from solid to liquid and liquid to gas can be reversed by cooling. On cooling, the gas condenses into liquid and finally the liquid freezes into solid. These changes are shown in the flow diagram below.



The arrow signs ⇄ means a reversible change.

The use of the thermometer enables us to observe that changes in the states of matter are not accompanied by temperature changes. Some forces of attraction hold together the particles which make up matter. Heating provides the energy required to overcome these forces.

Some substances such as iodine do not undergo the above changes because they sublime.

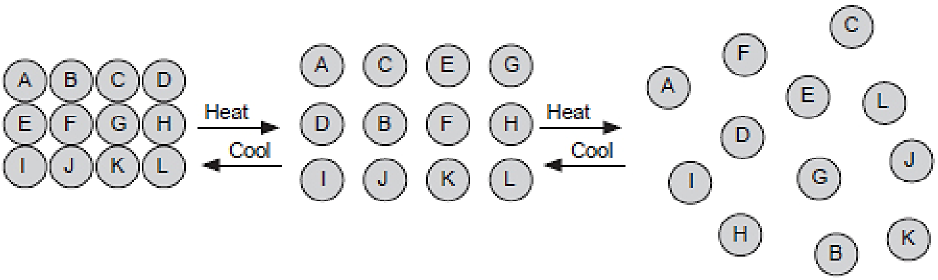
$$\underset{\text{(dark cystals)}}{\text{Iodine}} \underset{\text{cool}}{\overset{\text{heat}}{\rightleftharpoons}} \underset{\text{(purple vapour)}}{\text{Iodine}}$$

The explanation for the behaviour of matter in terms of the movement of particles is provided by the kinetic theory of matter.

3. The Kinetic Theory of Matter

According to the theory, **matter is made up of particles which are in a continuous state of motion.** The kinetic theory forms the basis of the theoretical model of matter.

The figure below shows the model in which circles represent small particles of matter.



SOLID
particles closely packed.
Particles held
in fixed positions

LIQUID
Particles not as closely packed
as in solids. Particles move
within the liquid in a container

GAS
Particles widely
separated. Particles move
independly

Solid state

In the solid state, the particles are **closely packed together** and can **only vibrate within fixed positions**. They do not move from one point to another because there are forces that hold them in these positions. When a solid is heated, the kinetic energy of the particles increases and they begin to vibrate more vigorously. At a certain temperature which is fixed for particular substance, the forces holding the particles are weakened enough to allow the particles to change position as a result the solid changes into a liquid. This temperature is known as the **melting point.**

Liquid state

In the liquid state, particles are **not as close together** as they are in the solid state. They **can move from one position to another within the liquid.** This explains why a liquid has no definite shape and will take the shape of the container. However, a liquid has a definite volume. The particles exert some attraction on one another and these forces of attraction make them to stay together.

When a liquid is heated, the particles **move more rapidly** as the forces of attraction are further **weakened**. The weakening continues until the particles gain enough energy to overcome the forces between them. At this point, the liquid boils as particles break free and enter the gaseous phase/state. The constant temperature at which a pure liquid boils is called the **boiling point** and is fixed for a particular substance. The temperature at which a liquid boils depends on the external atmospheric pressure.

Gaseous state

In the gaseous state the particles are **far apart and free to move randomly in all directions.** This is why a gas does not have definite shape or volume but occupies the whole space within a container.

When a gas is cooled the particles lose kinetic energy and hence slow down. As they slow down they easily attract their neighbouring particles and move close to form a liquid. This process is called **condensation.** Condensation occurs at the **same temperature as evaporation.**

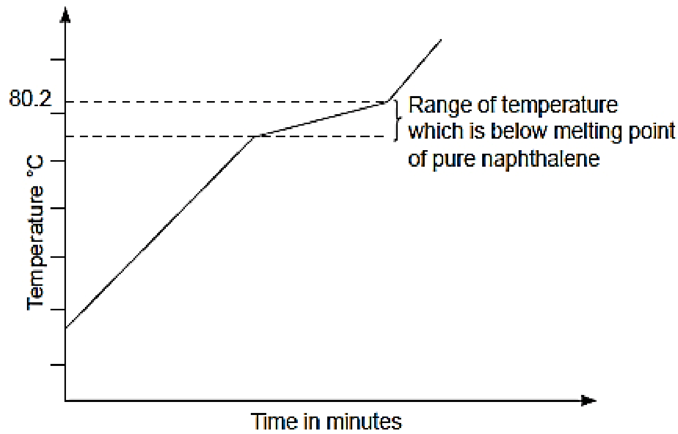
On further cooling of the liquid, the kinetic energy of the particles continues to decrease and the particles take up fixed positions as the liquid solidifies. This process is called **freezing.** Freezing takes place at the **same temperature as melting.**

Effect of Impurities on Melting and Boiling Points of Substances

Melting point

Impurities **lower the melting point** of substances. Impure substance **do not have sharp melting points.**

For example, the melting point of pure naphthalene is 80.2°C. If camphor or another substance is added as an impurity, the naphthalene melts over a temperature range that is lower than the melting point of pure naphthalene. **Impure naphthalene does not have a sharp melting point.** Impurities therefore lower the melting point of substances.



Applications

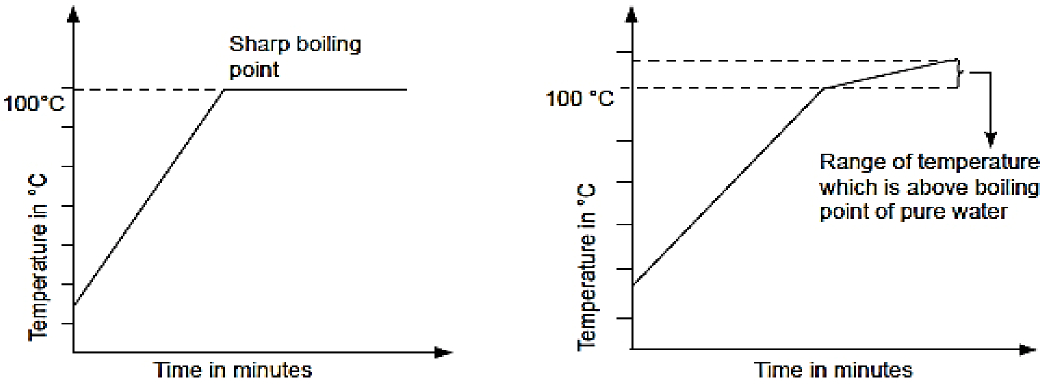
The lowering of melting point by impurities is applied in:

1. Clearing of ice from roads in temperate countries by spreading common salt on the ice.
2. Extraction of metals from their molten compounds. For example, calcium chloride is added to rock salt during the extraction of sodium from sodium chloride.

(b) Effect of impurities on the boiling points of substances

Impurities **raise the boiling points of substances.** Impure substances **do not have sharp boiling points.**

For example, the boiling point of pure water is 100°C at sea level. However, impure water starts to boil at a temperature above 100°C. The temperature continues to rise as the impure water boils. Thus, the impure water boils over a range of temperature. Impurities raise the boiling point of a liquid. The heating curves for pure and impure water are shown in graphs (a) and (b).



Pure water
(a)

Impure water
(b)

Criteria of Purity

Pure substances **melt and boil at constant temperatures** that are specific for a particular substance. Melting and boiling points are therefore used for determining purity of substances.

4. Temporary and permanent changes

Substances undergo various changes when subjected to different conditions of temperature.

Temporary changes.

A temporary change may be **physical or chemical. In a temporary physical change,** no new substance is formed. **In a temporary chemical change** new substances are formed. However, the reactions are reversible if the conditions are reversed.

Temporary physical change

A change which can **easily be reversed** and in which **no new substance is formed** is called a **temporary physical change.**

Characteristics of temporary physical changes.

(a) They are easily reversible.
(b) No new substance is formed.
(c) The mass of the substance does not change.
(d) They are not accompanied by net heat change.

Examples of temporary physical changes are heating zinc oxide, wax and iodine which does not result in the formation of a new substance. Cooling reverses the changes these substances undergo.

1. When zinc oxide is heated, its colour changes from white to yellow. On cooling, the yellow solid turns white. This change can be represented as:

$$\text{Zinc oxide (white)} \underset{Cool}{\overset{Heat}{\rightleftharpoons}} \text{Zinc oxide (yellow)}$$

2. Wax melts on heating. When cooled, liquid wax changes back to solid.

$$\text{Solid wax} \underset{Cool}{\overset{Heat}{\rightleftharpoons}} \text{Liquid wax}$$

3. When iodine is heated, the shiny black solid turns to a purple vapour. When cooled, the purple vapour changes back to the shiny black solid.

$$\underset{\text{(shinny black)}}{\text{Solid iodine}} \underset{Cool}{\overset{Heat}{\rightleftharpoons}} \underset{\text{(purple)}}{\text{Iodine vapour}}$$

II) Temporary chemical change

A **temporary chemical change** is a change which **can be reversed but a new substance is formed.**

Characteristics of temporary chemical change

(a) A new substance is formed.
(b) Heat energy is evolved or absorbed.
(c) There is change in mass.
(d) The change can be reversed.

Heating hydrated copper (II) sulphate or hydrated cobalt (II) chloride results into a **temporary chemical change.**

- **A hydrated substance is that which contains water of crystallization.**

When hydrated copper(II) sulphate is heated, it decomposes to produce white copper (II) sulphate powder and water. The white copper (II) sulphate powder does not contain water of crystallisation and is said to be **anhydrous.**

$$\underset{(blue)}{\text{Hydrated copper (II) sulphate}} \xrightarrow{heat} \underset{(white)}{\text{Anhydrous copper (II) sulphate}} + \text{Water}$$

The white anhydrous copper (II) sulphate does not regain the original blue colour on cooling.

$$\underset{(white)}{\text{Anhydrous copper (II) sulphate}} \xrightarrow{cool} \underset{(white)}{\text{Anhydrous copper (II) sulphate}}$$

Similarly, pink cobalt (II) chloride decomposes to form blue anhydrous cobalt (II) chloride and water vapour.

$$\underset{(pink)}{\text{Hydrated cobalt (II) chloride}} \xrightarrow{heat} \underset{(hydrated)}{\text{Anhydrous cobalt (II) chloride}} + \text{water}$$

The blue cobalt (II) chloride does not regain the pink colour on cooling.

$$\underset{(blue)}{\text{Anhydrous cobalt (II) chloride}} \xrightarrow{cool} \underset{(blue)}{\text{Anhydrous cobalt (II) chloride}}$$

- The decomposition of a substance when it is heated is referred to as **thermal dissociation.**

Heat is evolved when a little water is added to the anhydrous copper sulphate or the blue anhydrous cobalt (II) chloride. The anhydrous substances become hydrated and regain their original colour.

$$\underset{(anhydrous)}{\text{White copper (II) sulphate}} + \text{Water} \longrightarrow \underset{(hydrated)}{\text{Blue copper (II) sulphate}}$$

$$\underset{(anhydrous)}{\text{Blue cobalt (II) chloride}} + \text{water} \longrightarrow \underset{(hydrated)}{\text{Pink cobalt (II) chloride}}$$

Permanent chemical change.

A **permanent chemical change** is a change in which **a new substance is formed and the change cannot be reversed.**

Characteristics of permanent chemical changes

(a) New substances are formed.
(b) The change is irreversible.
(c) The change is accompanied by change in mass.
(d) Heat energy is released or absorbed.

The decomposition of copper (II) nitrate and potassium manganate (VII) are examples of **permanent chemical changes.**

When copper (II) nitrate is heated it decomposes to form a black solid and a mixture of gases. The black solid is copper (II) oxide. The mixture of gases consists of a red brown gas and another gas which relights a glowing splint. The red brown gas is nitrogen (IV) oxide while the gas which relights the glowing splint is oxygen.

$$\underset{(blue)}{\text{Copper (II) nitrate}} \xrightarrow{heat} \underset{(black)}{\text{Copper (II) oxide}} + \underset{(red\text{-}brown)}{\text{Nitrogen (IV) oxide}} + \underset{(colourless)}{\text{Oxygen}}$$

The mass of copper (II) oxide is found to be less than that of copper (II) nitrate because the gaseous products escaped into the atmosphere.

Also, Potassium manganate (VII) decomposes to form a black-green solid and a colourless gas, which relights a glowing splint. The black-green solid is a mixture of black manganese (IV) oxide and green potassium manganate (VI). The black-green solid weighs less than the original potassium manganate (VII).

$$\underset{(purple)}{\text{Potassium manganate (VII)}} \xrightarrow{heat} \underset{(green)}{\text{potassium manganate (VI)}} + \underset{(black)}{\text{Manganese (IV) oxide}} + \text{Oxygen}$$

5. Constituents of Matter

Pure substances can be classified as **elements** or **compounds.**

Elements

Elements are **pure substances which cannot be split into simpler substances by chemical means.**

Examples of elements include oxygen, hydrogen, copper, sulphur, carbon and iron. There are over a hundred known elements.

Elements are made up of **atoms.**

The **atom** is the **smallest particle of an element, which can take part in a chemical change.**

Atoms of the same element are similar.

The atoms of some elements cannot exist independently but join together to form small groups of atoms. These discreet particles are called **molecules.**

A **molecule** is defined as the smallest particle of an element or compound, which can exist separately.

Compounds

When two or more elements combine chemically they form a **compound.**

A **compound** is a pure substance made up of two or more elements chemically combined.

The compound formed when **iron** and **sulphur** chemically combine is called **iron (II) sulphide.**

In compounds, names ending in **–ide** means the compound is composed of **two elements only**. e.g:

Sodium Chloride is made up of **Sodium** and **Chlorine**.

Iron (II) Sulphide is made up of **Iron** and **Chlorine**.

Calcium Nitride is made up of **Calcium** and **nitrogen**.

Calcium carbide is made up of **Calcium** and **Carbon**.

Sodium hydride is made up of **Sodium** and **hydrogen**.

An exception to this are the hydroxides.

Names ending in **–ate** means the compound is composed of **three elements** one of which is oxygen.

eg:

Sodium Sulphate is made up of sodium, sulphur and oxygen.

Sodium Carbonate is made up of sodium, carbon and oxygen.

Potassium chlorate is made up of potassium, chlorine and oxygen.

Calcium nitrate is made up of calcium, nitrogen and oxygen.

Exceptions to this rule are the hydrogen carbonates and hydrogensulphates.

Names ending in **–ite** means the compound is made up of three elements one of which is oxygen.

However, the amount of oxygen is less than in those compounds whose names end in –ate e.g

Sodium Sulphite is made up of sodium, sulphur and oxygen.

Calcium Sulphite is made up of calcium, sulphur and oxygen.

Chemical Symbols

In Chemistry, elements are represented by letters. The letters are referred to as **chemical symbols**. A chemical symbol of an element is usually the first letter or the first and another letter of the element's English or Latin name.

The **first letter** of a chemical symbol **must always be a capital letter** while the **second letter is always a small letter.**

Symbols derived from first letter of name of element

Element	*Symbol*
Carbon	C
Nitrogen	N
Oxygen	O
Hydrogen	H

Symbols of several elements **may begin with the same letter.** It is therefore necessary to represent some of these elements with **two letters** as shown in the following table. **The second letter in a chemical symbol is always a small letter**.

Symbols derived from first and second letter of name of element

Elements	*Symbol*
Calcium	Ca
Cobalt	Co
Chlorine	Cl
Magnesium	Mg
Manganese	Mn

In some cases, the symbol of the element is derived from the element's **Latin name** as shown in the table below.

Symbols derived from latin name of element

Element	*Latin name*	*Symbol*
Potassium	Kalium	K
Sodium	Natrium	Na
Silver	Argentum	Ag
Gold	Aurum	Au
Iron	Ferrum	Fe
Lead	Plumbum	Pb
Mercury	Hydragyrum	Hg
Copper	Cuprum	Cu

Chemical Equations

Iron and sulphur combine chemically to form iron (II) sulphide. In this process iron and sulphur are referred to as the **reactants** whereas the iron (II) sulphide is referred to as the **product.**

Chemical combination of elements is known as a **reaction.**

$$\text{Iron + Sulphur} \longrightarrow \text{Iron (II) sulphide}$$
$$\text{(reactants)} \qquad\qquad \text{(products)}$$

When a reaction is represented as shown, the representation is called a **word equation.** In a chemical equation, **reactant** are written on the left hand side of the arrow sign $\longrightarrow$ while the **products** are written on the right hand side.

The **forward arrow** sign $\longrightarrow$ is used where the **reactions are permanent and proceed only in one direction.**

Two arrow signs in opposite directions $\rightleftarrows$ are used where **the reactions are reversible.** This means the reaction **can proceed in either direction.**

NOTE:

The **plus sign** on the **reactants side** means **"react with."**

The **plus sign** on the **product side** means **"and"**

The **arrow sign between the reactants and the products** means to **"yield".**

1. Iron reacting with sulphur

   Iron + Sulphur $\longrightarrow$ Iron (II) sulphide

2. Sulphur reacting with oxygen

   Sulphur + Oxygen $\longrightarrow$ Sulphur (IV) oxide

3. Carbon reacting with oxygen

   Carbon + Oxygen $\longrightarrow$ Carbon (IV) oxide

4. Sublimation of Iodine

$$\text{Iodine} \rightleftharpoons \text{Iodine Vapour}$$

Review Exercises

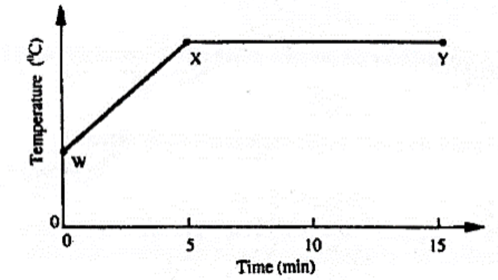
1. 2006 Q 10a P1
Name the process which takes place when solid carbon (IV) oxide (dry ice) changes directly into gas (1 mark)

2. 2006 Q25 P1
Study the properties of substances V_1 to V_4 in the table below and answer the questions that follow.

Substance	Solubility in water	Solubility	Melting Point(°C)	Boiling point(°C)
V_1	Insoluble	Soluble	-30	250
V_2	Insoluble	Insoluble	1535	3000
V_3	Insoluble	Soluble	16.8	44.8
V_4	Insoluble	Soluble	75	320

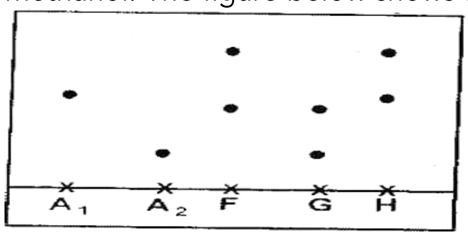
(a) Which of the substances are liquids at 240°C?
(b) Describe how a mixture containing V_2 and V_4 can be separated. (2marks)

3. 2006 Q 26 P1
The graph below shows a curve obtained when water at 20oC was heated for 15 minutes.



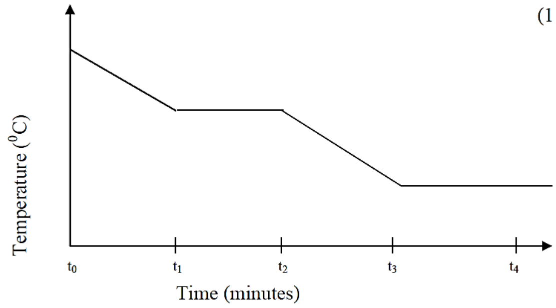
a) What happens to the water molecules between points W and x?
b) In which part of the curve does a change of state occur?
c) Explain why the temperature does not rise between points X and Y.

4. 2008 Q 14 P1
Samples of urine from three participants F, G and H at an international sports meeting were spotted onto a chromatography paper alongside two from illegal drugs A_1 and A_2. A chromatogram was run using methanol. The figure below shows the chromatogram.



a) Identify the athlete who had used an illegal drug. (1 mark)
b) Which drug is more soluble in methanol? (1 mark)

5. 2008 Q 25 P1
The graph below is a cooling curve of a substance from gaseous state to solid state.



Give the name of the:

(a) Process taking place between t_0 and t_1. (1mark)

(b) Energy change that occurs between t_3 and t_4 (1mark)

6. 2008 Q 1a P2

(a) Biogas is a mixture of mainly carbon (IV) oxide and methane.

(i) Give a reason why biogas can be used as a fuel. (1mark)

(ii) Other than fractional distillation, describe a method that can be used to determine the percentage of methane in biogas. (3 marks)

7. 2009 Q 20 P1

Classify the following processes as either chemical or physical. (3 marks)

Process	Type of change
(a) heating copper(II) sulphate crystals	
(b) Obtaining kerosene crude oil	
(c) souring of milk	

8. 2009 Q 5a,b P2

(a)Figure 3 shows the changes that take place between state of matter. Some of them have been identified and others labelled.

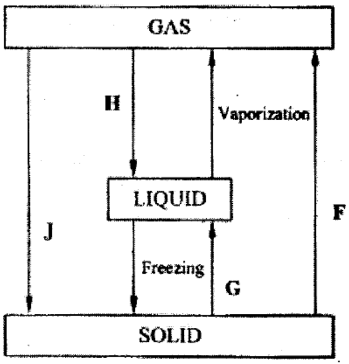


Figure 3

(i) Give the names of the process:

I. H (1 mark)

II. G (1 mark)

(ii) Name one substance that can undergo process F When left in an open container in the laboratory (1 mark)

(iii) The process J is called deposition. Using water is an example; write an equation that represents the process of deposition. (1 mark)

(b) Figure 4 shows the heating curve for water

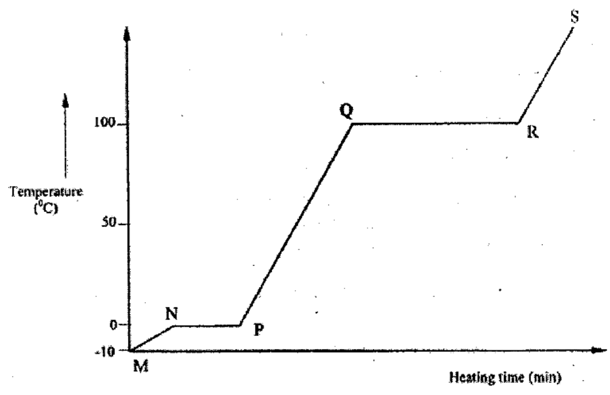


Figure 4

(i)Give the names of the intermolecular forces of attraction in the segments.

I. MN (1 mark)

II. RS (1 mark)

9. 2010 Q 5 P1

Hydrated cobalt (II) chloride exists as pink crystals and anhydrous cobalt (II) chloride is a blue powder. Describe a laboratory experiment that can be used to show that the action of heat on hydrated cobalt (II) chloride is a reversible reaction. (3 marks)

10. 2011 Q3 P1

A mixture contains ammonium chloride, copper (II) oxide and sodium chloride. Describe how each of the substances can be obtained from the mixture (3 marks)

11. 2012 Q5 P1

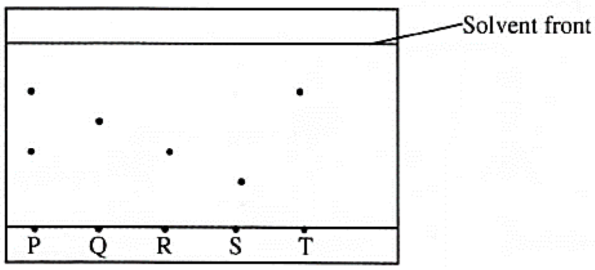
A sample of water in a beaker was found to boil at 101.5 °C at 1 atmosphere pressure. Assuming that the thermometer was not faulty, explain this observation. (1 mark)

12. 2012 Q2 P1

Iron (III) oxide was found to be contaminated with copper (II) sulphate. Describe how a pure sample of iron (III) oxide can be obtained. (3 marks)

13. 2013 Q15 P1

The chromatogram below was obtained from a contaminated food sample P. Contaminants Q, R, S and T are suspected to be in P. Use it to answer the following questions.



a) Identify the contaminants in mixture P. (1 mark)

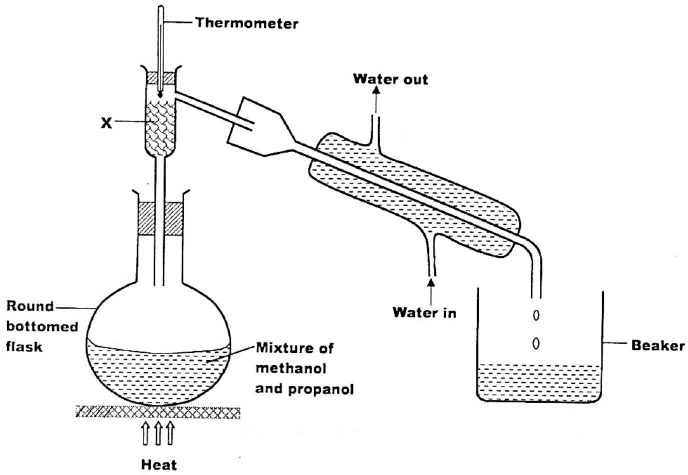
b) Which is the most soluble contaminant in P.? (1 mark)

14. 2014 Q19 P1

Draw a set up that can be used to separate a mixture of sand and iodine (3 marks)

15. 2014 Q22 P1

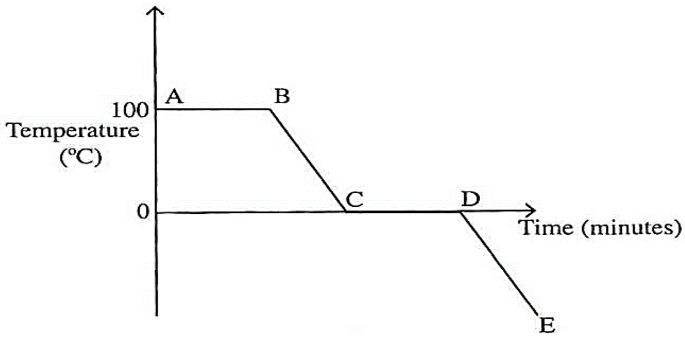
The set up below was used to separate a mixture of methanol and propanol. Study it and answer the question that follow.



(a) State the function of X (1 mark)
(b) Which liquid will collect first in the beaker? Give reason. (2 marks)

16. 2015 Q24 P1

The graph below is a cooling curve for water. Study it and answer the questions that follow.



(a) Explain what happens to the molecules of water in the region BC in terms of kinetic theory? (2 marks)
(b) In what state is the water in the region DE? (1 mark)

17. 2015 Q3 P2

(a) Name the method that can be used to obtain pure iron (III) chloride from a mixture of iron (III) chloride and sodium chloride. (1 mark)
(b) A student was provided with a mixture of sunflower flour, common salt and a red dye. The characteristics of the three substances in the mixture are given in the table below.

Substance	Solubility in water	Solubility in ethanol
Sunflower flour	Insoluble	Insoluble
Common salt	Soluble	Insoluble
Solid red dye	Soluble	Soluble

The student was provided with ethanol and any other materials needed.
Described how the student can separate the mixture into its three components.
(3 marks)

18. 2016 Q10 P1

Iron (III) oxide was found to be contaminated with copper (II) sulphate.
Describe how pure sample of iron (III) oxide can be obtained.

19. 2016 Q27 P1
Describe an experimental procedure that can be used to extract oil from nut seeds. (2 marks)

20. 2016 Q28 P1
A mixture contains ammonium chloride, copper (II) oxide and sodium chloride. Describe how each of the substances can be obtained from the mixture

(3 marks)

21. 2017 Q23 P1.
Explain how a student can establish whether a liquid sample extracted from a plant is pure. (2 marks)

22. 2018 Q9 P1
An experiment was carried out to determine the presence of substances P, Q, R and S in mixture T. The results obtained are as follows.

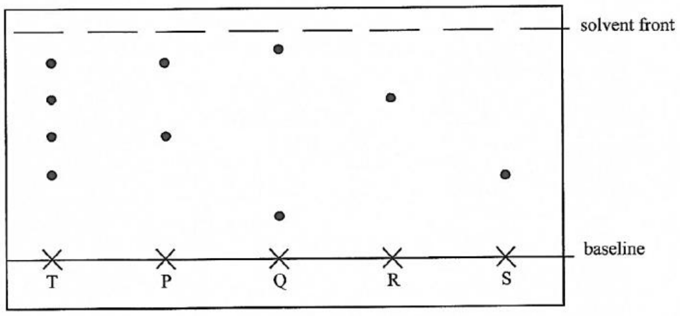


Figure 2

(a) Name the method of separation illustrated in **figure 2.** (1 mark)

(b) Select:

(i) One substance which contains a component not present in T (1 mark)

(ii) A substance which is least soluble in the solvent used. (1 mark)

23. 2018 Q22 P1
You are provided with the following: thermometer, boiling tube, beaker, Bunsen burner, pure substance X whose boiling point is about 80°C, water and any other apparatus that may be required. Draw a labelled diagram of the set-up that can be used to determine the melting point of X. (3 marks)

24. 2018 P2 Q3 (a).
(a) Complete Table 1 by indicating the observations, type of permanent or temporary change and name of new compound formed. (6 marks)

Experiment	Observation	Type of change	Name of product
(i)Heat candle wax strongly in a test tube.			
(ii)Anhydrous copper (II) sulphate is left exposed overnight			
(iii)Iron wool is soaked tap water for two days.			

25. 2019 Q10 P1

The graph in **Figure 4** was obtained when a certain substance was heated and its temperature recorded at regular intervals.

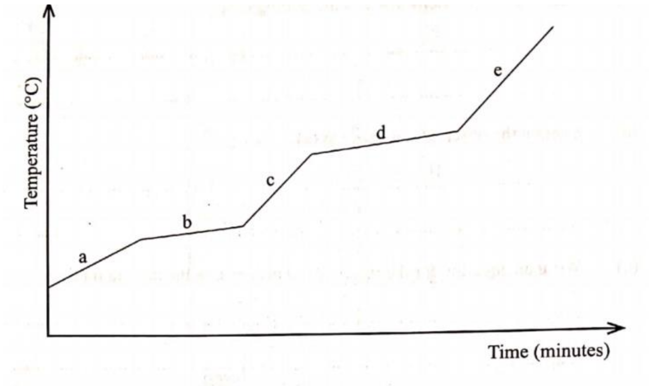


Figure 4

(a) State the purity of the substance. (1 mark)
(b) Explain the answer in (a). (1 mark)

26. 2019 Q15 P1

Figure 5 shows an apparatus used to separate a mixture of water and hexene.

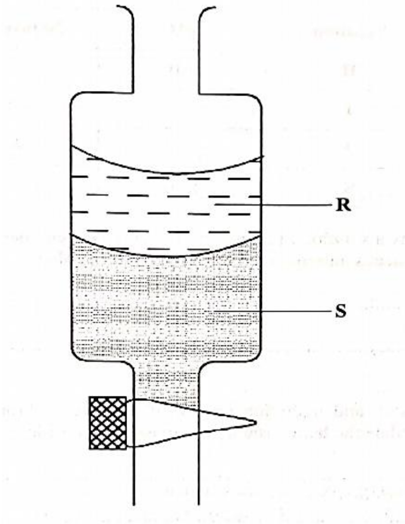


Figure 5

(a) Name the apparatus in **Figure 5**. (1 mark)
(b) State the principle by which the mixture of the two liquids is separated. (1 mark)
(c) Identify the liquids, R and S if the density of hexene is 0.66 g/cm^3.
 (i) R .... (½ mark)
 (ii) S .... (½ mark)

27. 2019 Q7 (d) P2

Some plants have seeds that contain vegetable oil.
(i) Describe how the oil can be obtained from the seeds. (3 marks)
(ii) Explain how it could be confirmed that the liquid obtained from the seeds is oil. (1 mark)