

States of matter and mixtures

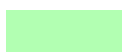
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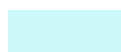
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These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Diagrams



Notes and warnings



Sub-topic headings

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Define Chemical change

- a reaction making new substances, usually not easily reversed.

Define Boiling point

- the temperature at which a liquid turns to a gas throughout the liquid.

Define Mixture

- two or more substances not chemically joined, separable by physical means.

Define Fractional distillation

- separating miscible liquids using their different boiling points.

Define Mobile phase

- the solvent that moves through the paper, carrying the dissolved substances.

Define R_f value

- the distance moved by a substance divided by the distance moved by the solvent.

HIGHER TIER

NOTE

No Higher Tier or chemistry-only content here. Every statement in Topic 2 (2.1–2.12) has a plain

CHEMISTRY ONLY .

number in ordinary type, so nothing is tagged

HT ONLY or

Define Physical change

- a change of state; no new substance is made and it can be reversed.

Define Melting point

- the temperature at which a solid turns to a liquid.

Define Pure substance (chemistry)

- a single element or compound and nothing else.

Define Simple distillation

- separating a solvent from a solution by evaporating then condensing it.

Define Paper chromatography

- separating soluble substances by running a solvent (the mobile phase) through the mixture on paper (which contains the stationary phase).

Define Stationary phase

- the phase that does not move; in paper chromatography, contained in the paper.

Define Potable water

- water that is safe to drink; not chemically pure, as it contains dissolved substances.

2.1 States of matter (2.1–2.4)

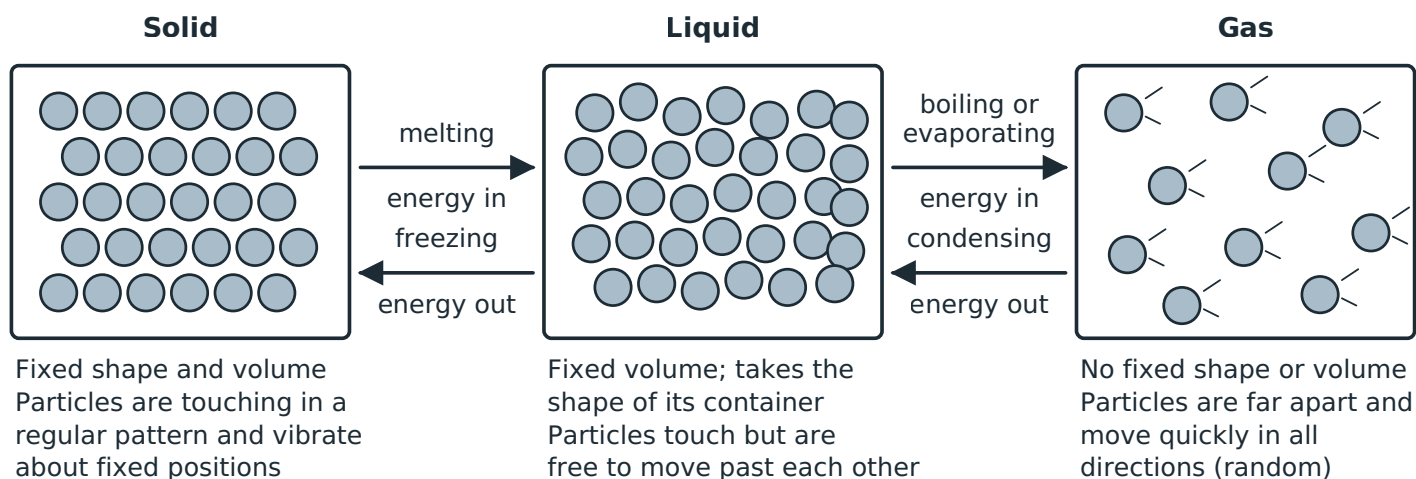
The three states of matter and the particle model (2.1)

You must **describe the arrangement, movement and the relative energy of particles in each of the three states of matter.**

	Solid	Liquid	Gas
Arrangement	Close together, regular pattern	Close together, random	Far apart, random
Movement	Vibrate about fixed positions	Move around each other	Move quickly, all directions
Relative energy	Lowest	Middle	Highest
Shape and volume	Fixed shape and volume	Takes its container's shape, fixed volume	Fills its container
Compressible?	No	Almost not at all	Yes — there is space between particles

Forces of attraction between particles are **strongest in a solid** and **weakest in a gas**; the stronger they are, the more energy is needed to separate the particles and the higher the melting and boiling points.

The three states of matter and the interconversions between them



Melting and freezing happen at the melting point. Boiling and condensing happen at the boiling point. The stronger the forces between the particles, the higher the melting point and the boiling point.

Limitations of the simple particle model

In this model the particles are drawn as small solid spheres, all identical, with no forces between them. Real particles are not solid inelastic spheres, are not all the same, and forces do act between them.

ANALOGY

The particle model. A **solid** is a class standing in rows for a photograph — everyone on their own spot, fidgeting. A **liquid** is the same class milling about at break, still shoulder to shoulder but shuffling past each other. A **gas** is that class let loose on an empty field. Same people, same number — only arrangement, movement and energy change.

Changes in arrangement, movement and energy (2.3)

You must **explain the changes in arrangement, movement and energy of particles during these interconversions.**

- **Melting** — energy is transferred in; particles vibrate more until they overcome some of the forces of attraction and break out of their fixed positions, becoming randomly arranged and moving around each other.
- **Boiling / evaporating** — more energy in; particles overcome the forces of attraction completely and escape as a gas, far apart and fast-moving. Evaporation happens at the surface at any temperature; boiling happens throughout the liquid at the boiling point.
- **Condensing** — gas particles lose energy, slow, come close together and are held as a liquid.
- **Freezing** — liquid particles lose more energy and settle into fixed positions in a regular arrangement.

Energy is transferred to the substance during melting, boiling and subliming; **from the substance** during condensing and freezing.

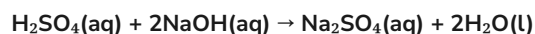
Interconversions between the states, and state symbols (2.2)

You must **recall the names used for the interconversions between the three states of matter, recognising that these are physical changes: contrasted with chemical reactions that result in chemical changes.**

- Solid → liquid: **melting**; liquid → solid: **freezing** (solidifying)
- Liquid → gas: **boiling** or **evaporating**; gas → liquid: **condensing**
- Solid → gas directly: **subliming** (sublimation)

These are **physical changes**: the particles are unchanged, no new substance is made, and heating or cooling reverses them. A **chemical reaction** rearranges atoms into new substances, is usually hard to reverse, and often shows a temperature change, a gas, a precipitate or colour change.

Balanced equations use **state symbols (s), (l), (g) and (aq)** (statement 0.3). Learn the difference between **(l)**, a pure liquid, and **(aq)**, something dissolved in water:



Predicting the state of a substance; heating and cooling curves (2.4)

You must **predict the physical state of a substance under specified conditions, given suitable data.** Compare the stated temperature with the melting point (m.p.) and boiling point (b.p.):

- **Below the melting point** → solid
- **Between the melting and boiling points** → liquid
- **Above the boiling point** → gas

Substance	m.p. / °C	b.p. / °C	State at 25 °C
Oxygen	-219	-183	Gas (25 > -183)
Ethanol	-114	78	Liquid (25 lies between)
Sodium chloride	801	1413	Solid (25 < 801)

Heating and cooling curves. Plot temperature against time as a solid is heated steadily: the graph rises, goes **flat (a plateau) at the melting point**, rises, then is flat again at the boiling point. During a plateau the energy transferred **overcomes the forces of attraction between particles** instead of raising the temperature, so the temperature holds steady while the substance changes state. A **cooling curve** is the mirror image. On either curve the **lower plateau is the melting point** and the **upper plateau the boiling point** (maths skill 4a).

Limitations of the particle model (1.41)

Statement 1.41 asks you to **describe the limitations of particular representations and models.** Applied to the simple particle model:

- Particles are drawn as **solid spheres**, but real atoms and molecules are neither solid nor always spherical.
- The spheres are all **identical in size**, hiding the difference between atoms, molecules and ions.
- The model shows **no forces between the particles**, yet those forces decide the state.
- It shows **no space inside particles** and ignores how atoms are bonded within a molecule.

2.2 Methods of separating and purifying substances (2.5–2.12)

Pure substances and mixtures (2.5)

You must **explain the difference between the use of 'pure' in chemistry compared with its everyday use and the differences in chemistry between a pure substance and a mixture.**

- In **everyday use**, "pure" means natural or with nothing added — "pure orange juice", "pure spring water".
- In **chemistry**, a **pure substance** is a **single element or compound** and nothing else. Pure orange juice is a mixture of water, sugars, acids and colourings, so to a chemist it is not pure.
- A **mixture** contains two or more substances **not chemically joined**. Its parts keep their own properties, the amounts can vary, and physical methods can separate it.

Melting point data: telling pure substances from mixtures (2.6)

You must **interpret melting point data to distinguish between pure substances which have a sharp melting point and mixtures which melt over a range of temperatures.**

- A **pure substance melts sharply at one fixed temperature** — pure ice melts at exactly 0 °C.
- A **mixture melts over a range of temperatures**, usually **lower** than that of the pure substance.

So a sample sold as pure aspirin that melts over 128–133 °C, when pure aspirin melts sharply at 135 °C, is **impure** — a mixture.

The separation techniques (2.7)

You must **explain the types of mixtures that can be separated by using the following experimental techniques.**

Technique	What it separates	How it works
a Simple distillation	The solvent from a solution (water from sea water)	The solvent boils off, condenses and is collected as the distillate ; the dissolved solid stays in the flask
b Fractional distillation	Miscible liquids with different boiling points (ethanol from a water–ethanol mixture)	Vapours rise up a fractionating column, hottest at the bottom. The liquid with the lowest boiling point reaches the top first and is collected; the rest condense and drip back
c Filtration	An insoluble solid from a liquid (sand from water)	Poured through filter paper in a funnel: the solid stays as the residue , the liquid passes through as the filtrate
d Crystallisation	A soluble solid from its solution (copper sulfate)	Evaporate solvent until saturated, cool slowly; crystals form, then filter and dry them
e Paper chromatography	Mixtures of soluble substances — dyes in ink, food colourings	A solvent carries the substances through the paper at different rates

Choosing the right technique (2.8)

You must **describe an appropriate experimental technique to separate a mixture, knowing the properties of the components of the mixture.** Work down the list:

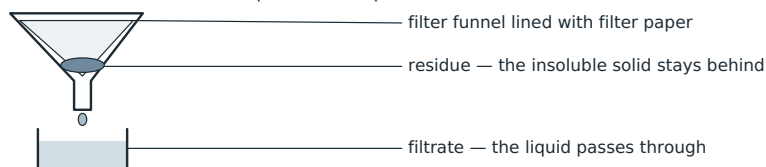
1. An **insoluble solid** in a liquid? → **filtration**.
2. Want the **dissolved solid** back? → **crystallisation**.
3. Want the **solvent** back, pure? → **simple distillation**.
4. **Liquids that mix**, with different boiling points? → **fractional distillation**.
5. **Soluble substances to identify** rather than collect? → **paper chromatography**.

Techniques combine: to get pure water *and* pure salt from rock salt, **filter** off the insoluble rock, then **distil** the salt solution, leaving the salt in the flask.

Filtration, crystallisation, simple distillation and fractional distillation

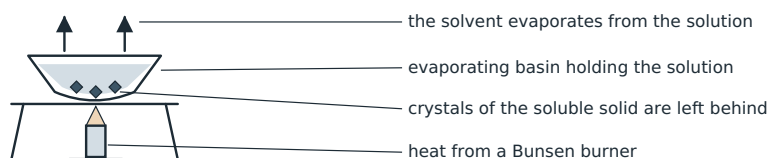
Filtration

Separates an insoluble solid from a liquid, for example sand from water.



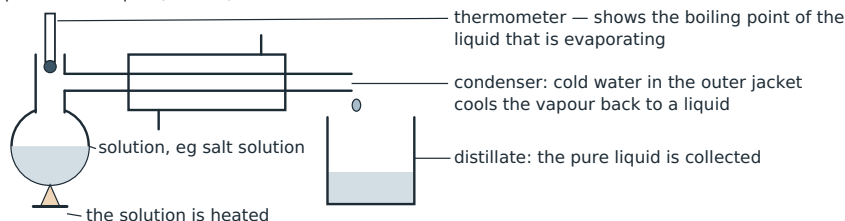
Crystallisation

Separates a soluble solid from its solution, for example salt from salt solution.



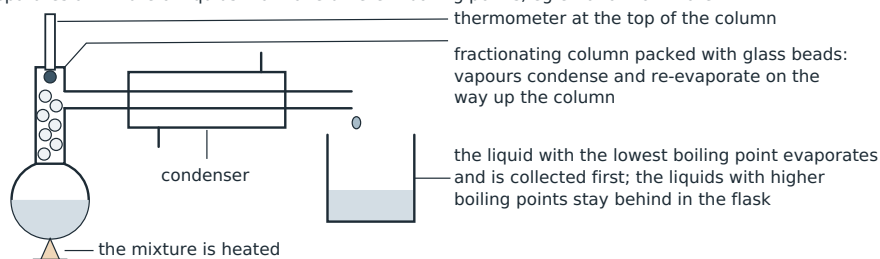
Simple distillation

Separates the liquid (solvent) from a solution — the dissolved solid is left in the flask.



Fractional distillation

Separates a mixture of liquids that have different boiling points, eg ethanol from water.

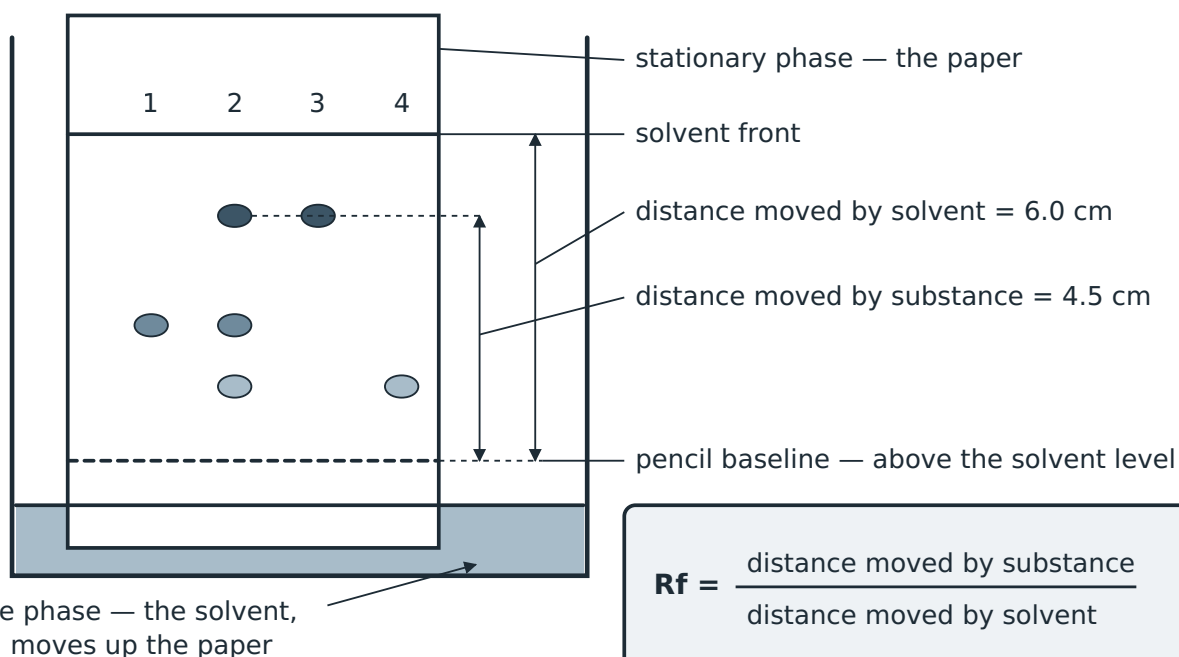


Paper chromatography (2.9)

You must **describe paper chromatography as the separation of mixtures of soluble substances by running a solvent (mobile phase) through the mixture on the paper (the paper contains the stationary phase), which causes the substances to move at different rates over the paper.**

- The **mobile phase** is the solvent (water, ethanol or another suitable solvent), which moves up the paper.
- The **stationary phase** is contained in the paper and does not move.
- A substance that is **more soluble in the solvent** and **less strongly attracted to the paper** travels **further and faster**, so each substance moves a different distance and the spots separate.
- Start the spots on a **pencil line** — pencil is insoluble and will not run — and keep the solvent level **below** it, or the spots dissolve straight into the solvent.

Paper chromatography and the R_f value



$$R_f = \frac{\text{distance moved by substance}}{\text{distance moved by solvent}}$$

$$R_f = 4.5 \div 6.0 = 0.75 \text{ (no units)}$$

A pure compound gives a single spot in all solvents; a mixture separates into several spots.

Separation depends on the distribution of the substances between the two phases.

ANALOGY

Chromatography as a tug-of-war. Every dye is pulled two ways at once: the solvent drags it up the paper, the paper holds it back. A dye that dissolves easily and clings only weakly is carried a long way; one that clings tightly barely moves. Each dye has its own balance of the two pulls, so they end up in different places.

WATCH OUT

Measuring from the wrong place. Measure from the **pencil start line**, not the bottom of the paper, and to the **centre** of the spot. Mark the solvent front in pencil the moment you lift the paper out, before it dries and disappears.

Interpreting a chromatogram and R_f values (2.10)

You must **interpret** a paper chromatogram: **a** to distinguish between pure and impure substances; **b** to identify substances by comparison with known substances; **c** to identify substances by calculation and use of R_f values.

- **a** A pure substance produces only one spot in all solvents. Two or more spots means a **mixture** (impure).
- **b** Run the unknown alongside **known reference substances** on the same paper; a spot level with a known substance identifies it.
- **c** R_f values let you compare different experiments, because a ratio does not depend on how far the solvent ran.

Making water potable (2.12)

You must **describe how**: a waste and ground water can be made potable, including the need for sedimentation, filtration and chlorination; b sea water can be made potable by using distillation; c water used in analysis must not contain any dissolved salts.

a Treating waste and ground water

Stage	What happens	Why it is needed
Sedimentation	Left to stand in a settlement tank so large insoluble particles (sand, grit, soil) sink	Removes the heaviest suspended solids
Filtration	Passed through beds of sand and gravel	Removes smaller insoluble particles still suspended
Chlorination	Chlorine gas bubbled through (or ozone / UV light)	Kills microorganisms , so the water cannot spread disease

b Sea water has far too much dissolved salt to drink, and dissolved salt cannot be filtered out. It is made potable by **distillation** — boiling the sea water and condensing the steam, leaving the salts behind. This gives very pure water but needs a **large amount of energy**, so it is expensive.

c Water used in analysis must not contain any dissolved salts. Potable water is **not pure** chemically — its dissolved salts and chlorine would react during a test and give a false result, so analysis uses **distilled** or **deionised** water.

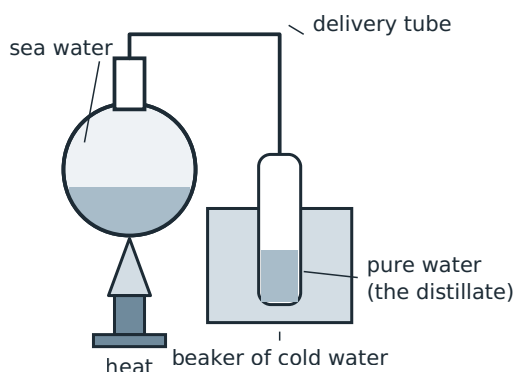
Making waste, ground and sea water potable

Making waste water and ground water potable

Potable water is water that is safe to drink. It is not pure water: it still contains some dissolved substances, but at levels low enough to be safe.



Making sea water potable — simple distillation



How it works

- 1 The sea water is heated until it boils.
- 2 The water evaporates, but the dissolved salts are left behind in the flask.
- 3 The steam is cooled by the cold water and condenses back to a liquid.
- 4 The liquid collected is pure water — it contains no dissolved salts.

Distillation needs a great deal of energy to boil the water, so it is expensive. It is used where fresh water is scarce.

Water used in chemical analysis

Water used in analysis must not contain any dissolved salts. Dissolved ions would take part in the test reactions and give a false result.

Distilled water is used instead of tap water, because distillation removes every dissolved salt.

Testing whether water is pure

- Pure water has a sharp melting point of 0 °C and boils at exactly 100 °C.
- Water with dissolved salts melts and boils over a range of temperatures, not at a single fixed value.
- Evaporate a sample to dryness: pure water leaves no solid residue behind.

Testing the purity of water. A pure substance has sharp fixed points, so measure the **boiling point (exactly 100 °C at normal pressure)** or **melting point (exactly 0 °C)**: boiling above 100 °C or melting below 0 °C shows dissolved solids. Or **evaporate to dryness** — pure water leaves no residue.

WATCH OUT

"Potable means pure." It does not. Potable water is *safe to drink*, but it is a **mixture** containing dissolved salts and a trace of chlorine. Only distilled or deionised water is pure water in chemistry.

2.3 Use of mathematics in this topic

- **Translate information between diagrammatic and numerical forms (4a)** — read melting and boiling points off heating and cooling curves.
- **Interpret charts (4a)** — read and measure from a chromatogram.
- Use **ratios (1c)** for R_f , to a sensible number of significant figures.