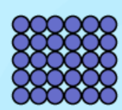
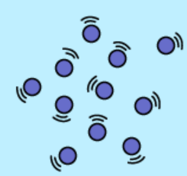
The Three States of Matter

- The three states of matter are **solids**, **liquids** and **gases**
- A substance can usually exist in all three states, dependent on temperature (and pressure)
- Different state changes occur at the **melting point** and at the **boiling point** depending on whether the substance is heating up or cooling down
    - At the melting point
        - Melting (solid → liquid) when heating up
        - Freezing (liquid → solid) when cooling down
    - At the boiling point
        - Boiling (liquid → gas) when heating up
        - Condensing (gas → liquid) when cooling down

- Individual atoms themselves do not share the same properties as bulk matter
- The three states of matter can be represented by a simple model
    - In this model, the particles are represented by small solid spheres

Summary of the Properties of Solids, Liquids and Gases

STATE	SOLID	LIQUID	GAS
DIAGRAM			
ARRANGEMENT OF PARTICLES	REGULAR ARRANGEMENT	RANDOMLY ARRANGED	RANDOMLY ARRANGED
MOVEMENT OF PARTICLES	VIBRATE ABOUT A FIXED POSITION	MOVE AROUND EACH OTHER	MOVE QUICKLY IN ALL DIRECTIONS
CLOSENESS OF PARTICLES	VERY CLOSE	CLOSE	FAR APART

Interconversion Between the States of Matter

- The amount of energy needed to change state from solid to liquid and from liquid to gas depends on the strength of the forces between the particles
    - The stronger the forces of attraction, the more energy that is needed to overcome them for a state change to occur
    - Therefore, the stronger the forces between the particles the higher the melting point and boiling point of the substance
- When matter changes from one state to another due to changes in temperature or pressure, the change is called an **interconversion** of **state**
- It is a **physical change** involving changes in the **forces** between the particles of the substances, the particles themselves remain the **same**, as do the chemical properties of the substance
- Physical changes are relatively easy to reverse as no new substance is formed during interconversions of state
- The interconversions have specific terms to describe them:

A Summary of State Changes

Interconversion	Change
Melting	Solid to a liquid
Boiling	Liquid to a gas (from below surface as well as at surface)
Freezing	Liquid to a solid
Evaporation	Liquid to a gas (at surface only)
Condensation	Gas to a liquid
Sublimation	Solid to a gas

Melting

- Melting is when a solid changes into a liquid
- The process requires heat energy which transforms into **kinetic** energy, allowing the particles to move

- It occurs at a specific temperature known as the **melting point** which is **unique** to each pure solid

Boiling

- Boiling is when a liquid changes into a gas
- This requires heat which causes bubbles of gas to form **below** the surface of a liquid, allowing for liquid particles to escape from the surface and from within the liquid
- It occurs at a specific temperature known as the **boiling point** which is **unique** to each pure liquid

Freezing

- Freezing is when a liquid changes into a solid
- This is the reverse of melting and occurs at exactly the **same temperature** as melting, hence the melting point and freezing point of a pure substance are the same
  - Water for example freezes and melts at 0 ºC
- It requires a significant decrease in temperature (or loss of thermal energy) and occurs at a specific temperature which is **unique** for each pure substance

Evaporation

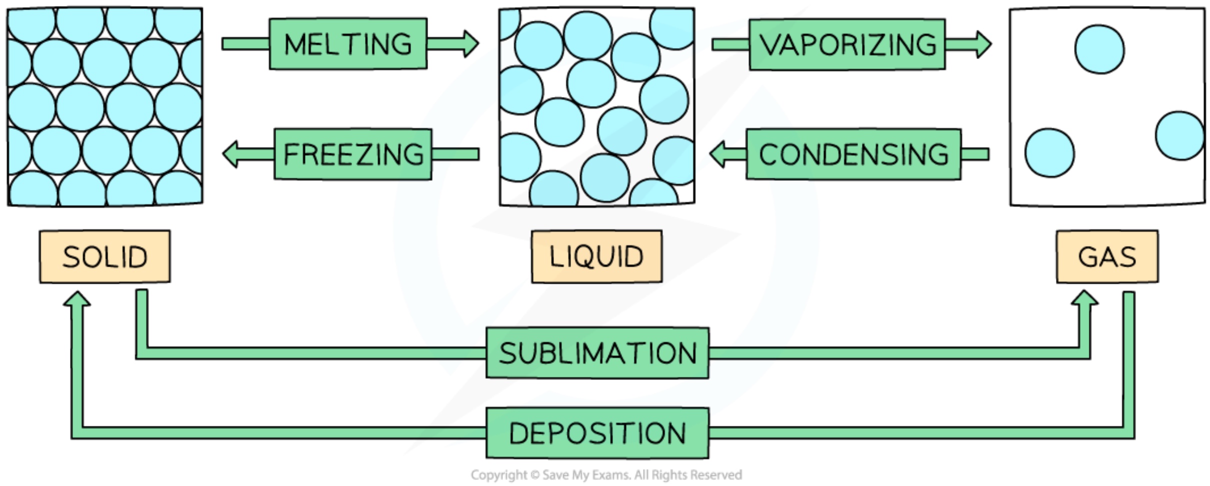
- When a liquid changes into a gas
- Evaporation occurs only at the **surface** of liquids where high energy particles can escape from the liquids surface at **low** temperatures, below the boiling point of the liquid
- The larger the surface area and the warmer the liquid/surface, the more quickly a liquid can evaporate
- Evaporation occurs over a **range** of temperatures, but heating will speed up the process as particles need energy to escape from the surface

Condensation

- When a gas changes into a liquid, usually on cooling
- When a gas is cooled its particles lose energy and when they bump into each other, they lack energy to bounce away again, instead grouping together to form a liquid

Sublimation

- When a solid changes directly into a gas
- This happens to only a few solids, such as iodine or solid carbon dioxide
- The reverse reaction also happens and is called desublimation or deposition

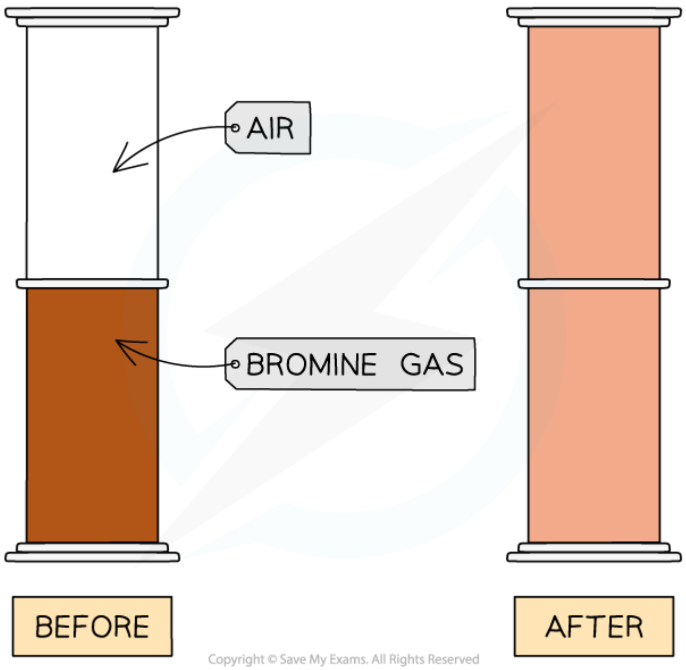


Interconversion between the three states of matter

Diffusion & Dilution

Diffusion and dilution experiments support a theory that all matter (solids, liquids and gases) is made up of tiny, moving particles

Diffusion in gases



Diffusion of red-brown bromine gas

Description:

Here, we see the diffusion of bromine gas from one gas jar to another

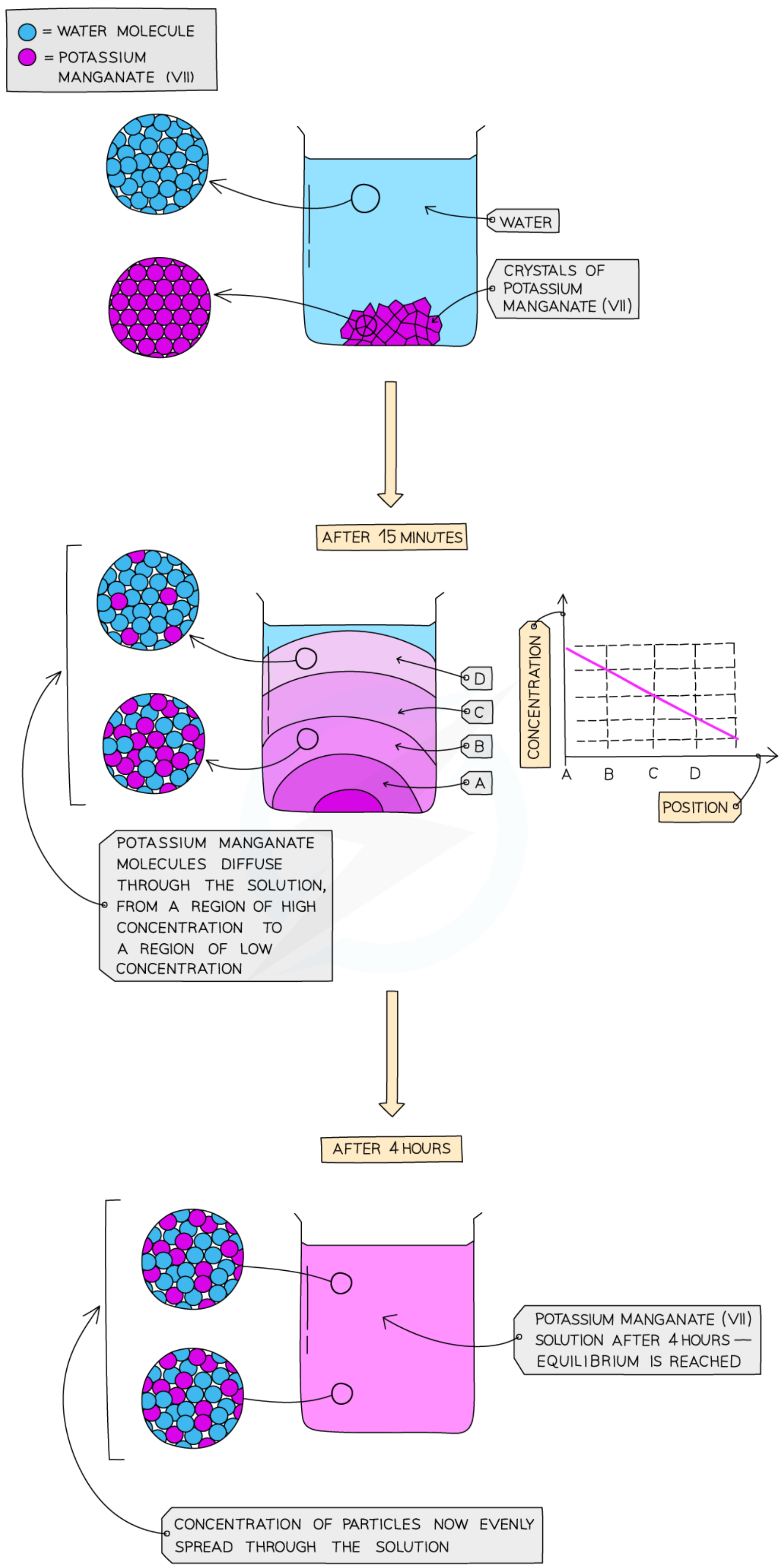
After 5 minutes the bromine gas has diffused from the bottom jar to the top jar

Explanation:

The air and bromine particles are moving randomly and there are large gaps between particles

The particles can therefore easily mix together

Diffusion in liquids



= WATER MOLECULE
= POTASSIUM MANGANATE (VII)
WATER
CRYSTALS OF POTASSIUM MANGANATE (VII)
AFTER 15 MINUTES
D
C
B
A
CONCENTRATION
POSITION
A
B
C
D
POTASSIUM MANGANATE MOLECULES DIFFUSE THROUGH THE SOLUTION, FROM A REGION OF HIGH CONCENTRATION TO A REGION OF LOW CONCENTRATION
AFTER 4 HOURS
POTASSIUM MANGANATE (VII) SOLUTION AFTER 4 HOURS — EQUILIBRIUM IS REACHED
CONCENTRATION OF PARTICLES NOW EVENLY SPREAD THROUGH THE SOLUTION

Diffusion of potassium manganate(VII) in water over time

Description:

When potassium manganate (VII) crystals are dissolved in water, a purple solution is formed

A small number of crystals produce a highly intense colour

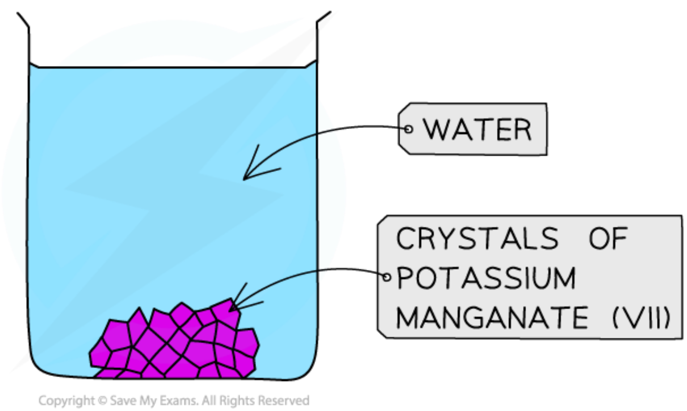
Explanation:

The water and potassium manganate (VII) particles are moving randomly and the particles can slide over each other

The particles can therefore easily mix together

Diffusion in liquids is slower than in gases because the particles in a liquid are closely packed together and move more slowly

Dilution



Dissolving potassium manganate (VII) in water

Description:

When potassium magnate (VII) crystals are dissolved in water, the solution can be diluted several times

The colour fades but does not disappear until a lot of dilutions have been done

Explanation:

This indicates that there are a lot of particles in a small amount of potassium manganate (VII) and therefore the particles must be very small

Solutions Terminology

You need to know all the following terms used when describing solutions:

Terminology About Solutions Table

Term	Meaning	Example
Solvent	The liquid in which a solute dissolves	The water in sea water
Solute	The substance which dissolves in a liquid to form a solution	The salt in seawater
Solution	The mixture formed when a solute is dissolved in a solvent	Seawater
Saturated solution	A solution with the maximum concentration of solute dissolved in the solvent	Seawater in the dead sea
Soluble	Describes a substance that will dissolve	Salt is soluble in water
Insoluble	Describes a substance that won't dissolve	Sand is insoluble in water

Solubility

Solubility is a measurement of how much of a substance will dissolve in a given volume of a liquid

The liquid is called the solvent

The solubility of a gas depends on pressure and temperature

Different substances have different solubilities

Solubility can be expressed in g per 100 g of solvent

Solubility of solids is affected by temperature

As temperature increases, solids usually become more soluble

Solubility of gases is affected by temperature and pressure; in general:

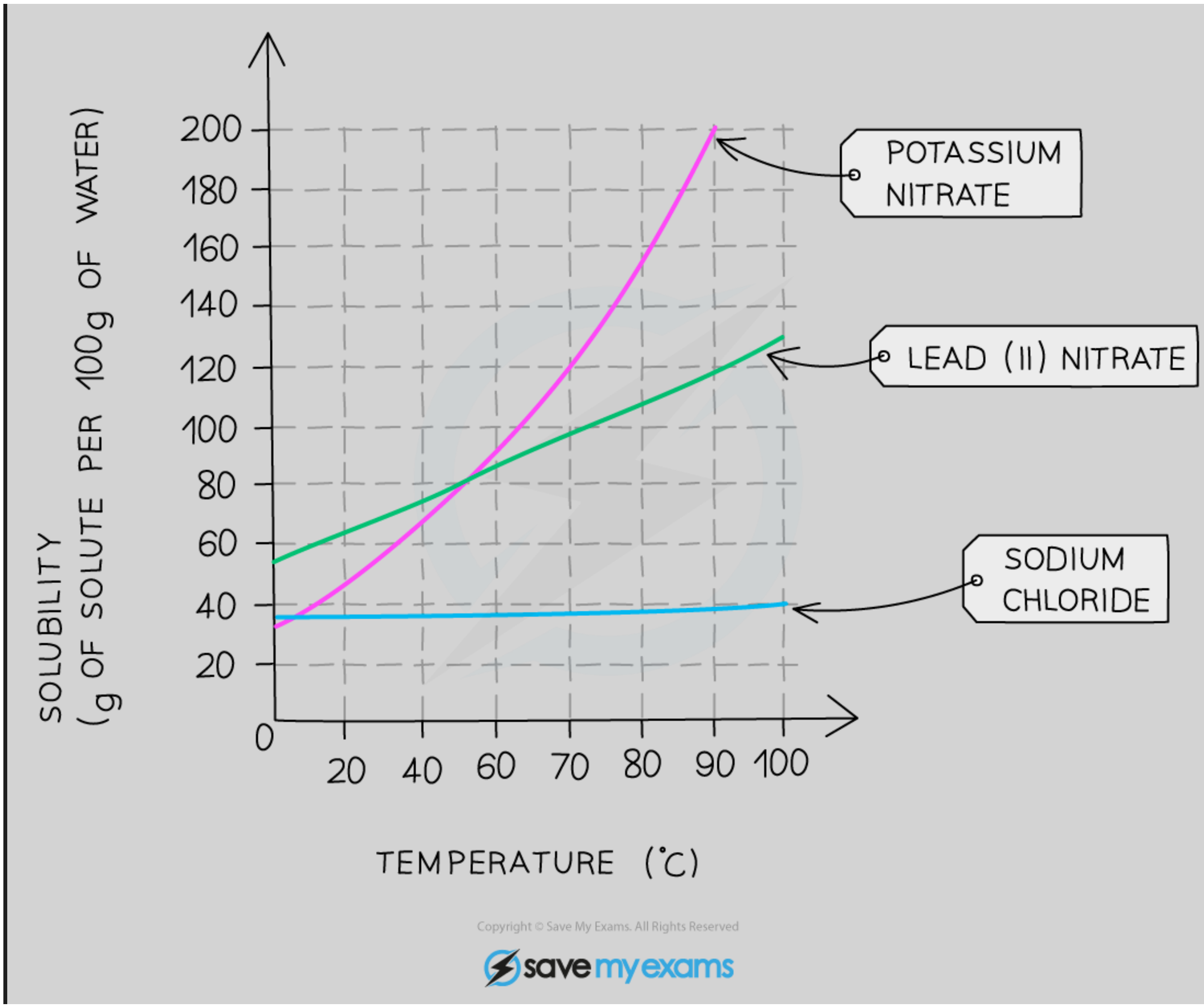
As pressure increases, gases become more soluble

As temperature increases, gases become less soluble

Solubility Curves

Solubility graphs or curves represent solubility in g per 100 g of water plotted against temperature

To plot a solubility curve, the maximum mass of solvent that can be dissolved in 100 g of water before a saturated solution is formed, is determined at a series of different temperatures



Solubility curve for three salts. While the solubility of most salts increases with temperature, sodium chloride, or common salt, hardly changes at all

Worked example

Use the solubility curve to answer these questions:

Determine how much potassium nitrate will dissolve in 20 g of water at 40 °C?

200 cm^3 of saturated lead(II)nitrate solution was prepared at a temperature of 90 °C. What mass of lead(II)nitrate crystals form if the solution was cooled to 20 °C?

Answers:

Problem 1

At 40 °C the solubility is 68 g per 100 g of water

So scaling, 68 x (20 / 100) = 13.6 g of potassium nitrate will dissolve in 20 g of water

Problem 2

Solubility of lead(II) nitrate at 90 °C is 118 g / 100 g water, and 64 g / 100 g water at 20 °C.

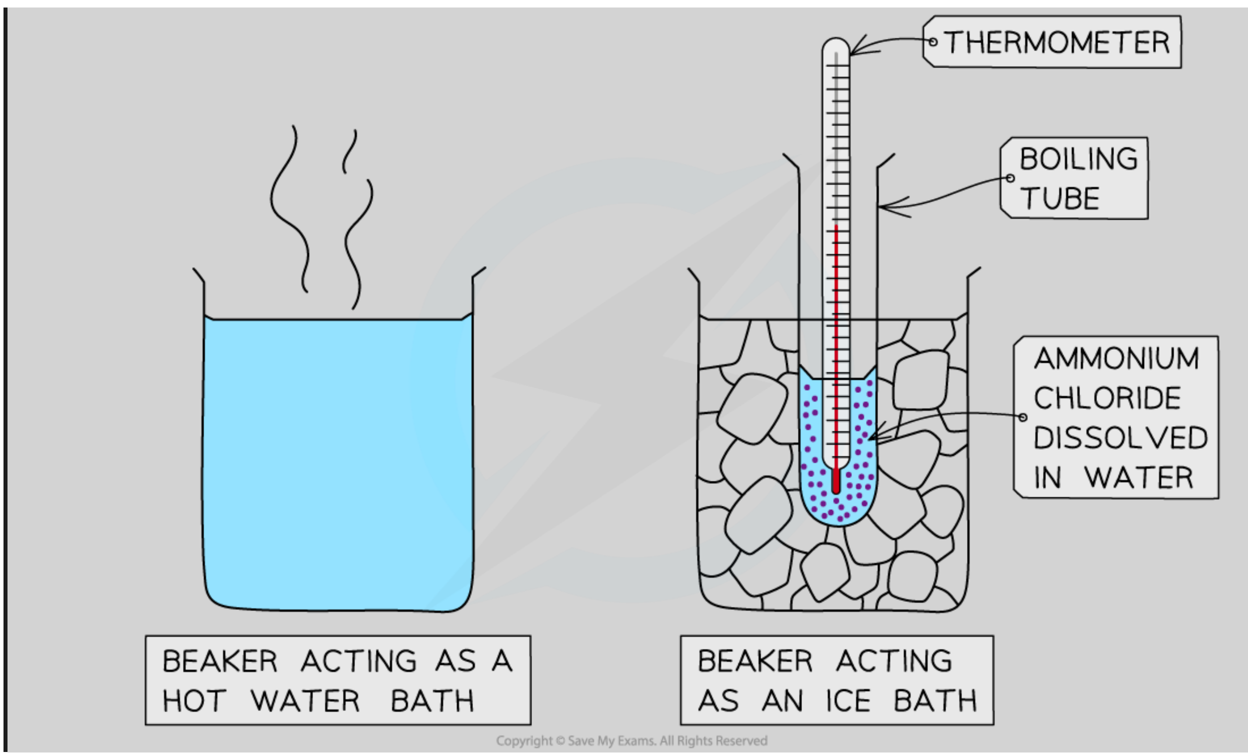
Therefore for mass of crystals formed = 118 – 64 = 54 g (for 100 cm^3 of solution).

However, 200 cm^3 of solution was prepared,

So total mass of lead(II) nitrate crystallised = 2 x 54 = 108 g

Practical: Investigate the Solubility of a Solid in Water at a Specific Temperature

- Aim:
- To measure the solubility of a salt at different temperatures
- Method:
- Prepare a two beakers, one as a hot water bath and one as an ice bath
- Using a small measuring cylinder, measure out 4 cm^3 of distilled water into a boiling tube.
- On a balance weigh out 2.6 g of ammonium chloride and add it to the boiling tube
- Place the boiling tube into the hot water bath and stir until the solid dissolves
- Transfer the boiling tube to the ice bath and allow it to cool while stirring
- Note the temperature at which crystals first appear and record it in a table of results
- Add 1 cm^3 of distilled water then warm the solution again to dissolve the crystals
- Repeat the cooling process again noting the temperature at which crystals first appear.
- Continue the steps until a total of 10 cm^3 of water has been added



Apparatus for investigating the solubility of a salt with temperature

Results:

Table of Results for Recording Solubility

Volume of water in the boiling tube / m³	Solubility in g per 100g	Temperature at which crystals appear / °C
4	65	
5	52	
6	43	
7	37	
8	32	
9	29	
10	26	

Graph:

- Use the results to plot a solubility curve for ammonium chloride at different temperatures. Solubility is on the *y*-axis and temperature is on the *x*-axisConclusion:
- The shape of the graph will allow to state how the solubility varies with temperature

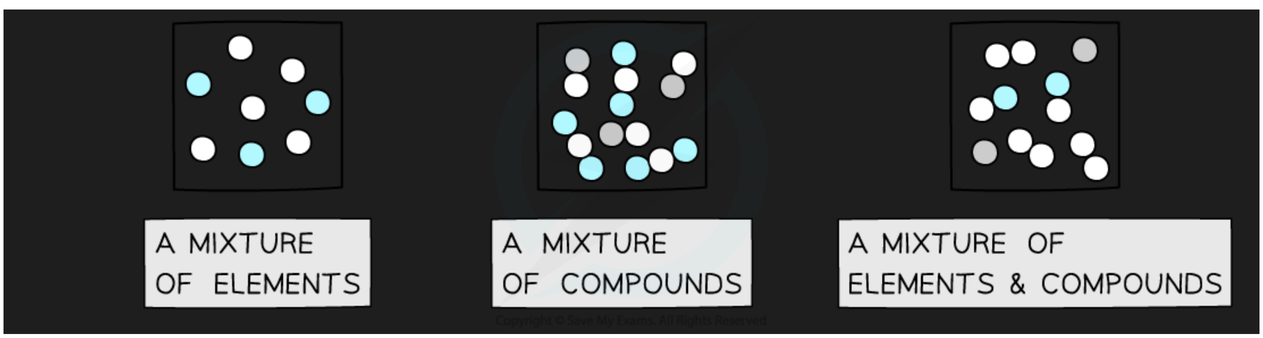
Classify an Element, Compound or Mixture

You need to know the following definitions

Classify an Element, Compound or Mixture Table

Class	Definition
Element	A substance made up of atoms that all contain the same number of protons (one type of atom) and cannot be split into anything simpler. There are 118 known elements. **Examples:** hydrogen, oxygen, carbon
Compound	A pure substance made up of two or more elements chemically combined together. There are unlimited types of compounds. Cannot be separated by physical methods of separation. **Examples:** copper (II) sulphate, calcium carbonate
Mixture	A combination of two or more substances (elements and/or compounds) that are not chemically joined together. Can be separated by physical methods of separation. **Examples:** salt and water, air

We can represent these concepts visually:



Mixtures of elements, compounds and both at the molecular level

Pure Substance vs Mixture

- In everyday language we use the word pure to describe when something is **natural** or **clean** and to which nothing else has been added
- In chemistry a pure substance may consist of a single element or compound which contains no other substances
- For example a beaker of a sample of pure water contains only H_2O molecules and nothing else
- If salt were added to the beaker then a mixture is produced
- A mixture consists of two or more elements or compounds that are **physically mixed** together, they are **not** chemically combined
- The chemical properties of the substances in a mixture remain **unchanged**
- Substances in mixtures can be separated by physical means
- Air for example is a mixture of nitrogen, oxygen and some other gases such as carbon dioxide and argon

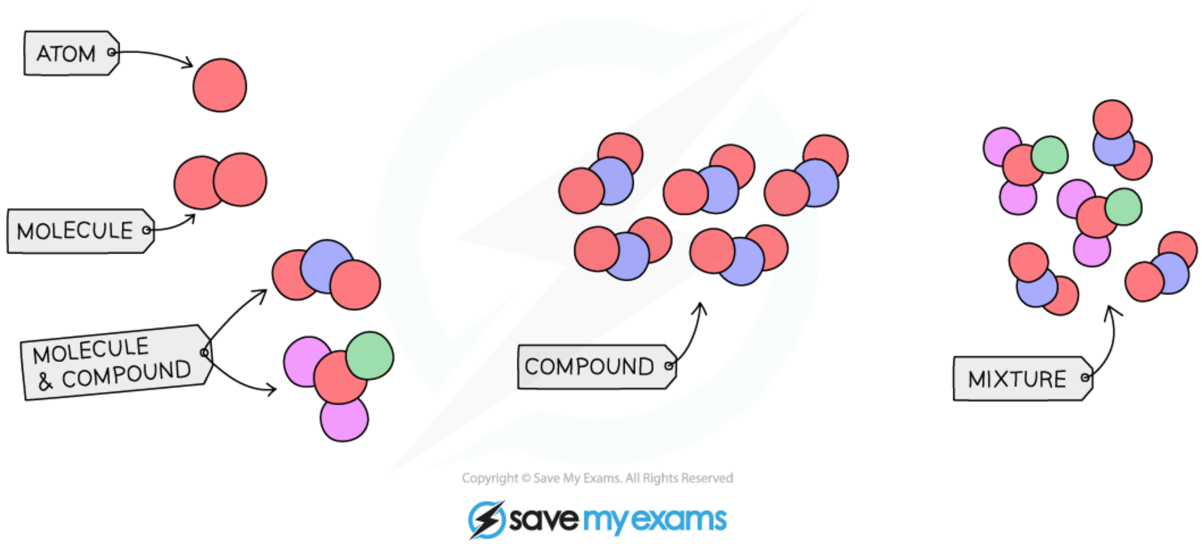


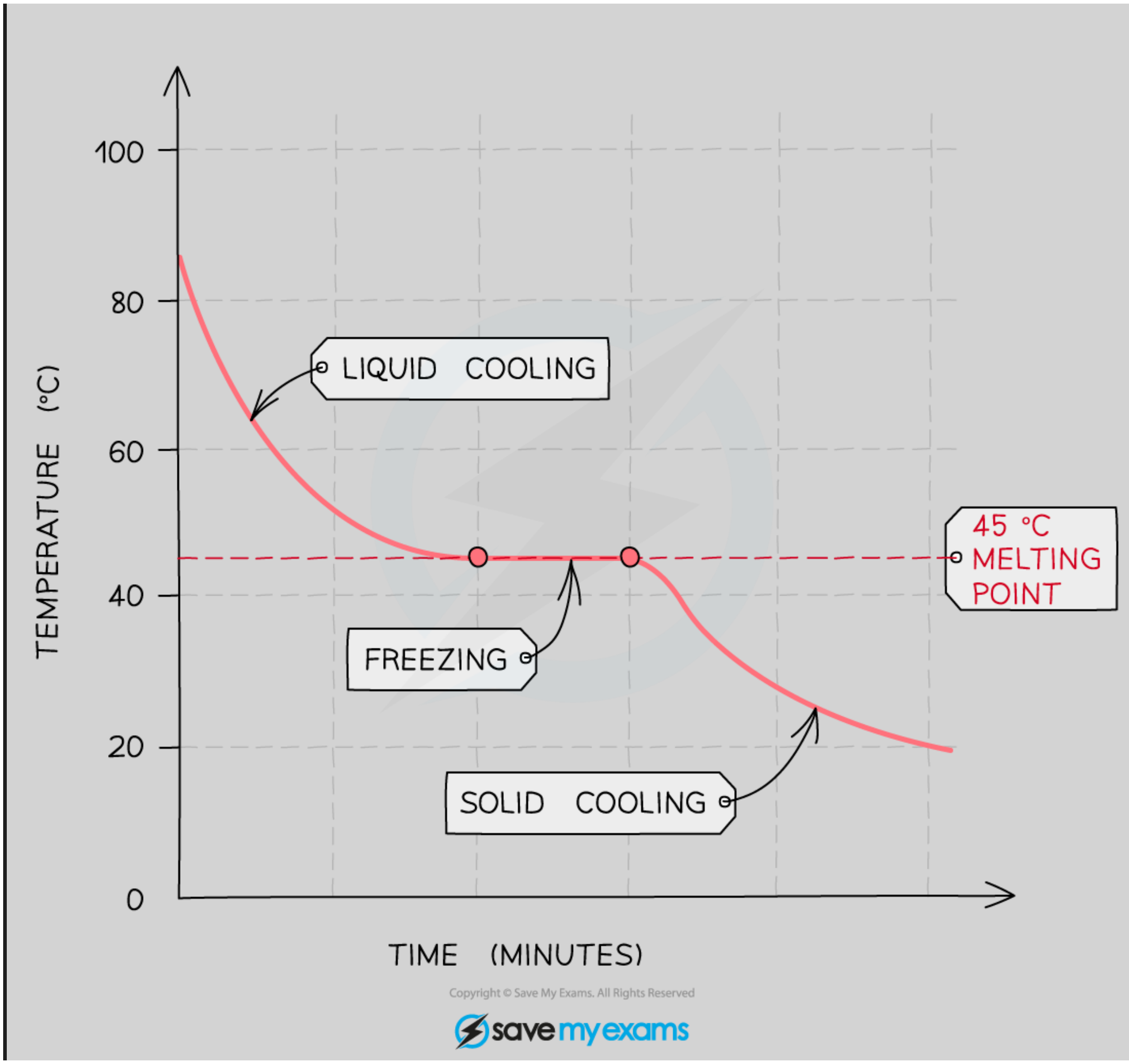
Diagram showing how to represent elements, compounds and mixtures using particle diagrams

Distinguishing Purity

- Pure substances melt and boil at **specific** and **sharp** temperatures e.g. pure water has a boiling point of 100 °C and a melting point of 0 °C
- Mixtures have a **range** of melting and boiling points as they consist of **different** substances that tend to lower the melting point and broaden the melting point range
- **Melting** and **boiling** points data can therefore be used to distinguish pure substances from mixtures
- Melting point analysis is routinely used to assess the purity of drugs
- This is done using a melting point apparatus which allows you to **slowly** heat up a small amount of the sample, making it easier to observe the **exact** melting point
- This is then compared to data tables
- The closer the measured value is to the actual melting or boiling point then the purer the sample is

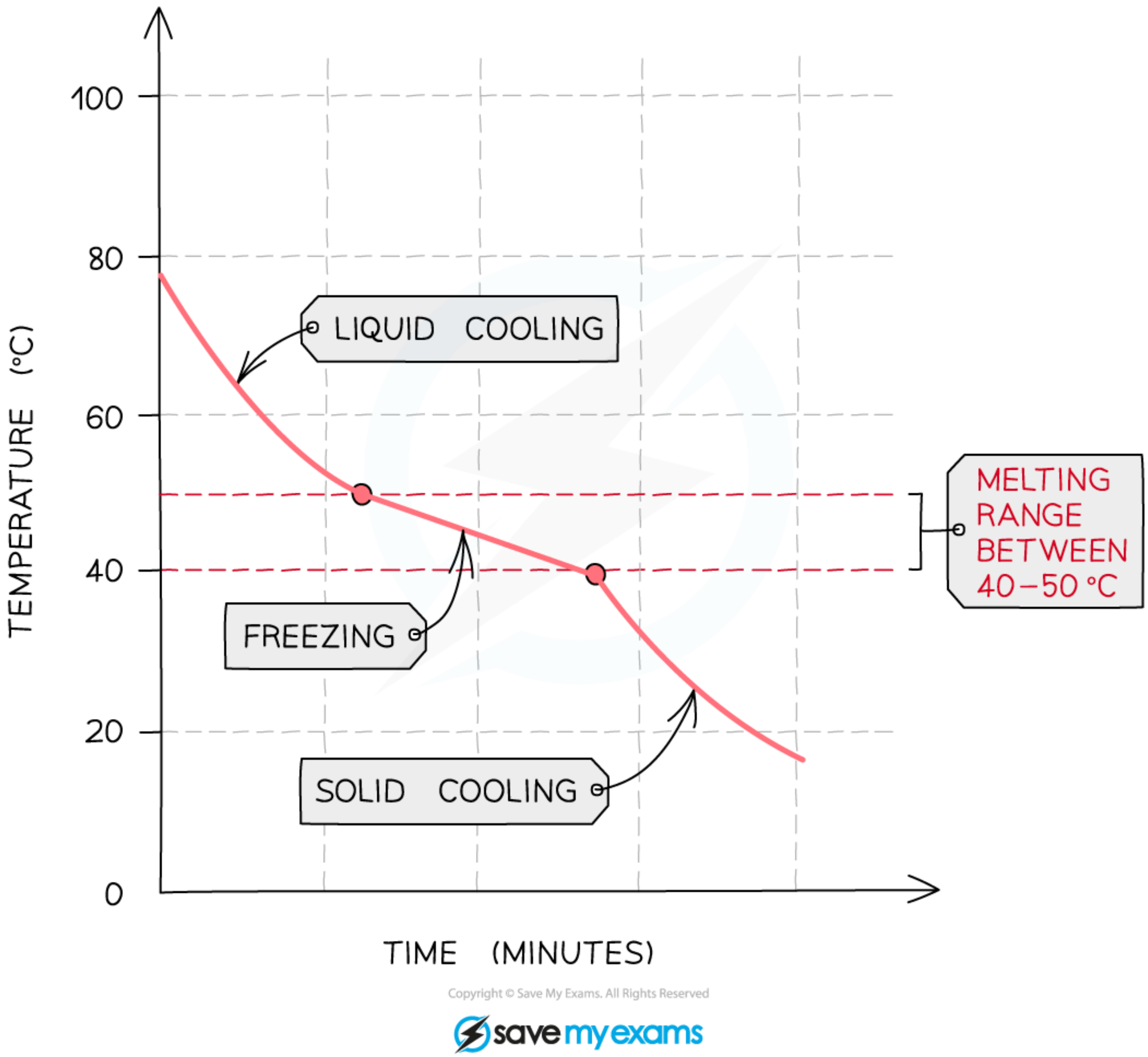
Cooling Curves

- The influence of impurities can be more clearly seen on a **heating / cooling curve**
- If the temperature of a liquid is measured as it cools and freezes the data can be used to produce a graph
- The following graph shows the cooling curve for a sample of a compound
- The horizontal part of the graph shows that the compound has a **sharp melting point**, so the compound is pure



Cooling curve for a pure substance

- An impure sample of the compound would produce a **gradual decrease** in temperature as it freezes as shown in the graph below



Cooling curve for an impure substance

Simple Distillation

- This is used to separate a liquid and **soluble solid** from a solution (e.g., water from a solution of salt water) or a pure liquid from a mixture of liquids
- The solution is heated, and pure water evaporates producing a vapour which rises through the neck of the round bottomed flask
- The vapour passes through the condenser, where it cools and condenses, turning into the pure liquid that is collected in a beaker
- After all the water is evaporated from the solution, only the solid solute will be left behind

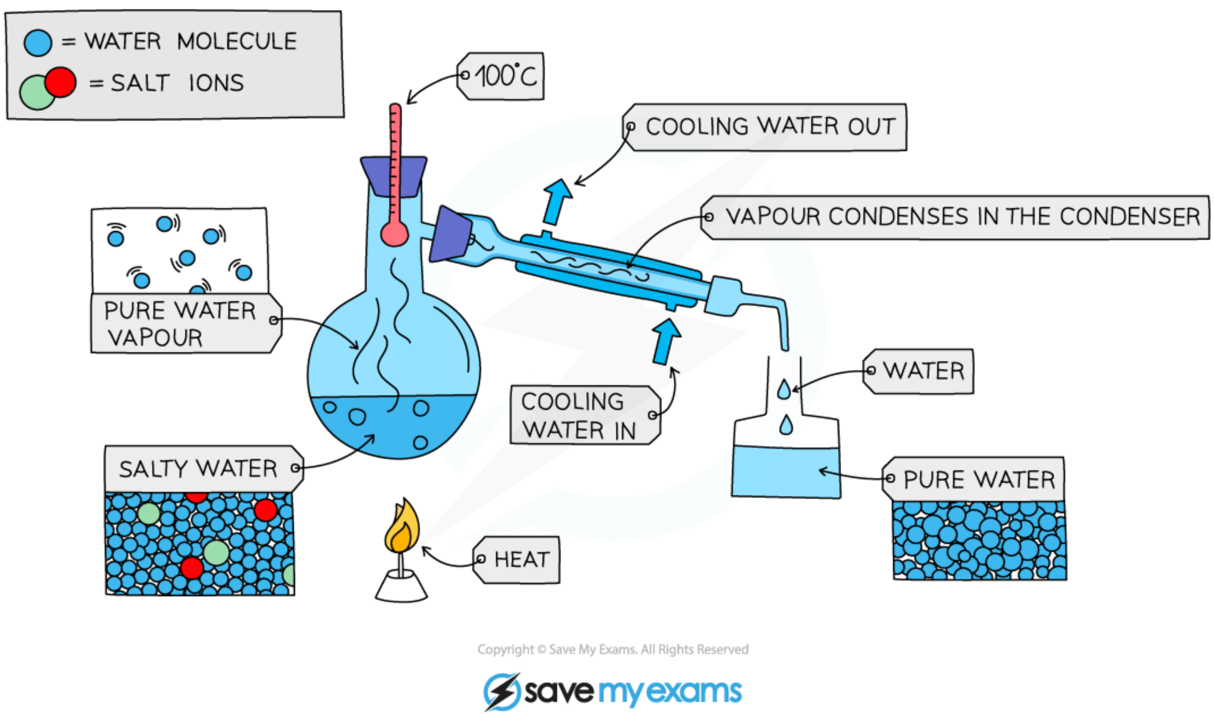
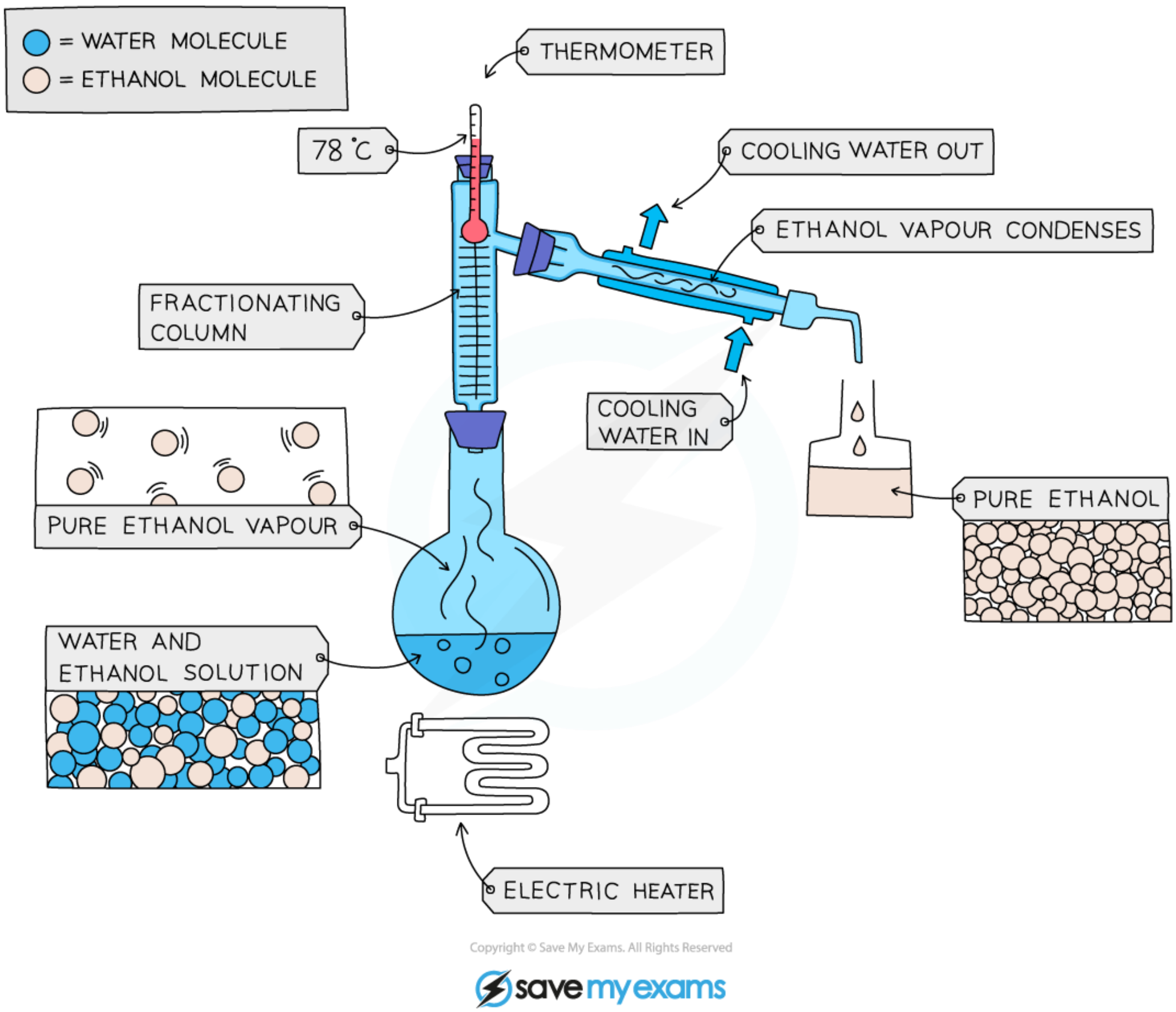


Diagram showing the distillation of a mixture of salt and water

Fractional Distillation

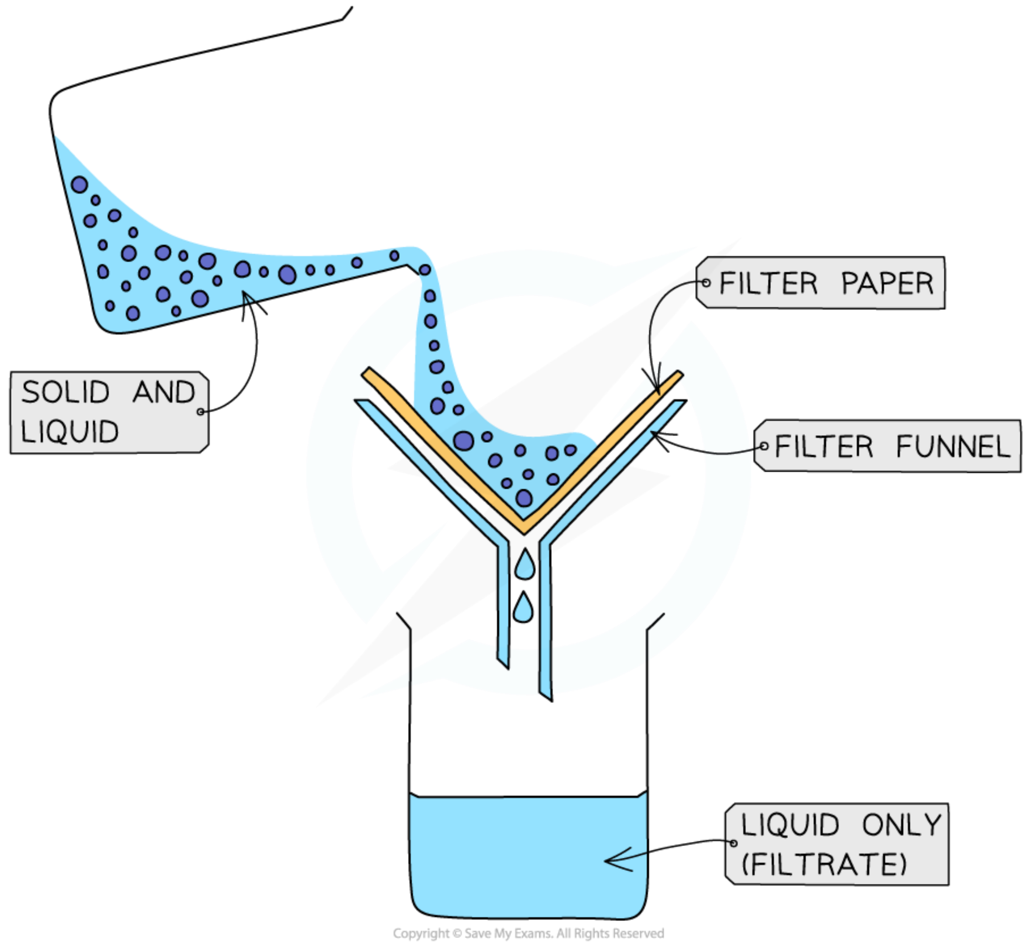
- This is used to separate two or more liquids that are **miscible** with one another (e.g., ethanol and water from a mixture of the two)
- The solution is heated to the temperature of the substance with the lowest boiling point
- This substance will rise and evaporate first, and vapours will pass through a condenser, where they cool and condense, turning into a liquid that will be collected in a beaker
- All of the substance is evaporated and collected, leaving behind the other components(s) of the mixture
- For water and ethanol
    - Ethanol has a boiling point of 78 ºC and water of 100 ºC
    - The mixture is heated until it reaches 78 ºC, at which point the ethanol boils and distills out of the mixture and condenses into the beaker
- When the temperature starts to increase to 100 ºC heating should be stopped. Water and ethanol are now separated



Fractional distillation of a mixture of ethanol and water

Filtration

- Used to separate an **undissolved solid** from a mixture of the solid and a liquid / solution (e.g., sand from a mixture of sand and water)
    - Centrifugation can also be used for this mixture
- A piece of filter paper is placed in a filter funnel above a beaker
- A mixture of insoluble solid and liquid is poured into the filter funnel
- The filter paper will only allow small liquid particles to pass through as filtrate
- Solid particles are too large to pass through the filter paper so will stay behind as a residue



Filtration of a mixture of sand and water

Crystallisation

- Used to separate a **dissolved solid** from a solution, when the solid is much more soluble in hot solvent than in cold (e.g., copper sulphate from a solution of copper (II) sulphate in water)
- The solution is heated, allowing the solvent to evaporate, leaving a saturated solution behind
- Test if the solution is saturated by dipping a clean, dry, cold glass rod into the solution
    - If the solution is saturated, crystals will form on the glass rod
- The saturated solution is allowed to cool slowly
- Crystals begin to grow as solids will come out of solution due to decreasing solubility
- The crystals are collected by filtering the solution, they are washed with cold distilled water to remove impurities and are then allowed to dry

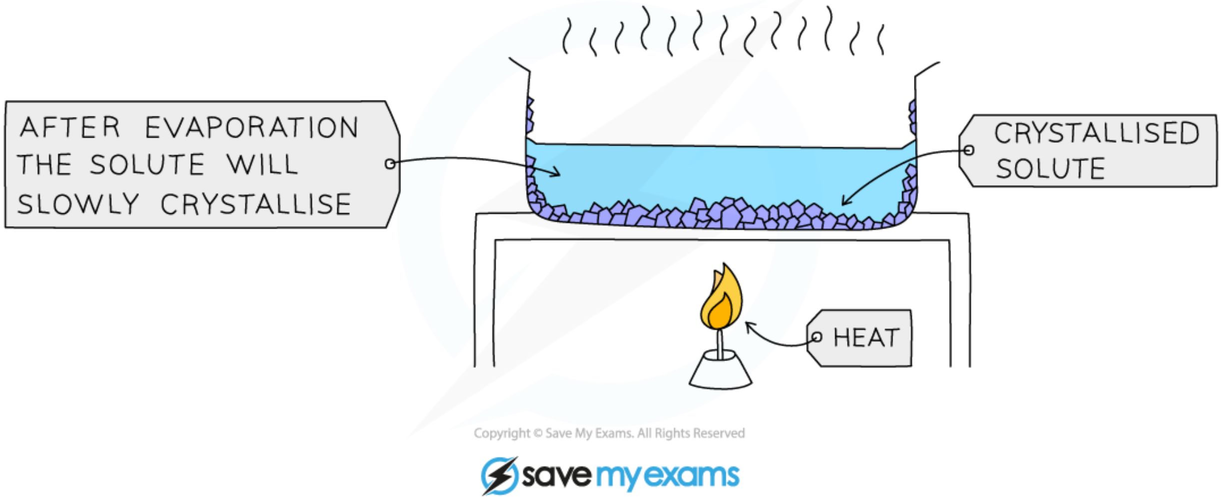
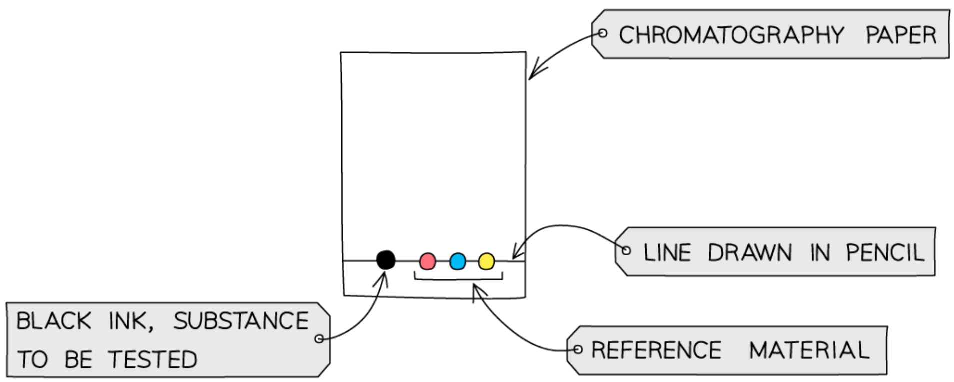


Diagram showing the process of crystallisation

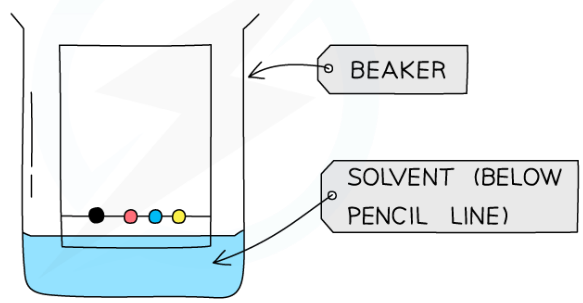
Paper Chromatography

- This technique is used to separate substances that have **different solubilities** in a given solvent (e.g., different coloured inks that have been mixed to make black ink)
- A **pencil line** is drawn on chromatography paper and spots of the sample are placed on it. Pencil is used for this as ink would run into the chromatogram along with the samples
- The paper is then lowered into the solvent container, making sure that the pencil line sits **above** the level of the solvent, so the samples don't wash into the solvent container
    - The paper is called the **stationary phase**
- The solvent travels up the paper by **capillary action**, taking some of the coloured substances with it; it is called the **mobile phase**
- Different substances have different solubilities so will travel at different rates, causing the substances to spread apart
    - Those substances with higher solubility will travel further than the others
- This will show the different components of the ink / dye
- If two or more substances are the same, they will produce identical chromatograms
- If the substance is a mixture, it will separate on the paper to show all the different components as separate spots
- An impure substance will show up with more than one spot, a pure substance should only show up with one spot

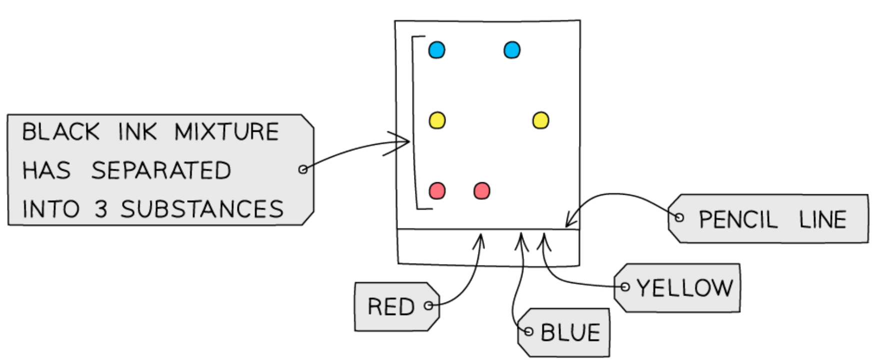
1 SET UP CHROMATOGRAPHY PAPER AS SHOWN



2 LOWER PAPER INTO A BEAKER WITH APPROPRIATE SOLVENT. WAIT FOR SOLVENT TO TRAVEL UP THE PAPER.



3 ANALYSE CHROMATAGRAM



Analysis of the composition of ink using paper chromatography

Identifying Mixtures

- Pure substances will produce only **one spot** on the chromatogram
- If two or more substances are the same, they will produce identical chromatograms
- If the substance is a **mixture**, it will separate on the paper to show all the **different components** as **separate** spots
- An impure substance therefore will produce a chromatogram with more than one spot

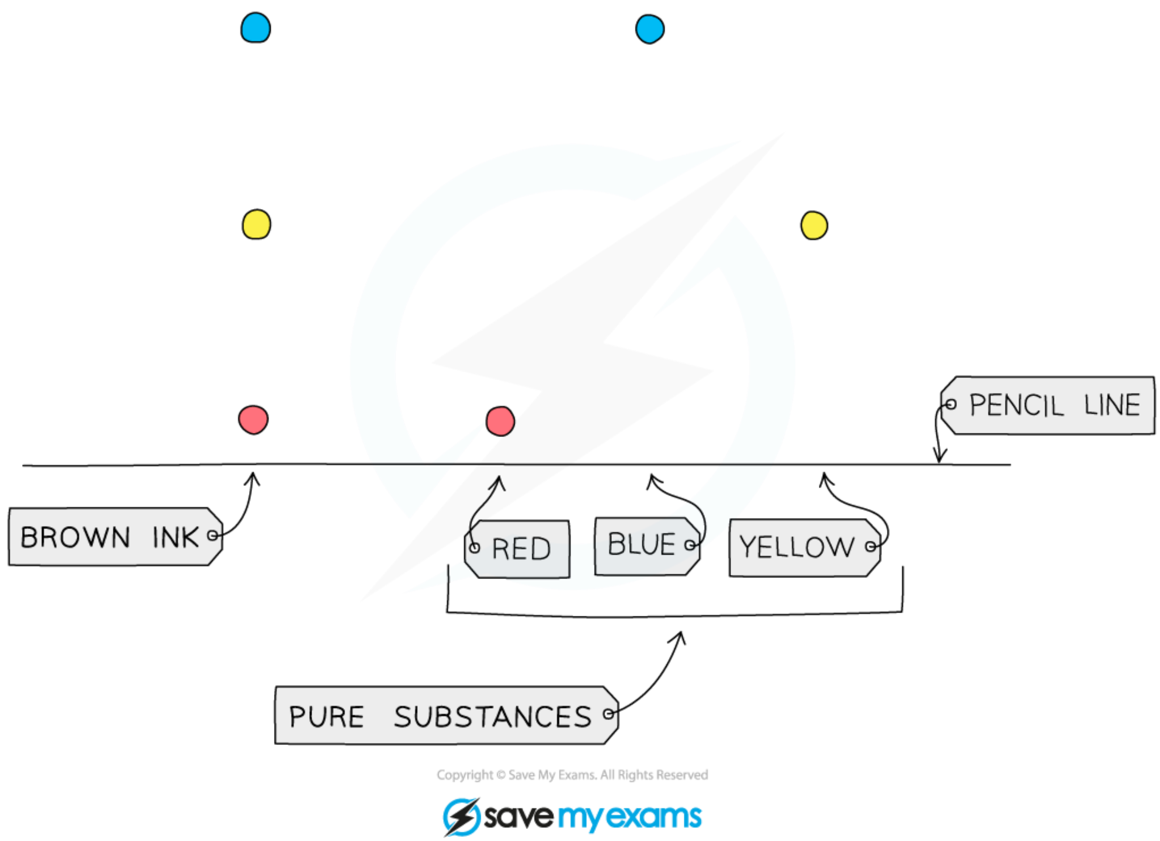


Diagram showing the analysis of a mixture and pure substances using chromatography

Rf Values

- These values are used to **identify** the components of mixtures
- The R_f value of a particular compound is always the **same** but it is dependent, however, on the solvent used
- If the solvent is changed then the value changes

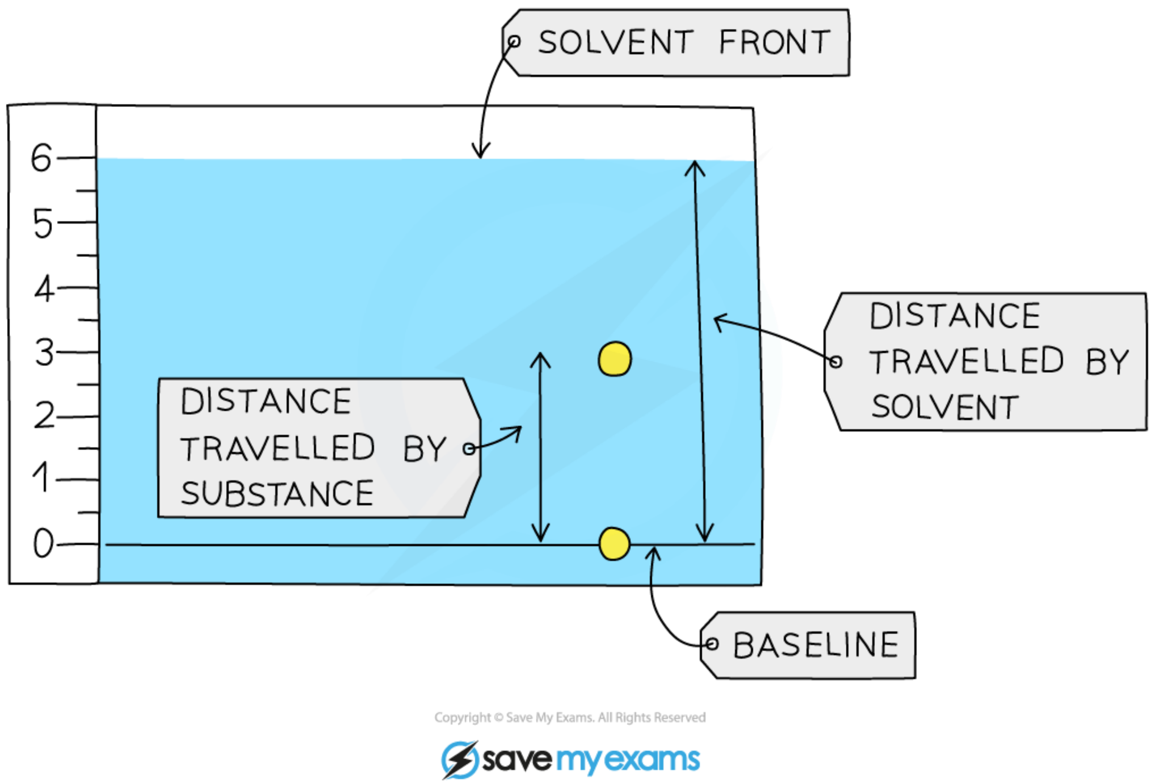
- Calculating the R_f value allows chemists to **identify unknown substances** because it can be compared with R_f values of known substances under the same conditions
- These values are known as **reference values**

Calculation

- The Retention factor is found using the following calculation:

Rf = distance travelled by substance ÷ distance travelled by solvent

- The Rf value will always lie between 0 and 1; the closer it is to 1, the more soluble is that component in the solvent
- The R_f value is a ratio and therefore has no units



Using R_f values to identify components of a mixture

Practical: Investigate Paper Chromatography Using Inks & Food Colourings

Objective:

- Investigate how paper chromatography can be used to separate and identify a mixture of food colourings
- Hypothesis:
- R_f values can be used to identify the components of an unknown mixture by comparison with R_f values of known substancesMaterials:
- A 250 cm^3 beaker
- A wooden spill
- A rectangle of chromatography paper
- Four known food colourings labelled A–D
- An unknown mixture of food colourings labelled U
- Five glass capillary tubes
- Paper clip
- Ruler & pencil

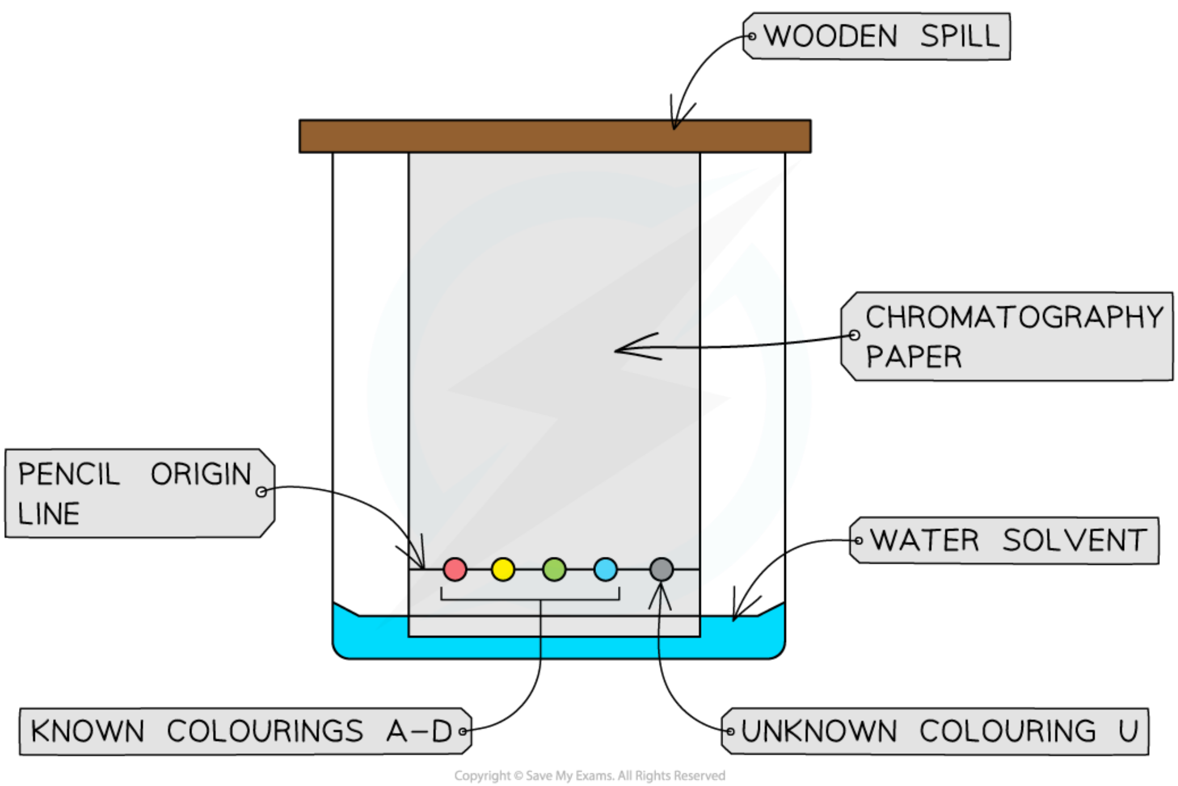


Diagram of the apparatus needed for paper chromatography

Practical Tip:

- The pencil line must never be below the level of the solvent as the samples will be washed away
- Method:
- Use a ruler to draw a horizontal pencil line 2 cm from the end of the chromatography paper
- Use a different capillary tube to put a tiny spot of each colouring A, B, C and D on the line
- Use the fifth tube to put a small spot of the unknown mixture U on the line
- Make sure each spot is no more than 2-3 mm in diameter and label each spot in pencil
- Pour water into the beaker to a depth of no more than 1 cm and clip the top of the chromatography paper to the wooden spill. The top end is the furthest from the spots
- Carefully rest the wooden spill on the top edge of the beaker. The bottom edge of the paper
- should dip into the solvent
- Allow the solvent to travel undisturbed at least three quarters of the way up the paper
- Remove the paper and draw another pencil line on the dry part of the paper as close to the wet edge as possible. This is called the solvent front line
- Measure the distance in mm between the two pencil lines. This is the distance travelled by the water solvent
- For each of food colour A, B, C and D measure the distance in mm from the start line to the middle of the spot
- Results:
- Record your results in a suitable table

Food colouring	Distance in mm		R_f value
	Solvent	Spot	
A	5	2.5	0.5
B	5	1.8	0.36

Evaluation:

- The R_f values of food colours A, B, C and D should be compared to that for the unknown sample as well as a visual comparison being made
- Conclusion:
- The use of chromatography and R_f values is a viable method of identifying unknown mixtures given reference material

From Chapter First to 1.2.5 according to SaveMyExams.net