CHAPTER 4

Exploring Diversity of Matter Using Separation Techniques

Introduction

In this chapter, we will apply our understanding of the physical properties and chemical composition of matter in choosing appropriate separation techniques to separate different mixtures. Separating mixtures can help us in reusing and recycling our resources.

Learning Map

This table shows the content covered in this chapter, relating to the Primary Science (PS), Lower Secondary Science (LSS) and Upper Secondary Science (USS) syllabuses.

Content	PS	LSS	USS
Constituents of a mixture separated and purified based on their properties using magnetic attraction	✓	✓	✓
Constituents of a mixture separated and purified based on their properties using filtration	✓	✓	✓
Constituents of a mixture separated and purified based on their properties using evaporation	✓	✓	✓
Constituents of a mixture separated and purified based on their properties using distillation		✓	✓
Constituents of a mixture separated and purified based on their properties using paper chromatography		✓	✓
Constituents of a mixture separated and purified based on their properties using a fractionating column			✓
Constituents of a mixture separated and purified based on their properties using sublimation			✓
Constituents of a mixture separated and purified based on their properties using crystallisation			✓
Applications of the various separation techniques in everyday life and industries		✓	✓
Water is a precious resource	✓	✓	✓
Water and changes in state	✓	✓	✓
Conservation of water	✓	✓	✓
Separation techniques to ensure a sustainable source of potable water		✓	

Prior Knowledge

In Primary Science, you had learnt the following:

Topics: Diversity of materials, matter, water, three states of matter, heat, magnets and their characteristics

- Each material has its own properties, and we can identify materials based on their properties.
- The three states of matter are solid, liquid and gas. The state of matter can change during heating or cooling.
- Evaporation and condensation are processes that involve heat gain and heat loss respectively.
- A magnet attracts magnetic materials, such as nickel, iron, cobalt and steel.

4.1 Separation Techniques

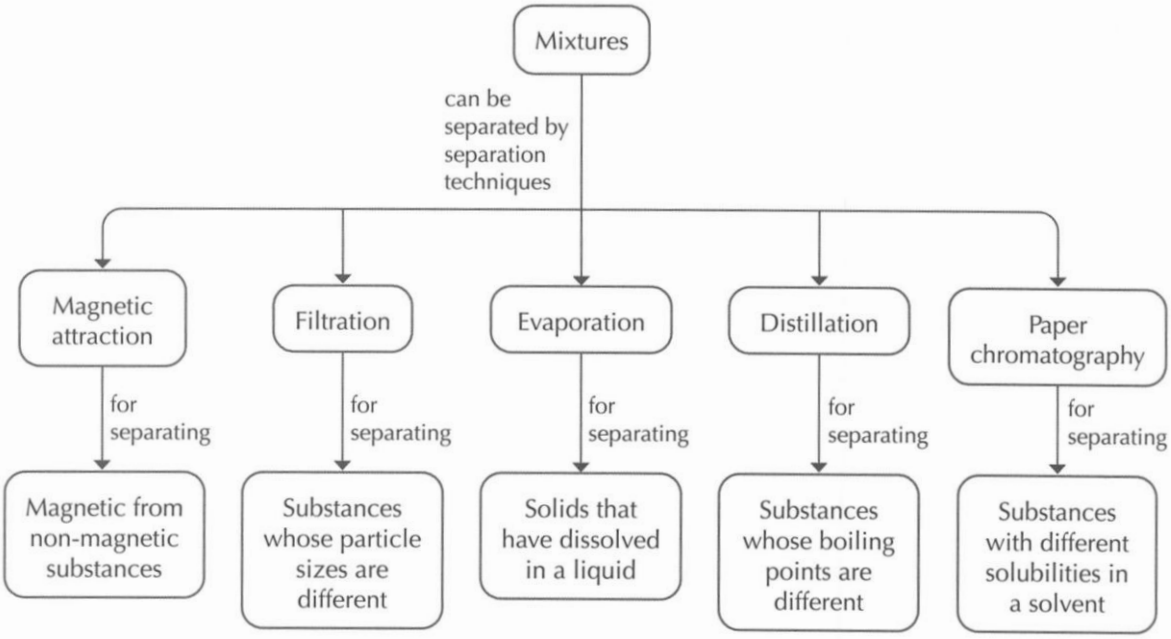
Learning Outcomes

You should be able to:

- understand the principles behind the separation techniques: magnetic attraction, filtration, evaporation, distillation and paper chromatography
- describe how the constituents of a mixture can be separated based on their properties, using the separation techniques: magnetic attraction, filtration, evaporation, distillation and paper chromatography
- state examples of the applications of separation techniques in everyday life and in the industries such as in water treatment (i.e., distillation or *reverse osmosis of sea water in desalination plants, and filtration and *reverse osmosis of treated used water), food safety and waste management

Choosing a Suitable Separation Technique

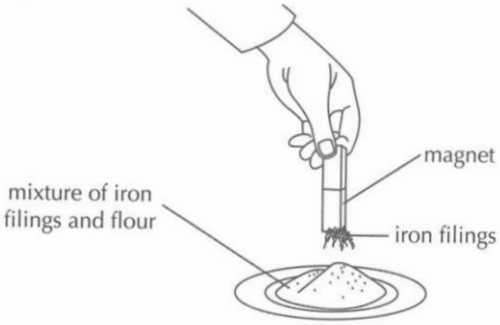
- A mixture consists of at least two constituents, which can be solid, liquid or gas.
- We purify substances so that we can study the properties of a particular constituent in the mixture, or remove impurities in food and drugs for our safety.
- The different substances in mixtures are usually easily separated from one another by physical methods.
- To choose the most suitable separation technique for a particular mixture, the following should be considered:
  - the differences in properties of the constituents of the mixture;
  - the cost;
  - its reliability; and
  - its impact on the environment.
- The physical methods of separation for the different types of mixtures are as shown:



* denotes "Optional for N(A)"

Magnetic Attraction

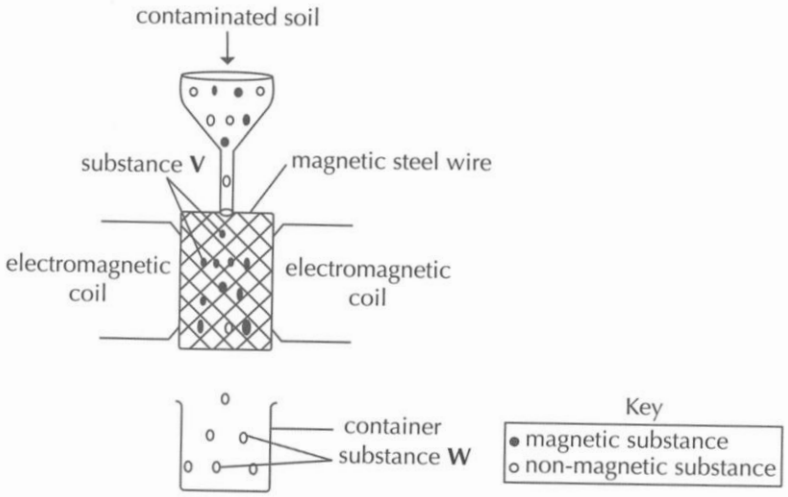
- In this method, a magnet is used to separate magnetic substances from non-magnetic substances.
- Examples of magnetic substances include nickel, iron, cobalt and steel.
- For example, we can use a magnet to separate a mixture of iron filings and flour. The iron filings are attracted to the magnet and can be removed from the mixture, leaving the flour behind.



- Here are some applications of magnetic attraction:
  - **(a)** Recovery of iron and steel
    - Iron and steel are recovered from junkyards and recycled.
    - This helps to preserve precious natural resources such as iron ores which are limited.
    - Recycling metals also requires less energy than mining new metals from metal ores.
  - **(b)** Food processing
    - Magnetic separators filter magnetic contaminants from food products.

Worked Example 1

When the electromagnetic coils are turned on, substance **V** is attracted to the magnetic steel wire. Substance **W** passes through the magnetic steel wire and is collected in a container.



(a) State the physical property of substance **W**.

Answer

It is non-magnetic.

Tip

The electromagnetic coils behave as magnets. The magnetic steel wire becomes magnetised as it is in contact with the electromagnetic coils. It thus attracts magnetic substances such as substance **V**. Since substance **W** is not attracted to the magnetic steel wire, it is non-magnetic.

(b) Anuar conducted an experiment using this device to decontaminate a sample of wastewater. Will the water collected at the end of the experiment be safe to drink? Explain your answer.

Answer
No. This method removes magnetic substances from wastewater only. It does not remove other contaminants such as bacteria and viruses.

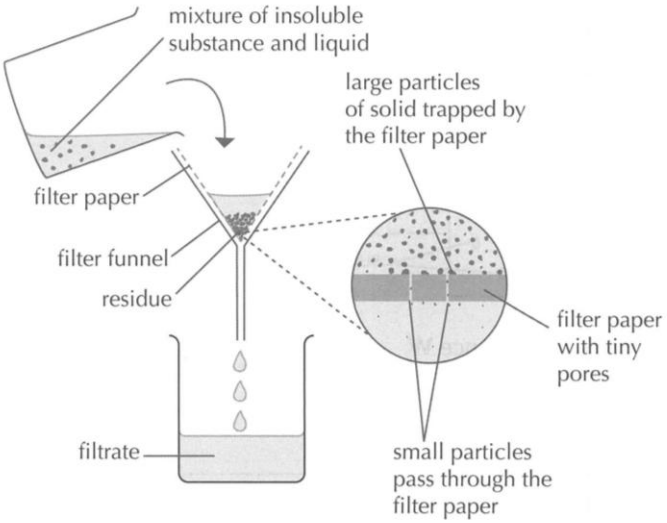
Tip
The diagram on page 71 shows a magnetic separator. It is commonly used to decontaminate soils and wastewater. Magnetic attraction is a physical separation technique that sorts materials based on their magnetic properties.

Filtration

- Filtration is used to separate substances of different particle sizes with the help of a sieve.
- In the laboratory, filtration is used to separate an insoluble substance from a liquid with the help of a filter paper.
- A filter paper has tiny pores. Particles that are smaller than the pores of the filter paper pass through and collect as a filtrate.
- The insoluble substance with particles larger than the pores of the filter paper collects as a residue on the filter paper.

Tip
A soluble substance is able to dissolve in a solvent to form a solution. An insoluble substance does not dissolve in a solvent even after stirring.

- For example, filtration can be used to separate a mixture of sand (insoluble substance) and water (liquid). Sand is collected as the residue on the filter paper. Water flows through the filter paper and is collected as the filtrate.



- Here are some applications of filtration:
  (a) Coffee filters are used to trap and remove coffee grounds from coffee.
  (b) In water treatment plants, filters are used to remove solid impurities from water.
  (c) In air conditioners, filters remove dirt and dust from the air.
  (d) In N95 respirator/masks, filters remove airborne particles from the air.

Worked Example 2

Some copper carbonate was accidentally spilled into a beaker of water. Copper carbonate is insoluble in water. Suggest a separation technique to separate copper carbonate from water.

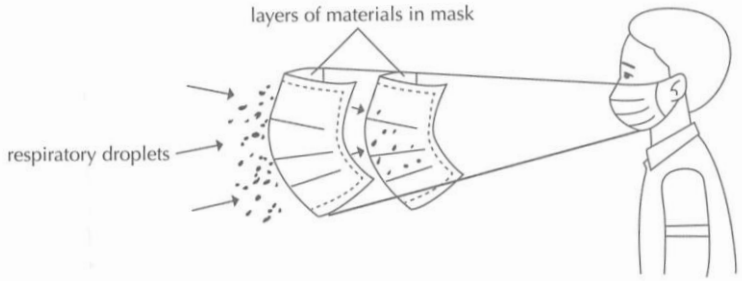
Answer
Filtration

Tip
Filtration can be used to separate an insoluble solid from a liquid mixture. Since copper carbonate is insoluble in water, it will be collected as a residue on the filter paper during filtration. Water will pass through the filter paper and collect as a filtrate.

Worked Example 3

Researchers around the world have shown that wearing masks can significantly reduce the spread of COVID-19 (Coronavirus Disease 2019) caused by SARS-CoV-2 virus. SARS-CoV-2 virus can be transmitted between people when someone breathes in the droplets produced by an infected person when he or she talks, sneezes or coughs. These respiratory droplets are more than 5–10 micrometres in diameter.
*(**Note:** 1 micrometre = 1 micron = 0.0001 centimetre)*

Masks provide an important barrier against respiratory droplets that may infect others when someone speaks, sneezes or coughs.



(a) State the separation technique applied in masks to act as a barrier against respiratory droplets.

Answer
Filtration

Tip
Filtration is a process that separates substances of different particle sizes with the help of a sieve. A mask acts as a sieve in this case. The respiratory droplets in the air are physically blocked by the layers of materials that make up the mask, allowing only air to enter the respiratory system through the nose.

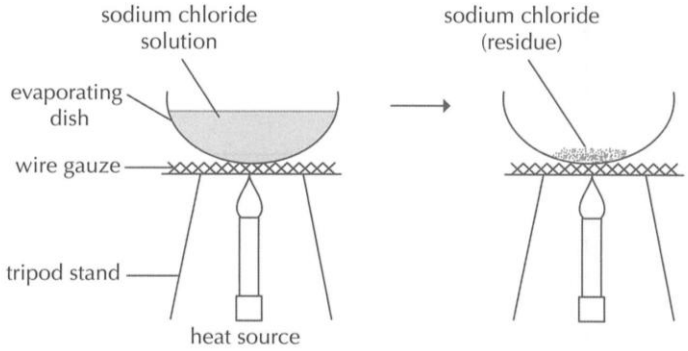
(b) Based on the information given above, suggest how a mask should be made to effectively protect the wearer against the spread of COVID-19 through droplet transmission.

Answer
The respiratory droplets are around 5 to 10 micrometres in diameter. Masks should have pore sizes smaller than the size of the respiratory droplets to effectively filter them from the air breathed in. This will prevent the virus in the respiratory droplets from entering the body.

Tip
The pore sizes of the respiratory droplets and the layers of materials must be considered in making masks.

Evaporation

- Evaporation is used to separate a soluble substance (solute) from a liquid (solvent).
- The solvent has a lower boiling point than the solute. Hence, the liquid changes into gaseous state at a lower temperature than the solute.
- When all the solvent evaporates, the solute that dissolved will be left behind as a residue.
- For example, when a solution of sodium chloride is heated in an evaporating dish, the liquid evaporates and solid salt is left behind as the residue.



- Here are some applications of evaporation:
  (a) In salt pans, seawater is evaporated to obtain salt.
  (b) Dried fruits, herbs and spices are obtained by evaporating the water from the fresh products.
  (c) In pharmaceutical industry, evaporation is used to remove excess moisture from medicines.

Tip

Alcohol is a volatile liquid. This means that it can change quickly into the gaseous state at room temperature without heating. Alcohol is also flammable. Direct heating of alcohol in a test tube should be avoided. A water bath should be used. This applies to any flammable solvent, such as ethanol. If a soluble solid is not heat-stable, such as sugar, it will decompose easily with strong heating.

Worked Example 4

You are given a solid mixture of sea salt, sand and iron filings. Outline the steps needed to separate each constituent from the mixture.

Tip

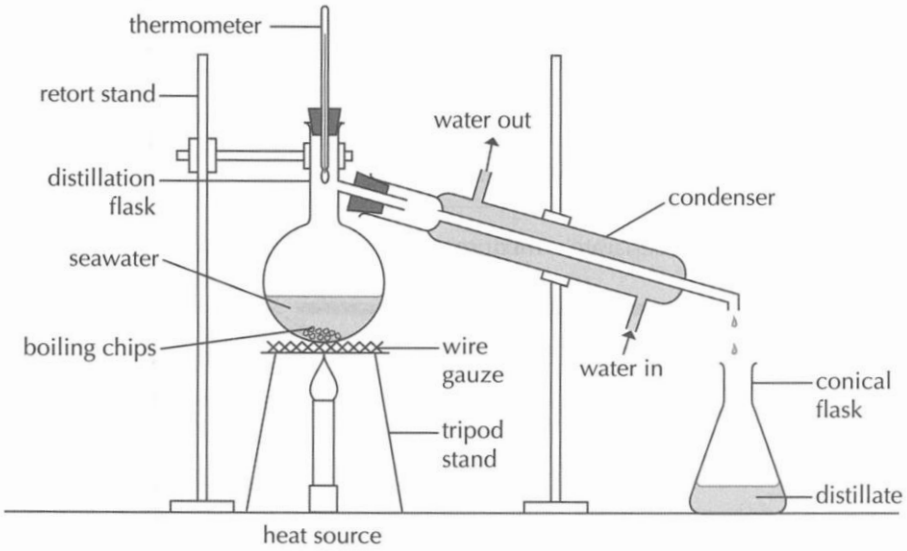
Identify the properties of each constituent of the mixture. Then, identify the separation technique to use.

Answer

Step 1: Iron filings are magnetic. A magnet can be used to separate the iron filings from the mixture.
Step 2: Sea salt is soluble in water while sand is not. The mixture of sea salt and sand is mixed with water and stirred. Sea salt dissolves in water to form a salt solution.
Step 3: Sand is larger than the pores of the filter paper. The insoluble sand can be collected as a residue by filtration. The salt solution is collected as a filtrate.
Step 4: Sea salt is heat-stable. The salt solution can be heated to remove water by evaporation.

Distillation

- Distillation is used to separate a pure liquid from a mixture.
- Distillation involves evaporation and condensation.
- The boiling point of the liquid is usually very much lower than that of the dissolved solid.
- The temperature of the liquid remains constant at the boiling point until all the liquid has vapourised.



Steps:

- Place the mixture of seawater in the distillation flask containing some boiling chips. The boiling chips ensure that the liquid boils without bumping.
- Heat the mixture until the temperature reaches the boiling point of water.
- Place the bulb of a thermometer at the opening of the arm of the distillation flask to measure the boiling point of the vapour distilled.
- At the boiling point of water, water vapour leaves the distillation flask and passes through the condenser where it is cooled.
- Collect the condensed liquid in the conical flask as the distillate.

- Here are some applications of distillation:
  (a) To obtain pure distilled water from seawater
  (b) In making essential oils from plants

Tip

The condenser is cooled by a continuous flow of cooler water from the water tap. The hot vapour is condensed as it passes down the water-cooled condenser. It is then collected as the distillate in the conical flask. The direction of water entering the condenser is hence important. Water enters from the bottom of the condenser and leaves from the top to ensure an effective cooling system.

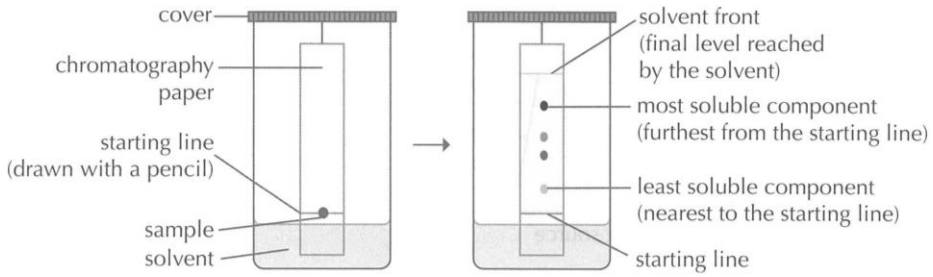
Chromatography

- This method can be used to separate small amounts of substances that are dissolved to different extents in a solvent.
- In paper chromatography, the solvent travels up a chromatography paper and substances that are more soluble in a solvent will travel further from the starting point than substances that are less soluble.
- A chromatogram showing the separated components of a mixture is obtained at the end.
- Many different solvents are used in chromatography. Water and ethanol (an organic solvent) are common solvents used.

Tip

Chromatography can be used to test the purity of a substance. If a sample is pure, only one spot will be seen on the chromatogram when run with different solvents.

- Chromatography can be used to separate a mixture of different dyes in ink.



Steps:

- A drop of the sample is placed on the starting line drawn with a pencil.
- The chromatography paper is placed in the solvent with the starting line above the solvent level.
- As the solvent moves up the paper, the different components travel up the paper to different extents.

- Here are some applications of chromatography:
  (a) Chromatography can be used to identify permitted food colourings used in food dyes and food products.
  (b) It helps to identify the inks used in forged cheques.
  (c) It helps to detect the use of illegal drugs by athletes.

Enrichment

Forensic document examiners are often asked to prove the authenticity of documents. One of the tasks they have to carry out is to examine ink samples and prove whether they are similar or dissimilar. To do this, they separate ink samples into their components using thin-layer chromatography (TLC) and high-performance thin-layer chromatography (HPTLC) before analysing them. These methods provide more accurate quantitative measurements in a shorter time.

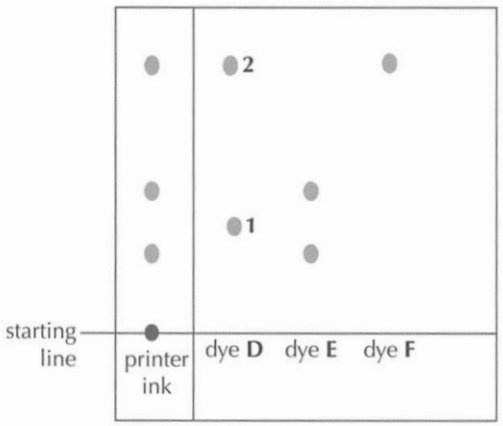
Tip

Chromatography is used to separate coloured substances, such as dyes, inks and pigments. It can also be used to separate colourless substances. Locating agents are then added to react with the colourless spots to form coloured products. The identities of the components in the mixture can then be determined by comparing against standard references. You will learn more about chromatography in Upper Secondary Chemistry.

Worked Example 5

Joseph used paper chromatography to analyse the ink from the printer ink cartridge together with three different dyes.

The diagram below shows the chromatogram which he obtained at the end of the experiment.



(a) Deduce whether the printer ink is a pure substance or a mixture. Explain your answer.

Tip
Recall the difference between a pure substance and a mixture. Count the number of spots the printer ink gives on the chromatogram. The number of spots indicates the number of substances present in the ink.

Answer
Mixture. There is more than one spot on the chromatogram. This indicates that there is more than one substance present in the printer ink.

(b) Before carrying out the experiment, Joseph ensured that the starting line is above the solvent level. Explain why this was necessary.

Answer
To ensure that the samples to be analysed do not dissolve in the solvent

Tip
The solvent selected is able to dissolve the ink and will become contaminated with the sample. The resulting chromatogram will not be accurate.

(c) Which substance in dye **D** is more soluble in the solvent, substance **1** or substance **2**? Explain your answer.

Tip
Recall how the solubility of a substance in a solvent affects the distance travelled by the substance.

Answer
Substance **2**. The more soluble a substance is in the solvent, the longer the distance it travels. Since substance **2** travels further than substance **1**, it is more soluble.

(d) Explain why the starting line is drawn in pencil.

Answer
If the starting line is drawn in pen, the ink would dissolve in the solvent and affect the results.

Tip
The ink from the pen may smudge. The pencil lead is made mainly of graphite, which is insoluble in most solvents.

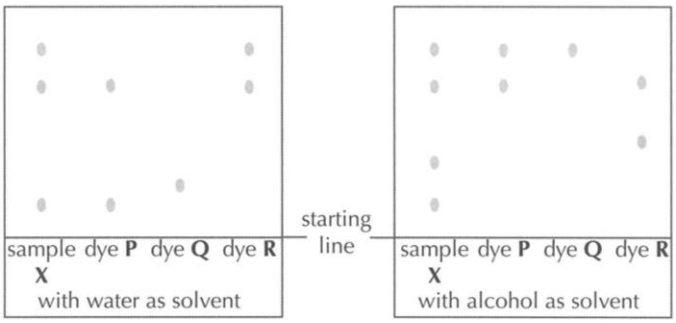
(e) Joseph repeated the experiment to analyse another type of ink, ink **Y**. However, no spots were obtained on the chromatogram. Explain the results obtained. Suggest how Joseph can modify the experiment in order to analyse ink **Y**.

Answer
Ink **Y** is insoluble in the solvent.
He should change the solvent to one which ink **Y** can dissolve in.

Tip
Chromatography depends on the solubility of the constituents in a given solvent. The sample spot will only separate if the constituents are soluble in that solvent.

Worked Example 6

Three dyes, **P**, **Q** and **R**, are suspected to be present in sample **X**. Chromatography experiments using two different solvents were carried out. The chromatograms are shown below.



(a) Which dye is found in sample **X**?

Answer
Dye **P**

Tip
Only dye **P** matched exactly to the spots of sample **X** in both chromatograms.

(b) Explain why different results were obtained with different solvents.

Answer
A solute will dissolve to different extents in different solvents.

Tip
The same solute has different solubilities in water and in alcohol. Hence, it will move at different rates when separated using different solvents.

(c) Three components were observed on the chromatogram for sample **X** when water was used as the solvent. Four components were observed on the chromatogram when alcohol was used. Explain this observation.

Answer

One component in sample **X** is insoluble in water, but soluble in alcohol. Hence, it dissolved in alcohol and moved up the chromatography paper.

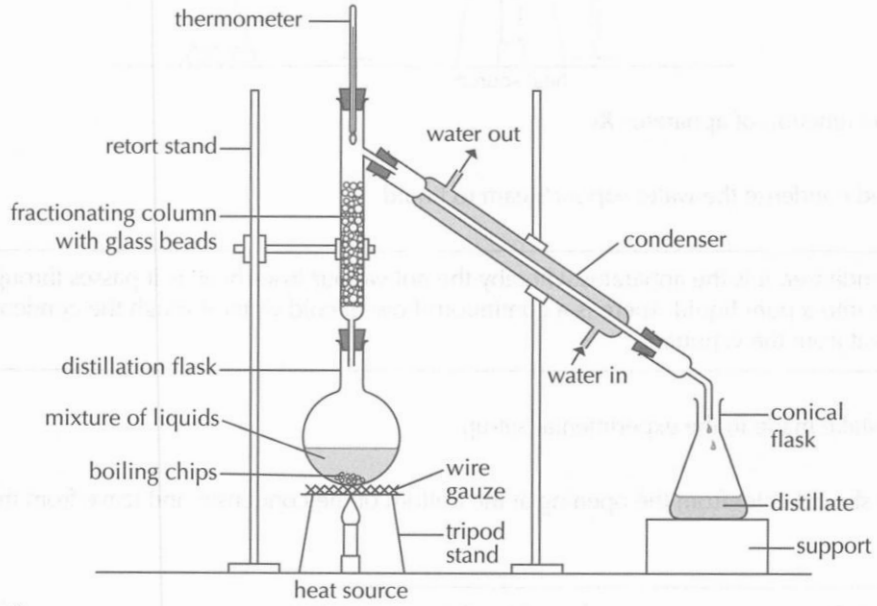
Tip

Different solvents will dissolve different substances.

Enrichment

Fractional Distillation

- Fractional distillation is used to separate and obtain a pure liquid from a liquid mixture.
- The mixture consists of two or more liquids with different boiling points.
- The substance with the lowest boiling point will gain heat and evaporate from the solution first. It will also condense to form a pure liquid first.
- A fractionating column, usually packed with glass beads, is used. The glass beads in the column provide a larger surface area for condensation.
- Evaporation and condensation occur many times as the vapour passes through the fractionating column.
- Hence, a longer fractionating column will allow the separation of different liquids more efficiently.



Steps:

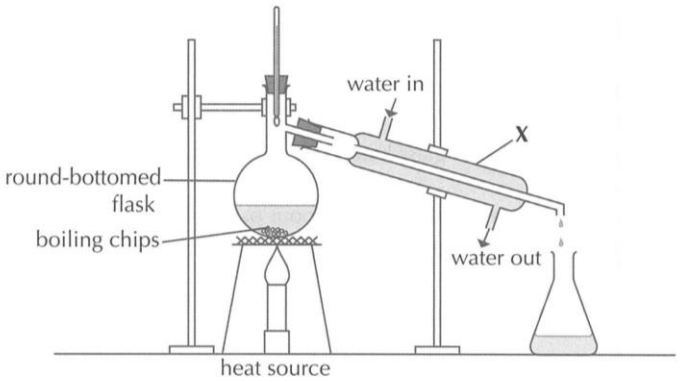
- Place the mixture of ethanol and water in the distillation flask containing some boiling chips.
- Heat the mixture until ethanol boils (78 °C).
- Ethanol vapour leaves the distillation flask, enters the fractionating column and is cooled in the condenser.
- Ethanol condenses and is collected in the conical flask as distillate.
- The temperature stays at 78 °C until all ethanol has distilled over. The temperature on the thermometer will then rise to 100 °C and water is distilled.
- Collect the two liquid fractions separately.

- Here are some applications of distillation:
  (a) When petroleum or crude oil is distilled, the various fractions can be obtained.
  (b) From liquid air, distillation can be carried out to obtain the different gas components.
  (c) Distillation is used to concentrate ethanol after fermentation from beer.

Tip
Distillation is used to obtain the pure liquid from a mixture of a solid and a liquid. Fractional distillation is used to separate a mixture of two or more liquids with different boiling points.

Worked Example 7

Joseph sets up the apparatus shown below to obtain water from grape juice.



(a) What is the function of apparatus **X**?

Answer
To cool and condense the water vapour/steam to liquid

Tip
X is the condenser. It is the apparatus whereby the hot vapour loses heat as it passes through and condenses into a pure liquid. There is a continuous flow of cold water through the condenser to remove heat from the vapour.

(b) State a mistake made in the experimental set-up.

Answer
The water should enter from the opening at the bottom of the condenser and leave from the opening at the top.

Tip
This is to enable more effective condensation of the vapour.

(c) Suggest why this separation technique may not work if we want to obtain sugar from a mixture of sugar solution.

Tip
This method involves direct heating. Recall that sugar is not heat-stable.

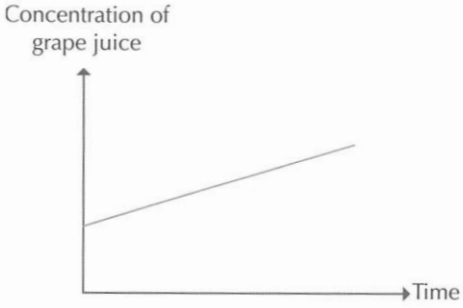
Answer
Sugar will decompose when heated directly.

(d) Sketch a graph to show how the concentration of the grape juice in the round-bottomed flask changes with time.

Tip

Consider how the concentration of the grape juice will change when the juice is heated and water changes into water vapour.

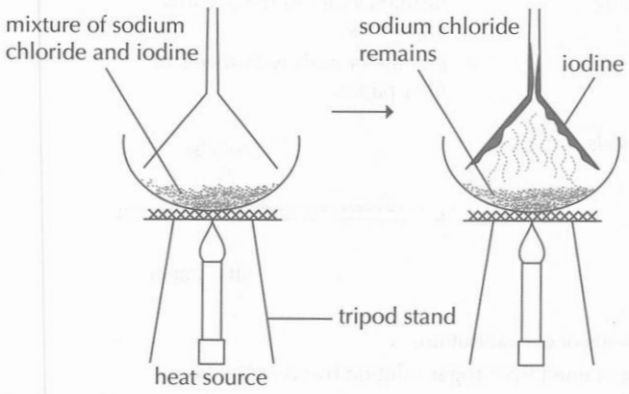
Answer



Enrichment

Sublimation

- Sublimation is the process in which a solid changes directly into a gas without becoming a liquid.
- This method is used to separate a solid substance that sublimes from those that do not.
- Substances that go through sublimation include iodine and dry ice (carbon dioxide).
- To separate sodium chloride from iodine, for example, heat the mixture as shown in the diagram.
- On warming, iodine sublimes and produces a violet vapour that solidifies on the cooler part of the funnel.



- A pure solid sublimes at a fixed temperature.
- Here are some examples of sublimation:
  - **(a)** Dry ice, which is solid carbon dioxide, sublimes.
  - **(b)** Napthalene balls, better known as moth balls, sublime.

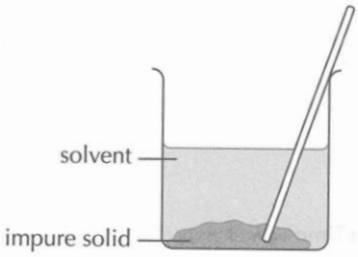
Enrichment

Crystallisation

- This method is used to separate a soluble solid from its solution. The soluble solid usually decomposes easily upon heating.
- The steps outline how crystallisation is carried out in a laboratory.

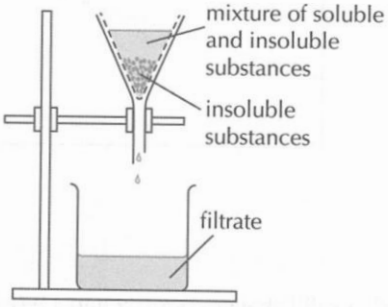
Step 1:

- Stir to dissolve the impure solid in the solvent.



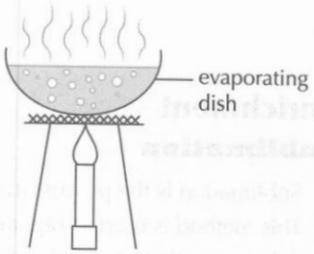
Step 2:

- Filter the solution to remove any insoluble substances.
- The soluble solid that has dissolved in the solvent to form a solution collects as a filtrate.



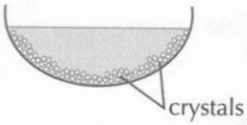
Step 3:

- The solubility of a solid increases with increasing temperature.
- Heat the solution until it is saturated.
- A saturated solution is formed when no more solute can dissolve at that temperature.



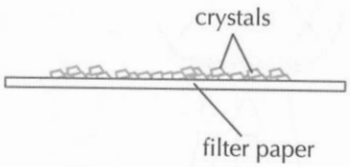
Step 4:

- Cool the hot saturated solution.
- Pure crystals of the soluble solid will form upon cooling.



Step 5:

- Filter to collect the crystals.
- Rinse the crystals with cold, distilled water to remove any impurities.
- Dry the crystals with sheets of filter paper.



- Here are some applications of crystallisation:
  - **(a)** Pure sugar can be obtained from sugar solution by crystallisation.
  - **(b)** In the pharmaceutical industry, pure active ingredients can be obtained by crystallisation.
  - **(c)** Crystallisation can be used to obtain silicon crystals used in computer microchips.

4.2 Applications of Separation Techniques to Obtain Potable Water in Singapore

Learning Outcomes

You should be able to:

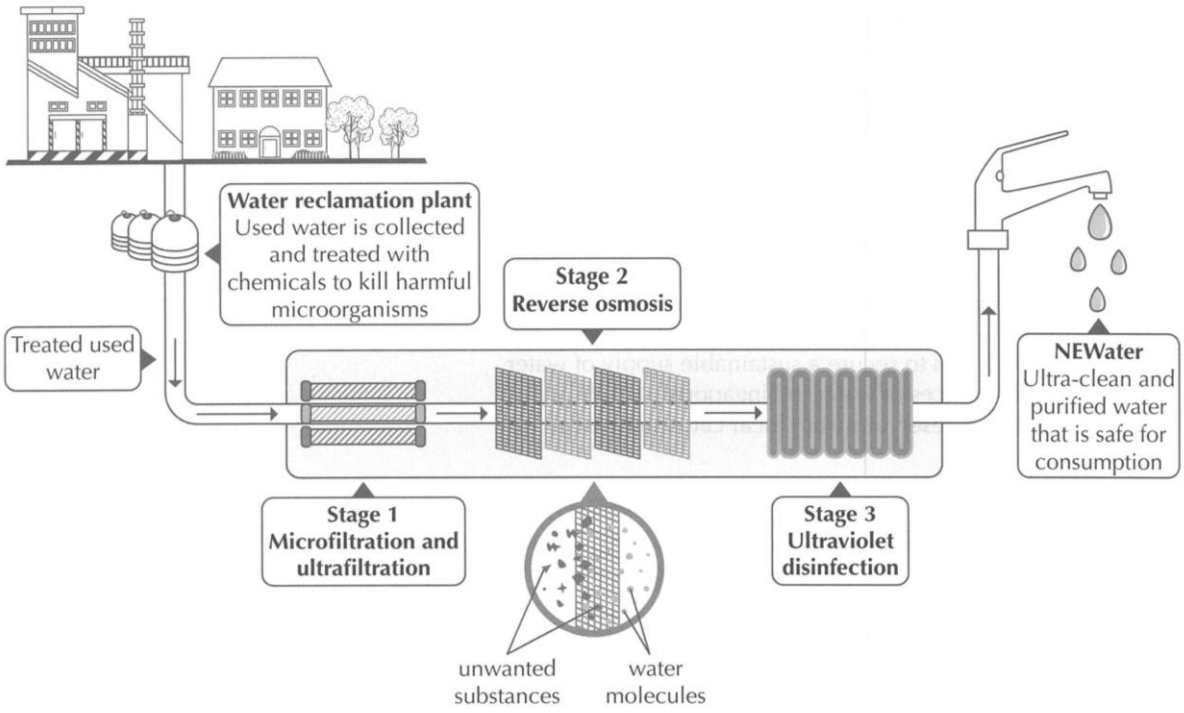
- appreciate that water is a precious national resource and understand why we need to conserve it
- appreciate how Singapore uses separation techniques to ensure a sustainable source of drinking water

Singapore's Water Sources

- Water is a precious resource.
- We need water to live, for industrial use, in the home and in activities such as swimming.
- In Singapore, water supply is limited. This is because there is limited land set aside for collecting and storing the water that we need.
- It is important for us to secure a sustainable supply of water.
- There are four sources of water in Singapore:
  - water stored in reservoirs from local catchment areas
  - imported water
  - NEWater
  - desalinated water
- Water from seawater, rivers, lakes and groundwater is non-potable water.
- Separation techniques are used to obtain drinking water from non-potable sources such as used water and seawater.
- Rainwater can be collected and treated to supply drinking water.
- The quality of our tap water is well within the World Health Organisation (WHO) Guidelines for drinking water quality. This means that it is safe to drink water directly from the tap without further processing.
- As the population and economy in Singapore continue to grow, the demand for water also increases. In order to ensure a continual supply of water, there is a need to conserve water.
- The water conservation methods in Singapore include:
  (a) applying the 3Rs (Reduce, Reuse and Recycle); and
  (b) encouraging the purchase of water efficient appliances and equipment for use in the home and workplace.

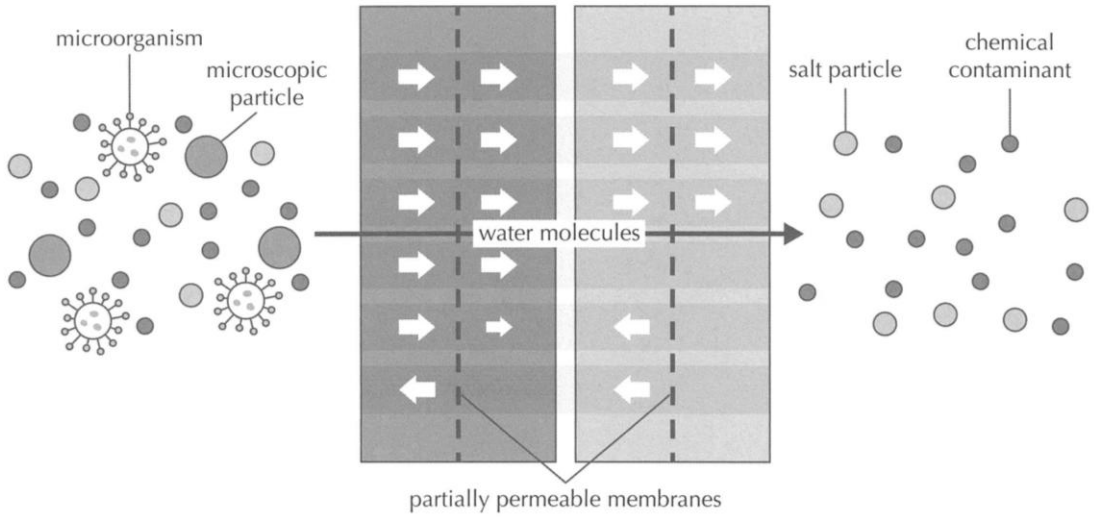
Obtaining Drinking Water From Used Water

- The NEWater process in Singapore recycles used water to ultra-clean, high-grade recycled water.
- A summary of how NEWater is produced is shown in the flow-chart below. Stages 1 and 2 involve separation techniques.



Stage 1: Microfiltration / Ultrafiltration

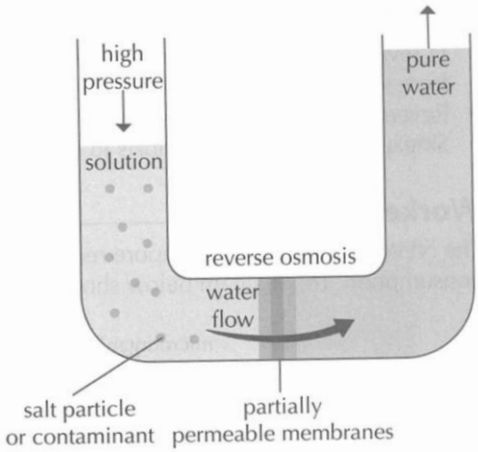
- Microfiltration removes small particles from the treated used water, with the help of a partially permeable membrane.
- Ultrafiltration further removes microscopic particles, bacteria and viruses using a membrane with pore size smaller than that of the membrane used in microfiltration.



Optional for N(A)

Stage 2: Reverse Osmosis

- Reverse osmosis is a method to obtain pure water.
- An external pressure pushes the water molecules through a partially permeable membranes.
- The partially permeable membranes have very tiny pores.
- Microscopic particles such as bacteria, viruses and dissolved salts are not able to go through the membrane.
- At this stage, once the unwanted substances are removed, pure water is obtained.



Stage 3: Ultraviolet Disinfection

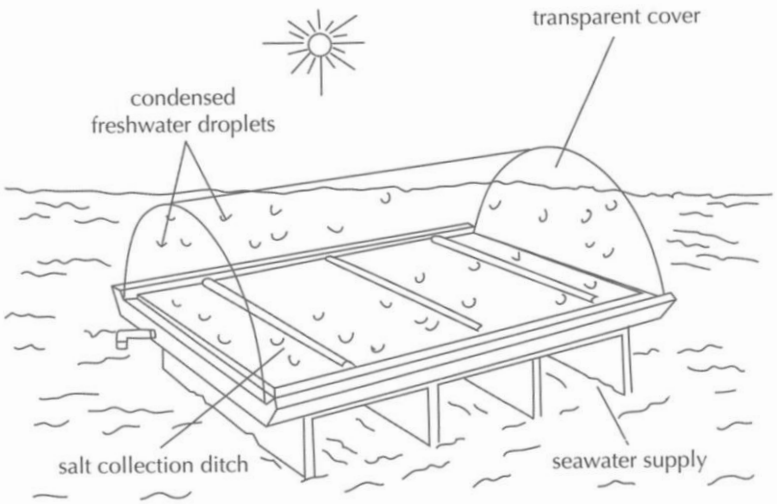
- After the reverse osmosis stage, the water is of a high quality.
- In stage 3, ultraviolet or UV disinfection is used to kill microorganisms including bacteria and viruses that may be in the water.
- This process is an additional safety measure to produce NEWater that is safe for consumption.

Obtaining Drinking Water From Seawater

- Seawater is non-potable as it contains a lot of salt.
- Seawater can be treated in a process called desalination.
- Desalination of seawater can be done using distillation or reverse osmosis to obtain pure water.

Desalination by Distillation

- Thermal water distillation is the oldest and most commonly used method of desalination.
- However, this method of obtaining seawater uses up a lot of energy and is not sustainable.
- Pure water is collected as the distillate.
- The saline water is heated to produce water vapour, which is then condensed to produce freshwater.
- A solar still is a device that utilises the evaporation–condensation technique to convert impure seawater into distilled water as shown in the diagram.
- In solar water distillation, heat from the Sun is used to evaporate the water so that it can be cooled, collected and purified.

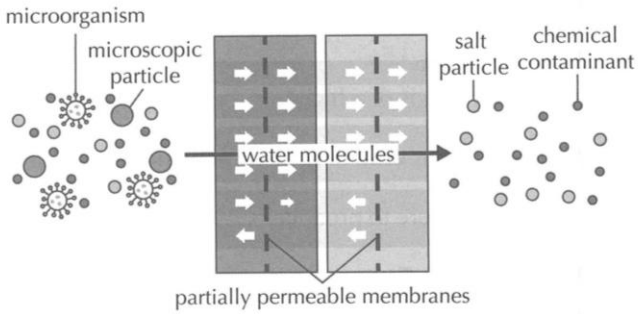


Desalination by Reverse Osmosis

- In reverse osmosis, partially permeable membranes and high pressure are used to separate salt from water.
- Reverse osmosis technology uses less energy than thermal distillation of seawater.
- Singapore uses reverse osmosis to desalinate and get pure water.

Worked Example 8

The NEWater process in Singapore recycles our treated used water into ultra-clean water that is safe for consumption. The diagram below shows one of the main stages in the production of NEWater in Singapore.



(a) State the separation technique used to produce NEWater shown in the diagram above.

Answer
Filtration

Tip
Microfiltration and ultrafiltration are both membrane filtration processes. The membranes sieve out the impurities that are bigger than their pore sizes.

(b) Explain how this separation technique helps to remove contaminants from the water.

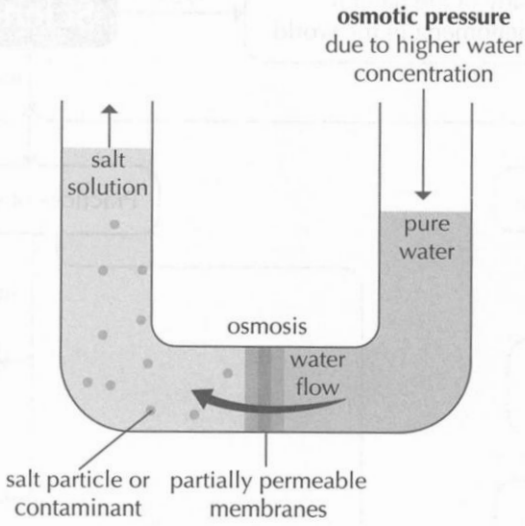
Tip
Consider the principle of the separation technique.

Answer
Contaminants are larger than the pore size of the partially permeable membranes, allowing only the smaller water molecules to pass through.

Enrichment

Osmosis

- To understand how reverse osmosis works, we must first understand how osmosis works.
- Refer to the set-up on osmosis in the diagram. Pure water is on the right side of the tube and contaminated water/ salt solution is on the left side of the tube.



- There is a higher concentration of water molecules in the pure water than the contaminated water. Hence, the side with a higher water concentration also has a higher osmotic pressure.
- Water moves from a region of higher water concentration to a region of lower water concentration through the partially permeable membrane by osmosis.

Tip

Diffusion is the net movement of particles from a region of higher concentration (i.e., more solute particles per unit volume of the solution) to a region of lower concentration. However, osmosis focuses on the movement of water molecules through a partially permeable membrane. We will discuss more on these two processes in the theme Models in Revision Guide 1B.