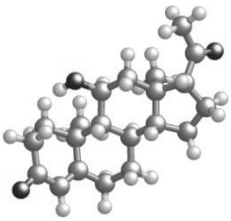


Sc!ence

Name: …… **( )**

Class: ……

Date: …… **/** …… **/** ……

Purification and Separation Techniques – Change and Systems – Answers

Introduction:

Many things in the world around us are mixtures. Some mixtures are useful and can be used as they are. Other mixtures are problematic or harmful if they are used directly, and the desired component of the mixture must be separated before it can be used for a specific purpose. In this unit, you will study…

- How scientists identify mixtures.
- How scientists decide the best way to separate a specific mixture.
- The different separation techniques that are available, and the principles by which they work.
- How scientists decide whether a substance is pure.
- Applications of purification and separation techniques in our everyday lives.

Conceptual Lenses: Change and Systems

- What do you understand about the concept of *change*? Think about examples of changes in the world around you and write down your ideas.
  Change is inevitable. Change occurs as things become different over time. Change can be positive (good) or negative (bad). Change can be planned or unexpected. Change can be linear or cyclic.

- What do you understand about the concept of *systems*? Think about examples of systems in the world around you and write down your ideas.
  Systems have elements that interact with each other to perform a function. Systems are composed of sub-systems. Systems may be influenced by other systems. Systems follow rules.

When the components of a mixture are separated, a *change* takes place to the composition of the mixture. This *change* can be considered to be reversible, since the components can be recombined to form the original mixture once again. The process used to separate the mixture is chosen based upon the properties of the components within the mixture. This process can be considered to be a *system*, since it is composed of several components which work together, following certain rules, to bring about the separation.

Guiding Questions:

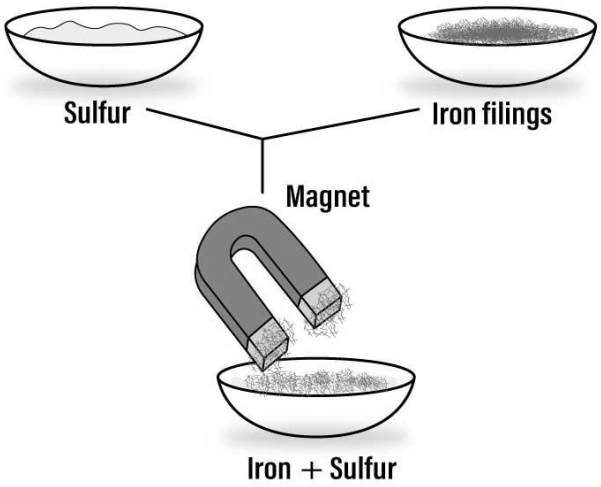
Some of these questions you may be able to answer now. Other questions you might only be able to give complete answers near the end of the unit.

1. What are the characteristics of a mixture? How do you recognise a mixture?
   A mixture has a variable composition. The components of a chemical mixture are not chemically combined together. A mixture has no fixed melting point or boiling point. The components of a mixture can be separated by a simple physical process (*e.g.* filtration). A mixture retains the properties of its individual components. A mixture maybe homogeneous or heterogeneous.
2. Why is it important to separate mixtures?
   In food (including drinking water) and medicine, mixtures may need to be separated to ensure that the final product is safe and effective. The components of a mixture may need to be separated from each other before they can be used correctly or before they can be identified.
3. How do we identify which component of a mixture is important?
   It is essential to know which component of a mixture is important, as this could influence the choice of separation technique that is used. The important component depends upon the application – *e.g.* in the pharmaceutical industry, the important component will be the active drug.
4. Which physical properties of a mixture allow us to choose the most appropriate separation technique?
   Different *particle size* (for filtration). Different *solubilities* in a solvent (for chromatography). Different *boiling points* (for distillation). Different *magnetic* properties (for magnetic attraction). *Volatility* – how readily a substance vaporises (for sublimation). Miscibility – how readily two liquids mix (for separating funnel).
5. Once a mixture has been separated, how do we know that the products are pure? What is purity? What are acceptable levels of purity?
   A pure substance has a *sharp* (fixed) *melting point* and a *sharp* (fixed) *boiling point*. *Chromatography* may also be used to determine the purity of a substance – a pure substance will give a *single spot* on a chromatogram. Acceptable levels of purity vary based upon the intended application – for food and drugs, all harmful chemicals should be separated / removed.
6. What are some important separation techniques that are relevant to our everyday lives?
   Filtration and distillation improve the purity and safety of drinking water. Magnetic attraction is used to separate materials at recycling plants. Fractional distillation is used to separate the components of crude oil into petrol, diesel and aviation fuel.
7. What would happen if separation techniques were *not* used in our everyday lives?
   Without separation and purification, everyday items such as food, water and medicine would be contaminated with potentially harmful chemicals – consuming these dangerous chemicals would lead to ill health. In addition, the environment would become more polluted and the quality and performance of manufactured products would be compromised.

• **Method One – Magnetic attraction:**

a) What type of mixture(s) can be separated by magnetic attraction?

A mixture in which one component is magnetic / can be magnetised, and the other component (or components) is not magnetic / cannot be magnetised.

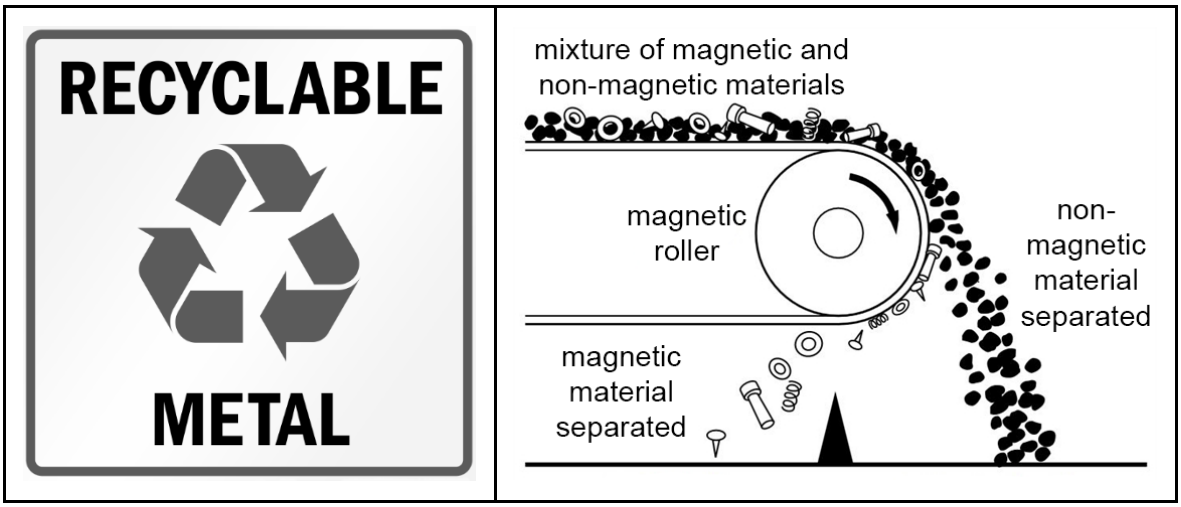


b) In the example given above, iron is a magnetic material and is attracted towards the magnet, while sulfur is not a magnetic material and is not attracted towards the magnet. Iron filings are attracted towards the magnet and separated from the sulfur which remains behind in the dish.

✓ **Quick Check on Magnetic Attraction:**

Explain how magnetic attraction is used to separate a mixture of different materials at a recycling plant.

Magnetic attraction is used to separate magnetic materials from non-magnetic materials in recycling plants. Magnetic materials such as iron, cobalt and nickel are attracted to strong electromagnets and separated into one container, while non-magnetic materials such as card, plastic and aluminium are not attracted to the magnet and fall into a separate container.

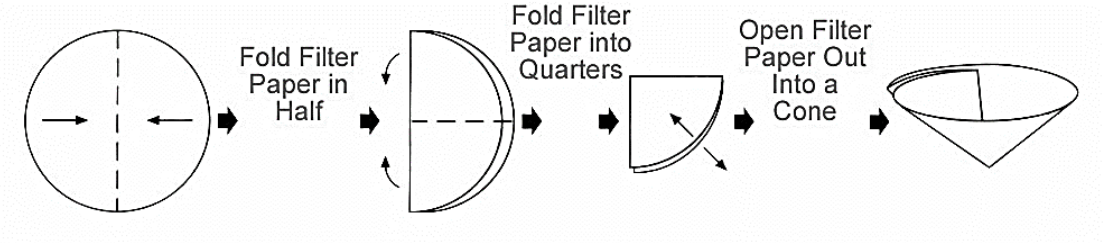


• **Method Two – Filtration:**

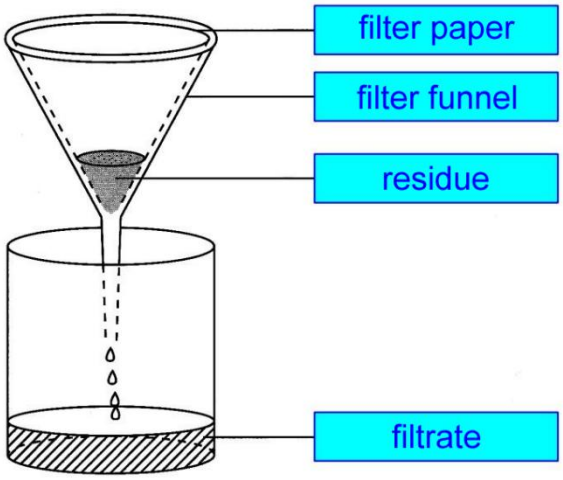
a) What type of mixture(s) can be separated by filtration?

Filtration separates the components of a mixture based upon a difference in the size of the particles. For example, grains of sand are too big to fit through a filter paper but the particles in a solution of table salt are small enough to fit through the filter paper, so the sand and the solution of table salt can be separated from each other.

b) A mixture of copper(II) sulfate (blue crystals which are soluble in water) and sand can be separated by filtration and crystallisation. A summary of the procedure is given in the diagram below.



Label the diagram of the filtration apparatus given below:



c) In the example given above, crystals of copper(II) sulfate are dissolved in water to form a blue solution. Sand is insoluble and does not dissolve in water. The mixture is poured into a filter funnel lined with filter paper. The small particles of copper(II) sulfate dissolved in water pass through small gaps in the filter paper, but the grains of sand are too large to pass through and get trapped in the filter paper. Sand is collected as the residue and the copper(II) sulfate solution is collected as the filtrate.

d) After the filtration is complete, what additional steps need to be taken to obtain a sample of *pure*, *dry* sand?

The sand must be washed with distilled water (to remove any copper(II) sulfate solution that might still be there) and then dried by pressing between layers of filter paper.

e) Give examples of how filtration is used to separate substances in our everyday lives.

- Filtration and distillation improve the purity and safety of drinking water.
- Surgical masks filter harmful particles from inhaled and exhaled air.
- Vacuum cleaner bags and filters in air conditioners remove dust from the air that passes through them.

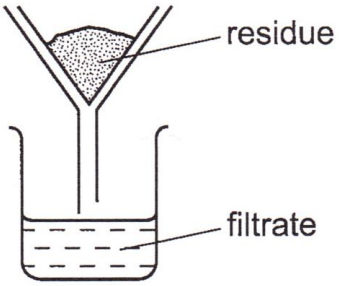
✓ **Quick Check on Filtration:**

The table shows the colours and solubilities in water of four solids.

solid	colour	solubility in water
W	blue	insoluble
X	blue	soluble
Y	white	insoluble
Z	white	soluble

A mixture containing two of the solids is added to excess water, stirred and filtered.

A blue filtrate and white residue are obtained.



Which solids are present in the mixture?

A **W** and **X** **B** **W** and **Y** **C** **X** and **Y** **D** **X** and **Z**

• **Method Three – Crystallisation:**

a) How can *crystals* of copper(II) sulfate be obtained from an aqueous solution of copper(II) sulfate efficiently?

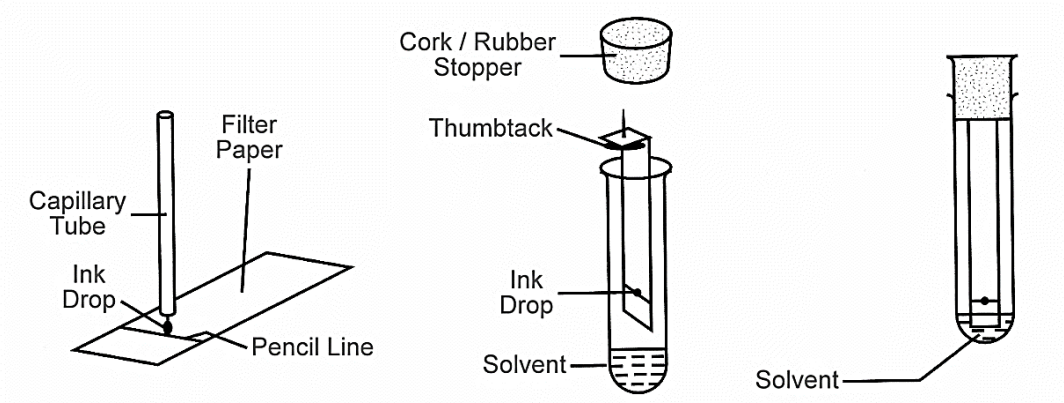
Heat the solution of copper(II) sulfate to boil away most of the water until the solution becomes *saturated*. Leave the saturated solution at room temperature for the rest of the water to evaporate, and blue crystals of copper(II) sulfate will be formed. Note: Do not heat to dryness (*i.e.* do not boil away all of the water) as the crystals may *decompose* if they are *thermally unstable*.	

• **Method Four – Chromatography:**

a) What type of mixture(s) can be separated by chromatography?

Chemicals that are soluble in the same solvent can be separated by chromatography, although their solubilities must be slightly different from each other. The chemicals in the mixture are often coloured, but this is not essential – colourless chemicals can also be separated by chromatography.

b) One possible way to separate a small mixture of chemicals that are often, but not necessarily, coloured is to use chromatography. The essential steps to perform chromatography are given below:



Chromatography works because the different solutes in the mixture have different solubilities in the same solvent. The solvent soaks into the filter paper and moves up the filter paper. Dyes in the ink dissolve in the solvent, but *different dyes have different solubilities*. A dye that is very soluble in the solvent will travel up the filter paper a greater distance than a dye that is less soluble in the solvent, hence the two different dyes will be separated from each other based upon their different solubilities in the solvent.

c) Explain how chromatography can be used to show whether a chemical is *pure*.

If a chemical is pure – *i.e.* it is only composed of one substance – then it will only produce a *single spot* on the filter paper at the end of the experiment. By comparison, a mixture will produce two-or-more spots on the filter paper, showing that there is more than one substance present.

d) Why must the starting line on the filter paper be drawn in *pencil*?

Pencil lead, or graphite, is insoluble in all solvents. It will not dissolve in the solvent used for the chromatography and will not travel up the filter paper. A line drawn in ink might dissolve in the solvent and travel up the filter paper – confusing the results.

e) Why is it essential for the ink drop be *above* the level of the solvent?

The ink drop must be above the level of the solvent in order to travel up the filter paper. If the ink drop is below the level of the solvent, then it will dissolve in the pool of solvent instead of travelling up the filter paper and being separated.

f) Why must the spot of ink be *small* and *concentrated*?

The ink must be concentrated so that the spots of dye are dark and easy to see – not faint. The spot of ink must be small so that as the spots of dye travel up the filter paper, they separate and do not overlap with each other.

g) Why should the solvent be allowed to travel as far up the filter paper as possible?

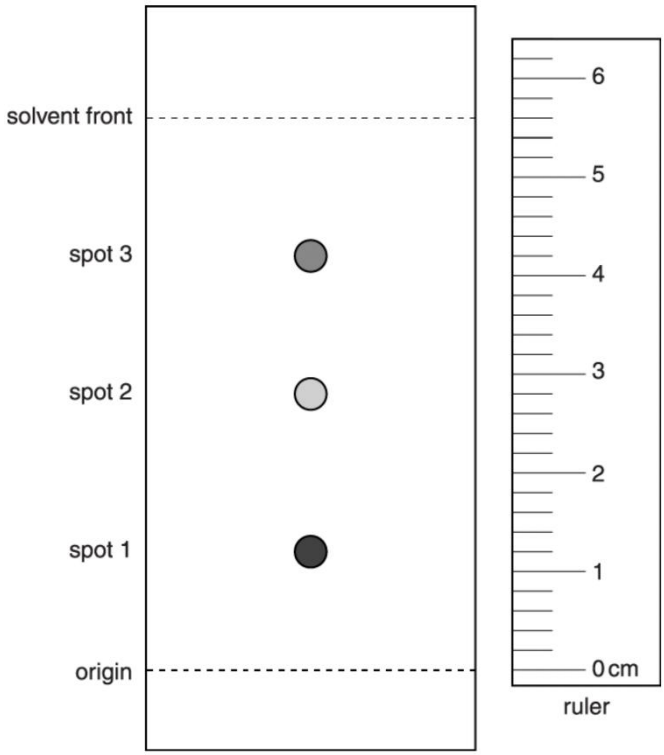
The further up the filter paper the solvent travels, the greater the separation between the chemicals in the mixture, and the less likely they are to overlap with each other. This makes identification of the chemicals in the mixture easier to do.

h) What additional step(s) must be taken when performing chromatography on a mixture of *colourless* chemicals?

Chemicals which are colourless can still be separated by chromatography, but they must be sprayed with a *locating agent*. The locating agent will react with the colourless chemicals making them coloured and visible to the naked eye.

i) Using the ruler provided in the question, calculate the R_f values of spot 2 and spot 3.

Which spot is *least* soluble in the solvent, and which spot is *most* soluble in the solvent?



R_f value of spot **2** = 2.8 ÷ 5.6 = 0.50

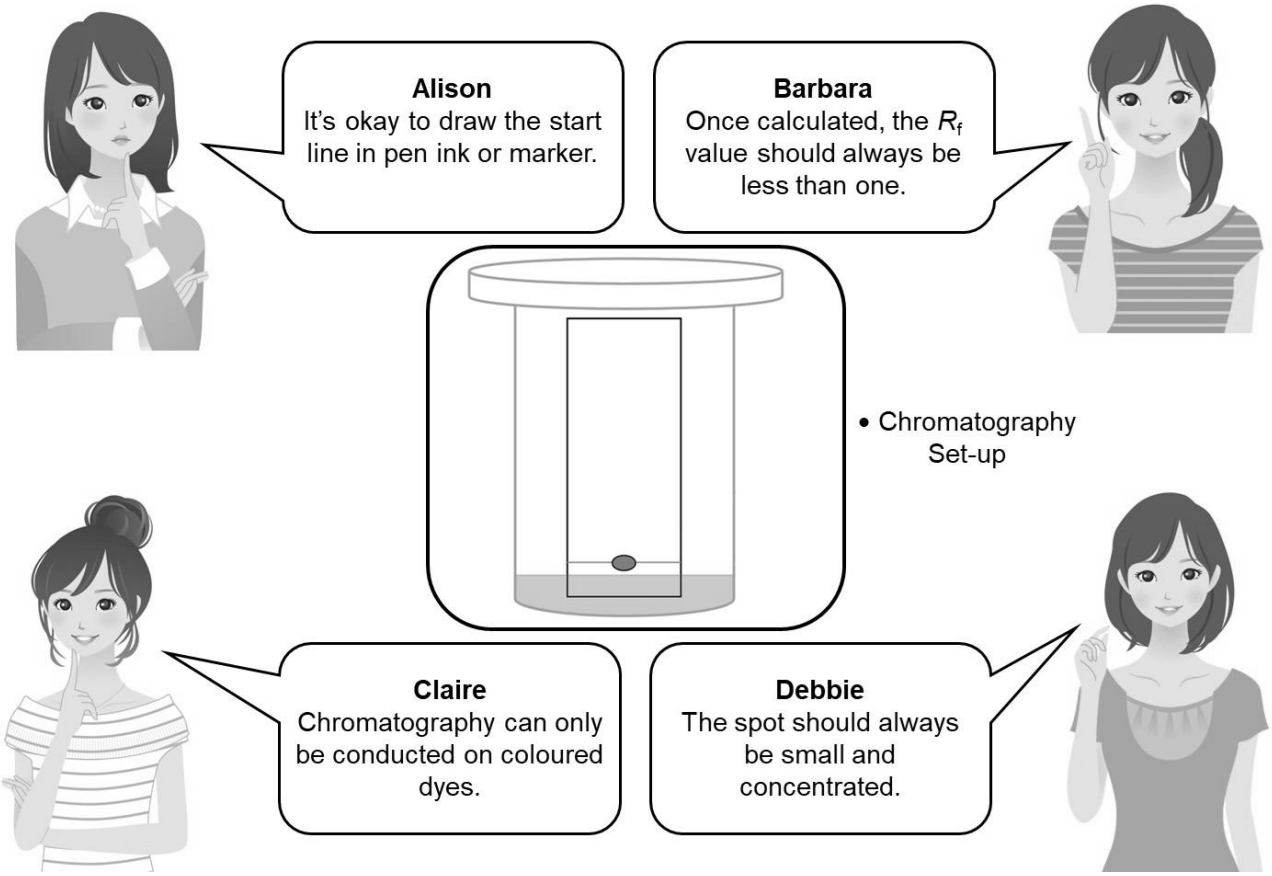
R_f value of spot **3** = 4.2 ÷ 5.6 = 0.75

Spot **1** is *least* soluble in the solvent while spot **3** is *most* soluble in the solvent.

✓ **Quick Check on Chromatography – Concept Cartoon #1:**

Four students are discussing the separation of a mixture using chromatography.

Their discussion is shown below.



- **Two** of the students have made **correct** statements about chromatography. Identify the two students and explain why their statements are correct.

  Student 1: Barbara

  Explanation: The R_f value is the distance travelled by the spot divided by the distance travelled by the solvent, and the solvent always travels further than the spot.

  Student 2: Debbie

  Explanation: This is so that the spots do not spread out too much as they travel up the chromatography paper and start to overlap with each other, making the results difficult to interpret.

- **Two** of the students have made **incorrect** statements about chromatography. Identify the two students and explain why their statements are incorrect.

  Student 1: Alison

  Explanation: Ink from the pen or marker might dissolve in the solvent and travel up the chromatography paper, interfering with and obscuring the results.

  Student 2: Claire

  Explanation: Chromatography can be conducted on chemicals that are colourless, but they must be sprayed with a locating agent to make them visible to the naked eye.

• **Method Five – Simple Distillation:**

a) **i)** What change in state is *boiling*?

Boiling is the change in state from liquid to gas.

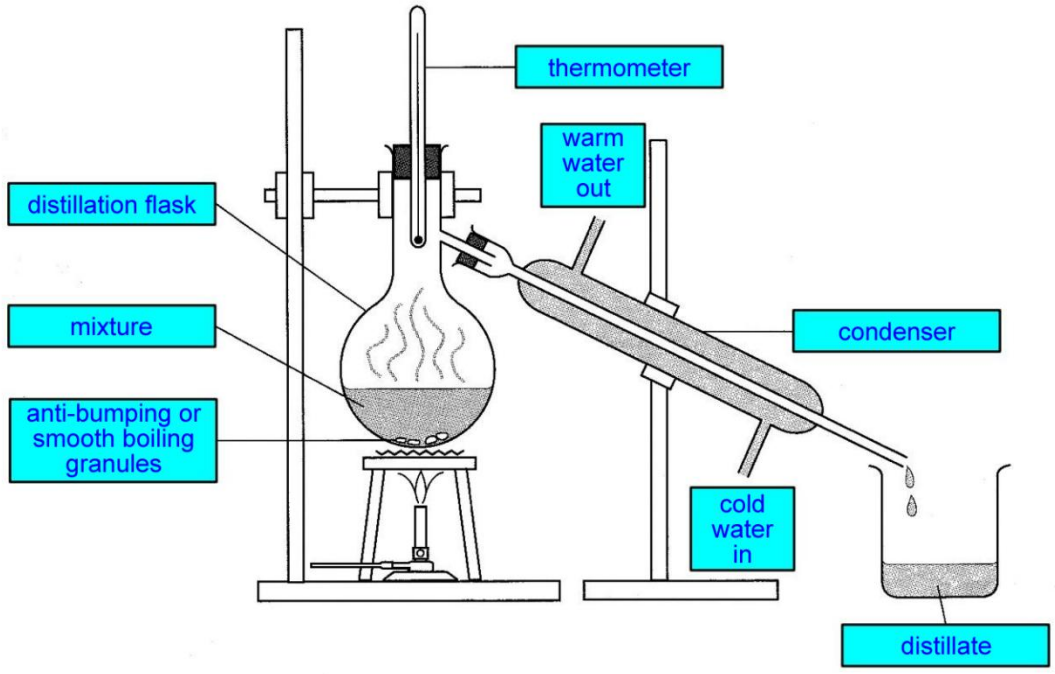
ii) What change in state is *condensation*?

Condensation is the change in state from gas to liquid.

b) What type of mixture(s) can be separated by simple distillation?

Chemicals with different boiling points can be separated by distillation. This could be two miscible liquids with different boiling points, or a solute and a solvent with different boiling points.

c) A mixture of ethanol (boiling point = 78°C) and water (boiling point = 100°C) can be separated by simple distillation. Label the diagram of the simple distillation apparatus given below:



d) In the example given above, the mixture of ethanol and water is heated. The ethanol has the lower boiling point (78°C), and so it will boil first, the water (100°C) remaining a liquid. The ethanol vapour rises upwards – some will condense on the bulb of the thermometer which will read 78 °C. The ethanol vapour enters the condenser, where it is cooled by the surrounding cold water, and condenses to a liquid. The liquid ethanol flows down the condenser and is collected in the beaker as the *distillate*. The water with a boiling point of 100 °C will remain as the *residue* in the flask, hence the two liquids are separated.

e) What is the role of the *smooth boiling granules* in the simple distillation apparatus?

Without the smooth boiling granules, a small number of large bubbles would form when the mixture in the flask boils. When these bubbles burst, the apparatus will shake. The smooth boiling granules allow many much smaller bubbles to form. When these smaller bubbles burst, the apparatus will not bump or shake.

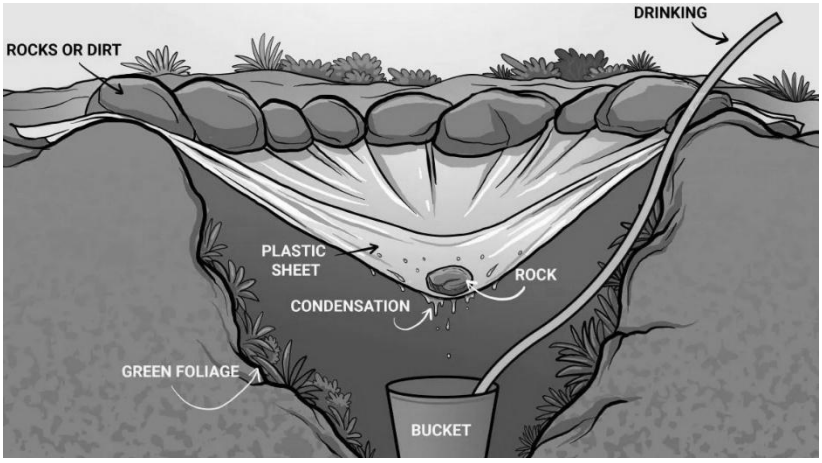
f) Pay careful attention to where the *thermometer* is located in the simple distillation apparatus. Why is the bulb of the thermometer placed at this exact location?

The bulb of the thermometer is placed at the point where the vapour enters the condenser, and so it measures the boiling point of the chemical that is being condensed and collected in the beaker – the *distillate*.

g) In which direction does the water flow through the *condenser*? Why is the direction in which the water flows through the condenser important?

Water flows into the condenser at the bottom and out of the condenser at the top. This allows for efficient cooling of the hot vapour, condensing it into a liquid in the shortest time.

h) The diagram below shows how drinking water can be obtained from impure water by a process known as *solar distillation*.



Briefly explain how solar distillation can be used to obtain drinking water from impure water in the ground.

Heat from the sun causes water from the soil and the green foliage to evaporate. This water vapour travels upwards and condenses on the cool plastic sheet. Drops of liquid water run down the plastic sheet to the centre, where it drips into the bucket. The bucket will contain pure water, as any high boiling point impurities should remain in the soil.

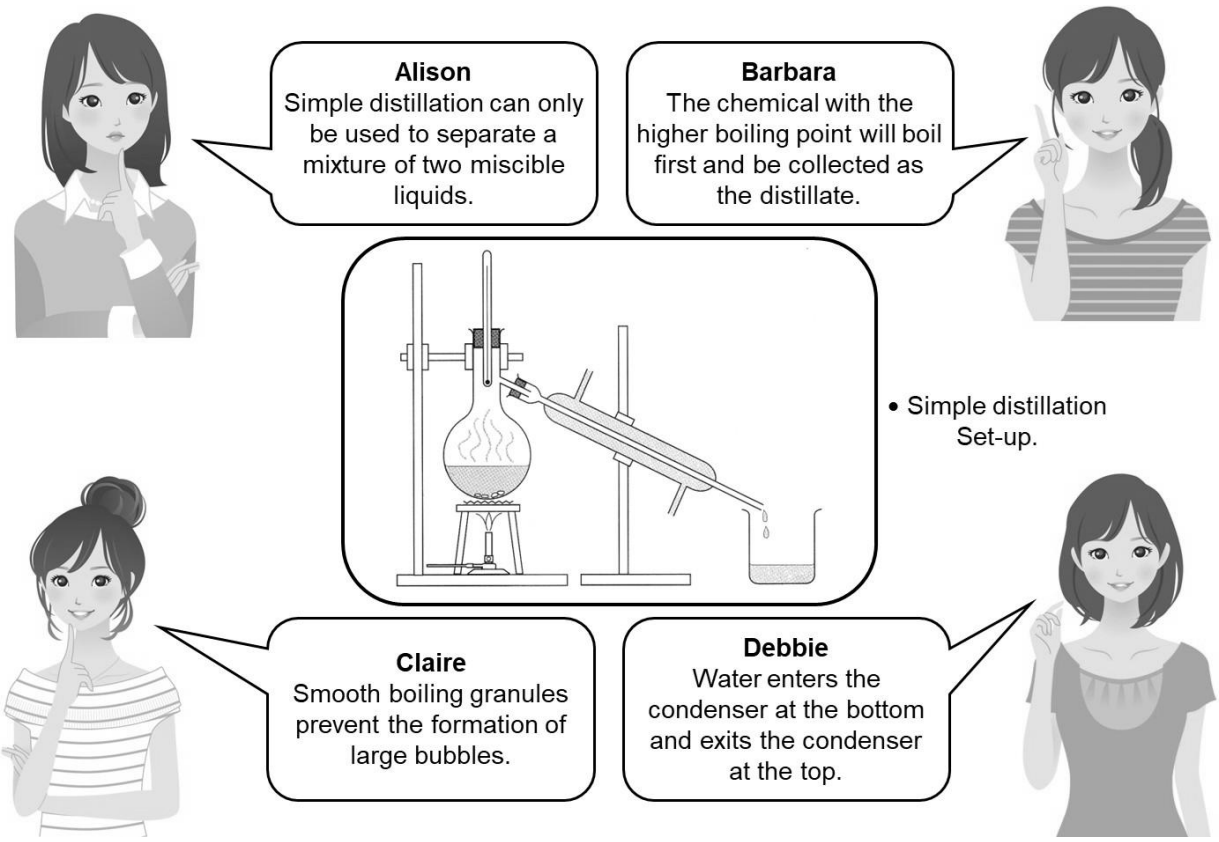
i) Give examples of how distillation is used to separate substances in our everyday lives.

Distillation is used to remove impurities from water so that it can be consumed or used in the manufacture of food. It is used to separate alcohol from water in the production of alcoholic drinks. It is used to extract essential oils from plants in the production of perfumes. Fractional distillation is used to separate petrol, diesel and aviation fuel from crude oil.

✓ **Quick Check on Simple Distillation – Concept Cartoon #2:**

Four students are discussing the separation of a mixture using simple distillation.

Their discussion is shown below.



- **Two** of the students have made **correct** statements about chromatography. Identify the two students and explain why their statements are correct.

  Student 1: Claire

  Explanation: The smooth boiling granules provide a large surface area for small bubbles to form on. When the small bubbles burst, they cause no harm to the apparatus.

  Student 2: Debbie

  Explanation: When cold water flows through the condenser from the bottom to the top, it flows in the opposite direction to the hot vapour, cooling the vapour efficiently.

- **Two** of the students have made **incorrect** statements about chromatography. Identify the two students and explain why their statements are incorrect.

  Student 1: Alison

  Explanation: Simple distillation can be used to separate a mixture of miscible liquids, and it can also be used to separate a solid solute (*e.g.* table salt) from the solvent (*e.g.* water) that it is dissolved in.

  Student 2: Barbara

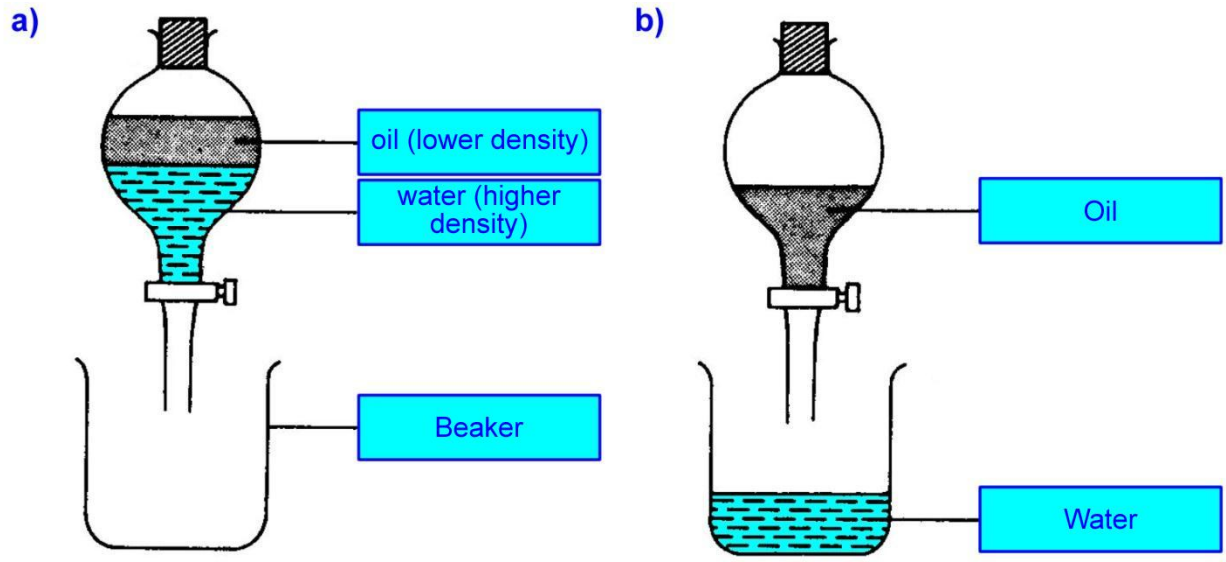
  Explanation: The chemical with the *lower* boiling point will boil first. For example, if there are three liquids in the mixture, boiling points 50°C, 70°C and 90°C, then the liquid that boils at 50°C will boil and be collected first.

• **Method Six – Separating Funnel:**

a) What type of mixture(s) can be separated using a separating funnel (tap funnel)?

A separating funnel or tap funnel is used to separate two *immiscible liquids* – liquids that do not mix together – such as oil and water. Note: *Miscible* liquids with different boiling points are separated by distillation.

b) A mixture of oil and water can be separated by using a separating funnel (tap funnel). A brief description of the procedure is given in the diagram below. Label the diagram below of the separating funnel experiment:



c) Oil and water are two immiscible liquids, *i.e.* they do not mix with each other. The less dense oil floats on the surface of the more dense water. The stopper is removed from the separating funnel, and then the tap is opened. Water (the bottom layer) will flow into the beaker. Just as the layer of oil reaches the tap, the tap is closed, leaving the water in the beaker and the oil in the separating funnel.

✓ **Quick Check on Separating Funnel:**

Study the following mixtures.

1 Olive oil and table salt.
2 Olive oil and water.
3 Water and alcohol.
4 Water and table salt.

Which mixture(s) can be separated using a tap funnel?

A 1 only **B** 2 only **C** 2 and 3 only **D** 3 and 4 only

• **Method Seven – Sublimation:**

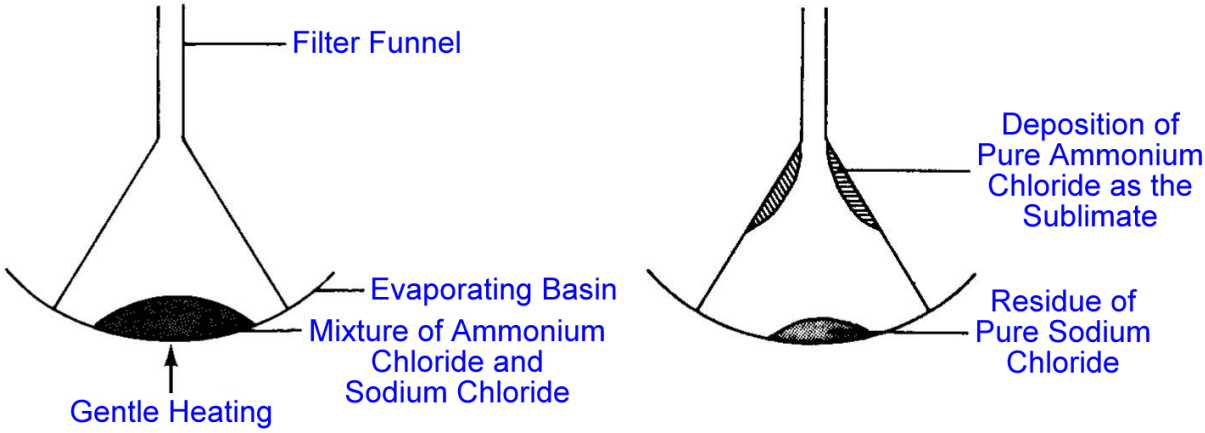
a) What change of state is sublimation?

Sublimation is the change in state from solid directly to gas.

b) What type of mixture(s) can be separated by sublimation?

Sublimation can be used to separate a volatile chemical which sublimes from another chemical or chemicals which does not sublime. For example, ammonium chloride – which sublimes – can be separated sodium chloride – which does not sublime.

c) A mixture of sodium chloride and ammonium chloride can be separated by sublimation. A brief description of how sublimation can be used to separate a mixture of sodium chloride and ammonium chloride is shown in the diagram below. Label the diagram to show how this separation can be accomplished.



d) The mixture of ammonium chloride and sodium chloride are heated gently (it might be advisable to heat the mixture gently over a water bath rather than heat directly over a Bunsen burner, as the non-luminous flame of the Bunsen burner might be too hot). The volatile ammonium chloride will sublime – change directly from solid to gas – while the solid sodium chloride will remain unchanged in the dish. When the ammonium chloride vapour comes into contact with the cold filter funnel, it will change from a gas back to a solid again (this is called *deposition*) hence the ammonium chloride and sodium chloride are separated.

✓ **Quick Check on Sublimation:**

Which one of the following mixtures can be separated by sublimation?

A Iodine and sand.

B Iodine and dry ice (solid carbon dioxide).

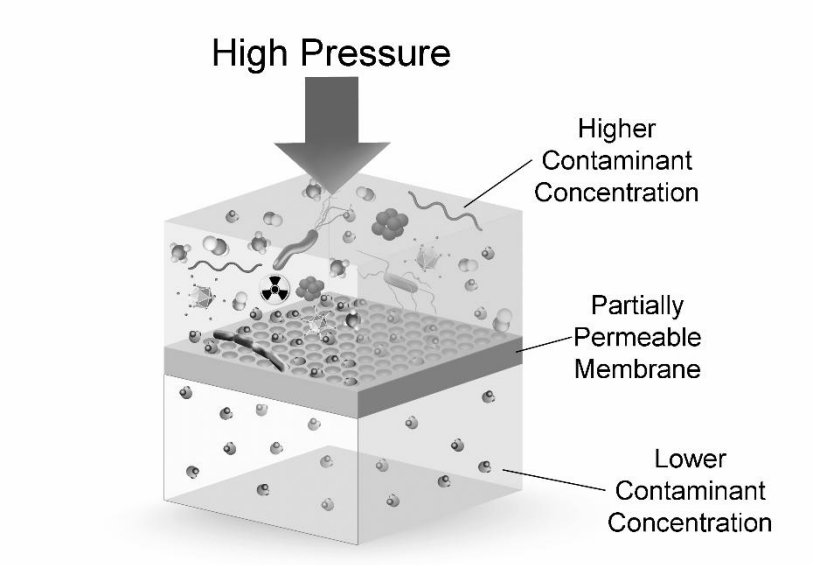
C Table salt and sand.

D Table salt and iron filings.

• **Method Eight – Reverse Osmosis:**

Reverse osmosis is an important separation technique as it allows countries with limited natural resources, such as Singapore, to obtain pure drinking water from seawater.

Osmosis is similar to the concept of diffusion, but applied specifically to *water*. Osmosis is defined as the net movement of water molecules from a region of higher water potential (*e.g.* pure water) to a region of lower water potential (*e.g.* seawater) across a partially permeable membrane. In the case of *reverse osmosis*, a high pressure forces water molecules to move in the opposite direction – from a region of lower water potential (seawater) to a region of higher water potential (pure water) across a partially permeable membrane.



• Diagram showing the process of reverse osmosis. A high pressure is applied to water that is contaminated with impurities. Only water molecules are small enough to be forced through the partially permeable membrane, creating water that is low in contamination and suitable for drinking.

a) You may recall that *simple distillation* can also be used to separate salt (the solute) from water (the solvent). What advantage does reverse osmosis have over simple distillation as a method of obtaining pure water from seawater?

Reverse osmosis consumes less energy than simple distillation. Reverse osmosis can be carried out at room temperature, with electrical energy being required to power the high pressure water pumps. Simple distillation requires a high temperature to boil the water and this will consume a lot of energy in order to boil the large volume of seawater that is required.

✓ **Quick Check on Reverse Osmosis:**

Which one of the following pieces of apparatus is necessary to obtain pure drinking water from seawater by reverse osmosis in a school laboratory?

A Bunsen burner.
B High pressure pump.
C Filter paper.
D Water cooled condenser.

• **Essential Questions and Decisions for Separation Techniques:**

What questions need to be asked, and what decisions need to be made, in order to achieve a complete and efficient separation of a mixture of chemicals?

• What are the chemical and physical properties of the components of the mixture in terms of their melting points, boiling points and solubilities? This will help to determine the best separation technique.

• What level of purity is acceptable / required for the separated chemicals?

• Is any harmful waste produced by the separation which might pollute the environment?

• Are there any safety concerns associated with the chosen separation technique?

• Do the chemicals need to be separated on a small scale (laboratory setting) or large scale (industrial setting)?

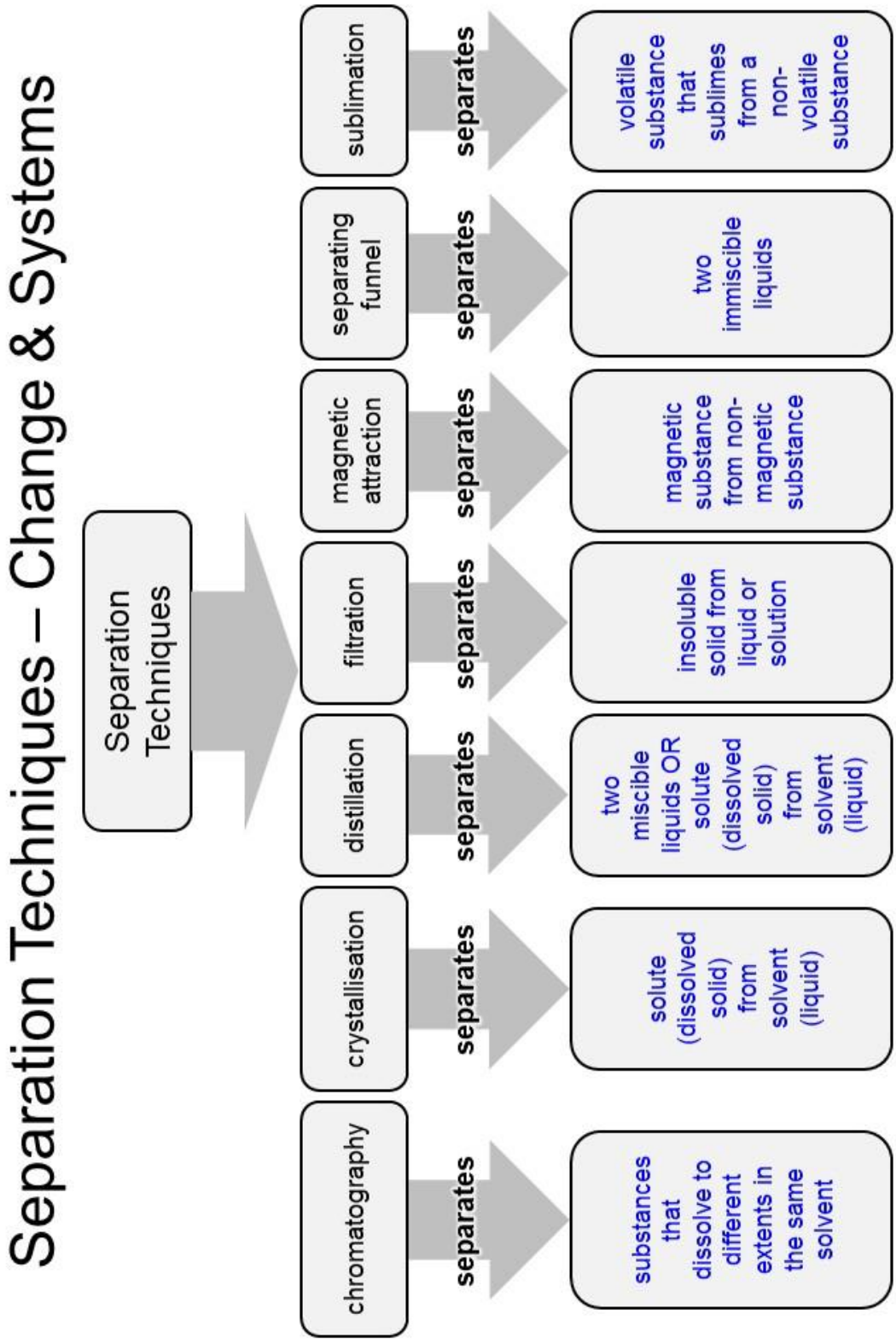
Self-check for Separation Techniques

- Tick the checkbox ☑ that best applies to your current situation. To give a truthful answer, think whether or not you could explain the answer to your friend. If you think that you need a little more help, then please consult your teacher.

Main Learning Objectives	Yes, I'm okay ☺	I need a little more help ☹
I understand why it is important to separate a mixture to obtain a pure substance.	☐	☐
I can give examples of where mixtures are separated in our everyday lives.	☐	☐
Knowing the components of a mixture, I can suggest the most suitable method to separate the mixture.	☐	☐
I understand the properties of a mixture that can be separated by *magnetic attraction*, and I know the principles behind how the separation technique works.	☐	☐
I understand the properties of a mixture that can be separated by *filtration*, and I know the principles behind how the separation technique works.	☐	☐
I understand the properties of a mixture that can be separated by *crystallisation*, and I know the principles behind how the separation technique works.	☐	☐
I understand the properties of a mixture that can be separated by *chromatography*, and I know the principles behind how the separation technique works.	☐	☐
I understand the properties of a mixture that can be separated by *simple distillation*, and I know the principles behind how the separation technique works.	☐	☐
I understand the properties of a mixture that can be separated using a *separating funnel*, and I know the principles behind how the separation technique works.	☐	☐
I understand the properties of a mixture that can be separated by *sublimation*, and I know the principles behind how the separation technique works.	☐	☐
I understand the properties of a mixture that can be separated by *reverse osmosis*, and I know the principles behind how the separation technique works.	☐	☐

Summary of Separation Techniques

- Complete the table below to give *general examples* of the types of chemicals that can be separated by each separation technique. For example, chromatography is essentially used to separate chemicals that have different solubilities in the same solvent.



QR Codes for Videos of the Different Separation Techniques

1. Magnetic Attraction https://youtu.be/uaMed_oml-Q	
2. Filtration https://youtu.be/w4UJur5EH1s	
3. Crystallisation https://youtu.be/LcMcODYtCLI	
4. Chromatography https://youtu.be/jl0ib6eFhNE	
5. Simple Distillation https://youtu.be/J1aAmhonF0s	
6. Separating Funnel https://youtu.be/iDzCm3EgNsU	
7. Sublimation https://youtu.be/YMP5s7cPvgo	