Cambridge IGCSE · Chemistry 0620 · Notes

Chromatography, separation and purification

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Read first: **States of matter**, **Experimental design and titrations**

What you need to know

By the end of this topic you should be able to:

1. **Describe paper chromatography**: how it separates a mixture of soluble coloured substances, using a suitable solvent.
2. **Read a simple chromatogram** to identify an unknown substance by comparing it with known ones, and to tell a pure substance from an impure one (a mixture).
3. **Extended only:** describe how paper chromatography separates **colourless** soluble substances: after the run, a **locating agent** makes the invisible spots show up. You don't need to name any particular locating agent.
4. **Extended only:** state and use the equation $R_f = \dfrac{\text{distance moved by the substance}}{\text{distance moved by the solvent}}$.
5. **Describe and explain five ways of separating and purifying**: dissolving one part in a suitable solvent, filtration, crystallisation, simple distillation and fractional distillation.
6. **Suggest a suitable method** (or order of methods) for a mixture, from information about its substances, such as which ones dissolve and their boiling points.
7. **Identify a substance and judge its purity** from its melting point and boiling point.

The words solvent, solute, solution, residue and filtrate are taught in Experimental design and titrations, and what makes a mixture different from a compound is in Elements, compounds and atomic structure. This note uses both.

Understand it

Every method uses a difference

A mixture can be separated because its substances are **not chemically joined**, and each one keeps its own properties. Every separation method uses one property the substances **don't share**:

The substances differ in	Method
whether they dissolve in a solvent	dissolve one of them, then filter
solid that won't dissolve, in a liquid	filtration
a dissolved solid, to be got back as crystals	crystallisation
a liquid (solvent) to be got back from a solution	simple distillation
boiling points, in a mixture of liquids	fractional distillation
how far they travel up paper in a solvent	chromatography

So the first question for any mixture is always: **what is different about the substances in it?**

Using a suitable solvent

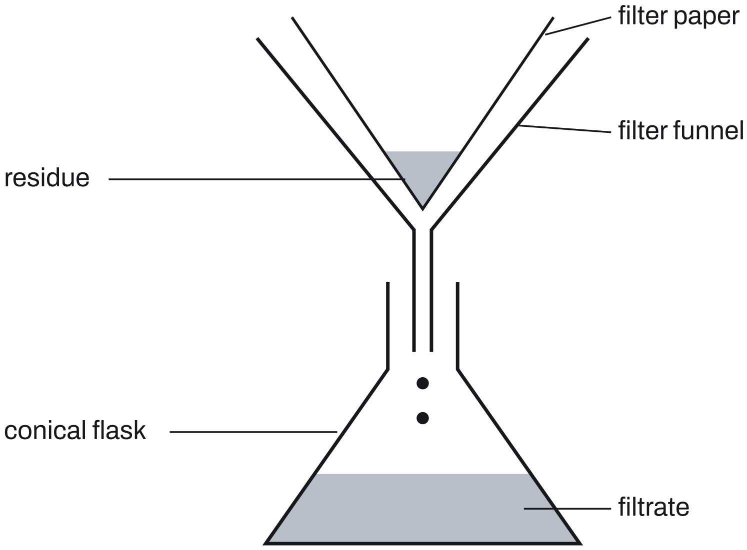
A **suitable solvent** dissolves the substance you want to remove (or keep) and **does not** dissolve the other one. Water is the usual choice for salts. For substances that don't dissolve in water, such as wax, oils or iodine, an organic solvent such as ethanol or hexane is used instead.

A solvent is useless if it dissolves **both** substances or **neither**. Salts such as sodium nitrate and potassium chloride both dissolve in water, so water alone cannot separate them. Silver chloride and barium sulfate both stay undissolved in water, so water can't separate them either.

Once one substance is dissolved, the mixture is filtered.

Filtration

Filtration separates an **undissolved (insoluble) solid** from a liquid or a solution. The mixture is poured into a filter funnel lined with folded filter paper. The liquid passes through the tiny holes in the paper; the solid particles are too big and stay behind.



- The solid left in the filter paper is the **residue**. Wash it with a little distilled water to rinse off the solution clinging to it, then dry it (between sheets of filter paper, or in a warm oven).
- Whatever passes through is the **filtrate**. It is often **not pure water**: anything dissolved in the mixture goes through the paper too. Sand in salty water gives a filtrate of salt solution.

Filtration is how you remove **excess solid reactant** after a reaction (for example leftover metal oxide after it has reacted with an acid), a **precipitate** from the solution it formed in, or **yeast** from a fermentation mixture.

Crystallisation

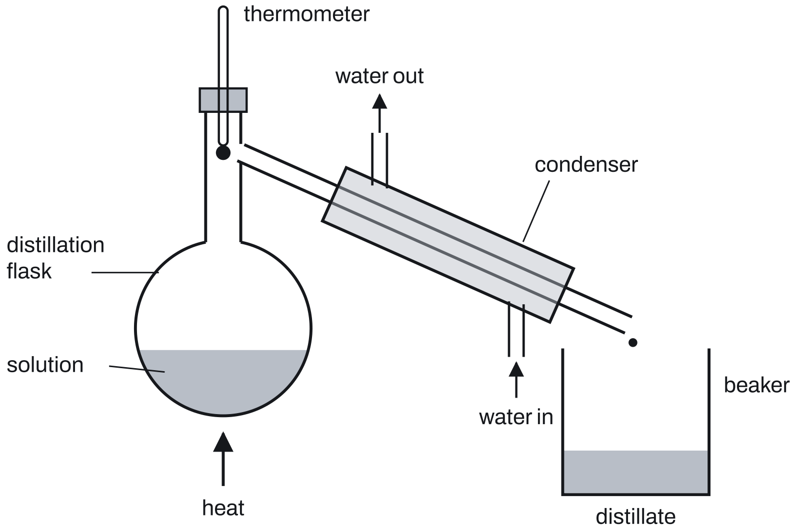
Crystallisation gets a dissolved solid back out of its solution as pure crystals. It is the last stage of making a soluble salt, which the Preparation of salts note covers in full. The steps are:

1. **Heat the solution** to evaporate some of the water, until it is nearly saturated (the **crystallisation point**). To check, dip in a glass rod: if small crystals form on it as it cools, stop heating.
2. **Leave it to cool.** Less solid can stay dissolved in cold water, so crystals form.
3. **Filter off the crystals**, wash them with a little cold distilled water, and **dry them** between sheets of filter paper.

Don't boil it **to dryness**. That gives a powder, not crystals, and any **soluble impurities** end up in it too; with crystallisation they stay behind in the leftover solution.

Simple distillation

Simple distillation gets the **solvent** back from a solution, for example pure water from salty water or from a coloured solution.



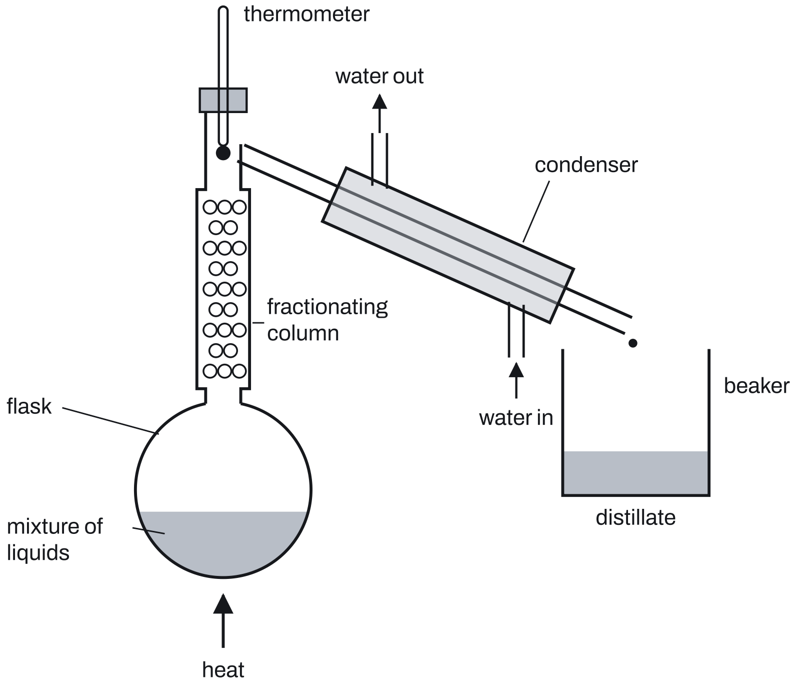
How it works:

1. **Heat** the solution. The **water boils** and turns to vapour. The dissolved solid has a far higher boiling point, so it **stays in the flask**.
2. The vapour passes into the **condenser**, where cold water flowing through the outer jacket **cools it, so it condenses** back to a liquid.
3. The pure liquid (the **distillate**) drips into the beaker.

The thermometer bulb sits level with the side arm, so it reads the temperature of the vapour actually leaving: 100 °C while pure water is distilling. Cold water enters the condenser at the **bottom** and leaves at the **top**, so the jacket stays full of water.

Fractional distillation

Fractional distillation separates **liquids that mix together** but have **different boiling points**, such as ethanol and water. A **fractionating column** (a tall tube packed with glass beads) is fitted between the flask and the condenser.

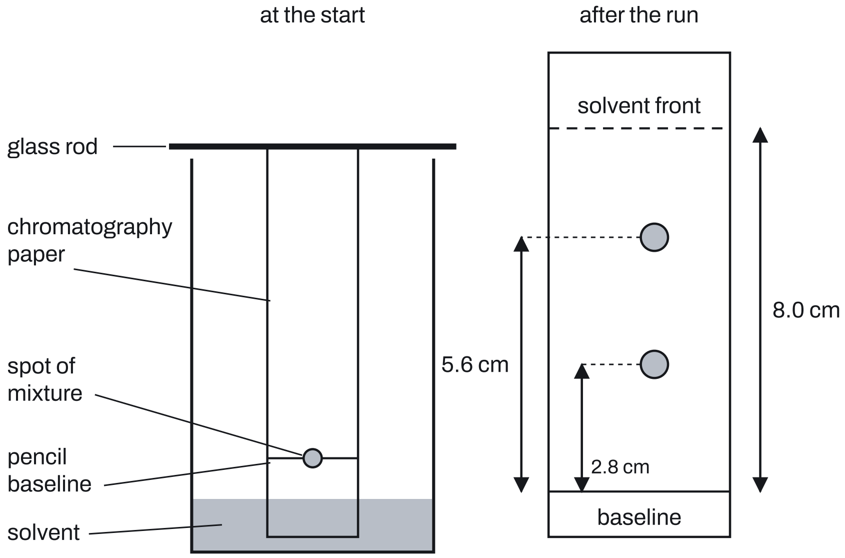


1. When the mixture is heated, both liquids evaporate, but the vapour rising up the column is **richest in the liquid with the lowest boiling point**.
2. The column is **hotter at the bottom and cooler at the top**. Vapour of the higher-boiling liquid **condenses** on the beads and runs back down; the lower-boiling liquid carries on up.
3. The liquid with the **lowest boiling point reaches the top first**, and the thermometer stays at **its** boiling point while it distils over.
4. When it has all gone, the temperature **rises** to the boiling point of the next liquid. Change the beaker to collect it separately.

The same idea separates petroleum into fractions, and oxygen and nitrogen from liquid air; those are in other topics. Here you need the method and why it works.

Paper chromatography

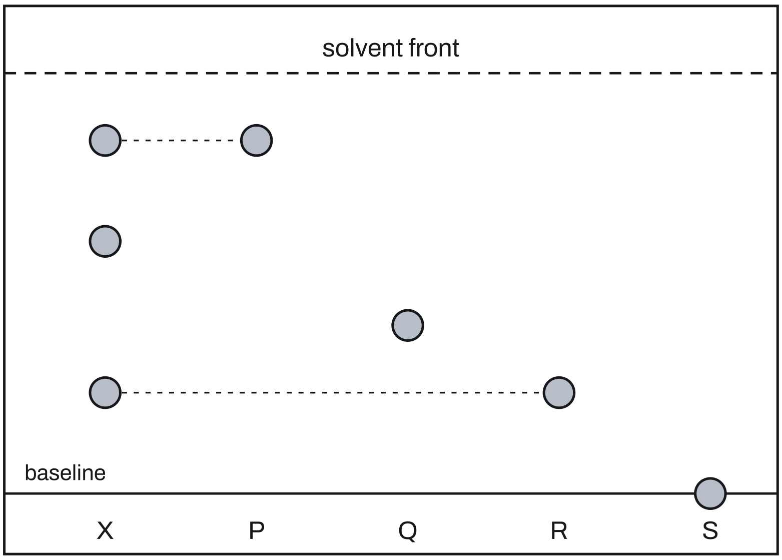
Chromatography separates **soluble** substances, such as the dyes in an ink or a food colouring. It uses so little of each that it is mainly used to **find out** what a mixture contains.



1. **Draw a baseline in pencil**, about 1–2 cm from the bottom of the paper. Pencil (graphite) does not dissolve in the solvent, so it stays put; ink would dissolve and run up the paper with the samples.
2. **Put a small spot** of the sample on the line (dissolve a solid first, for example in water or ethanol). Put spots of **known substances** on the same line, side by side.
3. **Stand the paper in a little solvent**, with the solvent level **below the baseline**. If the spots were under the solvent, they would dissolve into it instead of travelling up the paper.
4. The solvent soaks up the paper and carries each substance with it. A substance that **dissolves better in the solvent** is carried **further**; one that is held more by the paper lags behind. So the substances separate into spots.
5. Take the paper out before the solvent reaches the top, **mark the solvent front** (how far the solvent got) straight away in pencil, and let it dry. The finished paper is a **chromatogram**.

The solvent must suit the samples. A substance that doesn't dissolve in it at all **stays on the baseline**. Water works for many food dyes; other samples need an organic solvent such as ethanol.

Reading a chromatogram



- **One spot: a pure substance. Two or more spots: a mixture** (an impure substance). Above, P, Q and R are each pure; X is a mixture of at least three substances.
- **Spots at the same height** (in the same solvent, on the same paper) are **the same substance**. X's lowest spot is level with R and its top spot is level with P, so X contains **R and P**.
- **A spot that matches none of the known substances** is something else. X's middle spot is an **unknown** substance, not Q.
- **A spot still on the baseline** did not dissolve in this solvent: **S is insoluble** in it. X has no spot on the baseline, so X does not contain S.
- **Counting different substances** across several samples: count each **height** once, however many samples show it.

Colourless substances (Extended only)

Extended only: many substances, such as amino acids and sugars, are **colourless**, so their spots can't be seen. After the run, when the paper is dry, it is sprayed with a **locating agent**, which reacts with the substances and turns each spot a colour. Then the chromatogram is read in the usual way.

R_f values (Extended only)

Extended only: how far a substance travels depends on how long the run lasts, but the **fraction** of the solvent's distance it travels is fixed for that substance, that solvent and that paper. That fraction is its R_f value:

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

Measure **both distances from the baseline**: to the **centre** of the spot, and to the solvent front. In the chromatogram above, the solvent moved 8.0 cm, so

$$R_f = \frac{5.6}{8.0} = 0.70 \quad \text{and} \quad R_f = \frac{2.8}{8.0} = 0.35.$$

- R_f has **no units**, and it is always **less than 1**: no substance can travel further than the solvent carrying it.
- A **higher** R_f means the substance travelled further, because it is **more soluble in the solvent**.
- To identify a substance, compare its R_f with **known values for the same solvent**. Two substances that happen to have the same R_f in one solvent give a single spot; running the chromatogram again with a **different solvent** usually separates them.

Purity from melting and boiling points

A **pure** substance contains only one substance. It melts at **one exact temperature**, and boils at one exact temperature, which you can look up. For water they are 0 °C and 100 °C.

An **impurity** (anything mixed in, even a dissolved solid) changes this:

	Pure substance	Impure substance
melting point	sharp, at the known value	**lower**, and it melts over a **range** of temperatures
boiling point	sharp, at the known value	**higher**, and it boils over a range

So salty water freezes **below** 0 °C and boils **above** 100 °C. A solid that starts melting at 45 °C and has only just finished at 51 °C is impure.

This gives two uses:

- **Identify a substance**: measure its melting or boiling point and look for the substance with that value in a data table.
- **Judge purity**: measure it and compare with the pure substance's value. Sharp and equal means pure; different or over a range means impure.

Chromatography is a third purity test: a pure substance gives just one spot.

Purity matters most for things that go into the body. A medicine or a food must be pure, because an impurity could be harmful. In the laboratory, **distilled water** is used rather than tap water because it contains far fewer dissolved impurities, which might react or spoil a result.

Key facts and formulas

Nothing in this topic is printed on the exam paper, so everything is "Learn it".

Formula	Status
$R_f = \dfrac{\text{distance moved by the substance}}{\text{distance moved by the solvent}}$, both measured from the baseline (Extended only)	Learn it
$0 < R_f < 1$; no units	Learn it
Insoluble solid from a liquid or solution: **filtration**	Learn it

Formula	Status
Dissolved solid from its solution, as crystals: **crystallisation**	Learn it
Solvent (such as water) from a solution: **simple distillation**	Learn it
Liquids with different boiling points: **fractional distillation**	Learn it
Soluble coloured (or, Extended, colourless) substances: **chromatography**	Learn it
Impurities **lower** the melting point and **raise** the boiling point, and make both happen over a range	Learn it
Pure water: melts at 0 °C, boils at 100 °C	Learn it

How to do it

In the questions we have tagged for this topic (108 questions, 2021–2025; many multiple-choice questions appear on several papers, so there are 88 different ones), the types came up this often. 6 of the 108 questions mix two or three types, so the counts add up to 117.

Question type	Questions
Choosing the separation method	21
Reading a chromatogram	19
Carrying out chromatography	16
Rf values	15
Separation words: residue, filtrate, solute, solvent, mixture	15
Purity from melting and boiling points	12
Apparatus diagrams: identify, draw or label	10
Planning a separation from solubility information	8
Explaining simple distillation	1

1. Choosing the separation method (21 questions)

1. **Say what state each part is in**, and whether a solid is dissolved or not.
2. **Match it to the method** (table in "Key facts"):
   - an **undissolved solid** to be removed from a liquid or solution (excess reactant, a precipitate, yeast): **filtration**;
   - **crystals** from a solution: **crystallisation** (if the options are only evaporation, filtration, condensation and so on, choose **evaporation**, never filtration);
   - **pure water** from sea water or any solution: **distillation** (simple distillation);
   - a **mixture of liquids** with different boiling points (a set of alcohols, ethanol and water from fermentation): **fractional distillation**;

   - **soluble coloured substances**, or a mixture of amino acids or sugars, to separate or identify: **chromatography**.
3. Give the name exactly. "Distillation" for two liquids, or "evaporation" for pure water, loses the mark.

Variations you will meet:

- **Paper 4 "Name the process used to…" lists**, one word per line, mixed with processes from other topics (Haber process, electrolysis, cracking, titration). Read each line for the key words: "undissolved solid" → filtration; "water from aqueous sodium chloride" → distillation; "several liquids with different boiling points" or "nitrogen from liquid air" → fractional distillation; "soluble coloured substances" or "a mixture of amino acids" → chromatography.
- **Ethanol from a fermentation mixture**: filter off the yeast first; the ethanol is then separated from the water by **fractional distillation**, not by evaporating the water.
- **The reverse question**: "which kind of mixture does filtration separate?" An insoluble solid from a liquid.
- **Paper 3 "name a process that makes this water suitable for practical chemistry"**: distillation.

2. Reading a chromatogram (19 questions)

1. **Draw a ruler line across** from each spot of the unknown, level with it.
2. **A known substance with a spot on that line is present.** List them.
3. **Check what's left over**: a spot of the unknown matching nothing is an unknown substance; a known substance with no matching spot is not present.
4. **Count spots**: one = pure, more = mixture.

Variations you will meet:

- **"Which statements are correct?"** Check each one against the picture. A spot left on the baseline means that substance is **insoluble in the solvent** (not that it is "pure" or "not present").
- **"Contains P, S and another substance"**: pick this when one of the unknown's spots matches no reference.
- **"How many different dyes are there in these samples?"** Count each height once. Two red spots at the same height in two sweets are the **same** red dye; red spots at two heights are two different dyes.
- **A known dye with two spots** is itself a mixture, and a sample "is a mixture of Q and one other substance" when it has Q's spot plus one more.
- **Paper 3 structured**: "which sample contains the most substances?" (the one with the most spots) and "which two contain exactly the same substances?" (the same set of heights).
- **Extended only: fewer spots than substances.** If a mixture of four substances gives three spots, two of them have the **same** R_f in that solvent. Repeat with a **different solvent** to separate them.

3. Carrying out chromatography (16 questions)

1. Baseline **in pencil**, near the bottom of the paper.
2. **Spots** of the sample (and of known substances) **on the baseline**.

3. Paper in the solvent with the **solvent level below the baseline**.
4. **Remove** the paper before the solvent front reaches the top.
5. **Mark the solvent front**, and let the paper **dry**.
6. **Extended only:** for colourless substances, **spray with a locating agent**.

Variations you will meet:

- **"Why is the baseline drawn in pencil, not ink?"** Pencil does not dissolve in the solvent (it won't run up the paper); ink would dissolve and separate as well.
- **Put the steps in order**: exactly the order above. The solvent front is marked **before** spraying, because it can't be seen once the solvent evaporates.
- **Which diagram shows the right start?** The one with the solvent **below** the spots and the baseline.
- **Complete a diagram** (Paper 3): mark the sample on the baseline, **in line with** the other spots, and draw the solvent level **below** it, with the paper dipping into the solvent.
- **Label the solvent front**: the line reached by the solvent, above the highest spot.
- **Name the method** from a drawing of paper standing in a solvent: (paper) chromatography.
- **"Which statement about chromatography is correct?"** True: it can show whether a substance is pure; it separates **soluble** substances; colourless ones can be seen with a locating agent (Extended). False: it separates **insoluble** substances, splits a **compound into its elements**, dissolves the paper, separates solvents, or needs the solvent to cover the baseline.
- **Extended only: "what is used to detect colourless substances?"** A locating agent (not an oxidising, reducing or dehydrating agent).

4. Rf values (15 questions)

These are **Extended only**.

1. **Find the two distances from the baseline**: to the centre of the spot, and to the solvent front.
2. If the lengths are measured from the **bottom of the paper**, subtract the baseline's height from **both** first.
3. **Divide**: $R_f = \dfrac{\text{spot distance}}{\text{solvent distance}}$. Check the answer is less than 1.

Variations you will meet:

- **Pick the right formula**: substance on top, solvent underneath. Reject solvent ÷ substance (it gives more than 1), a difference of the distances, and anything with the locating agent in it.
- **Pick the right two distances** from labelled arrows: both start at the baseline; one ends at the spot, the other at the solvent front. Arrows from the bottom of the paper, or from the solvent level in the beaker, are traps.
- **Paper 4 "complete the equation for R_f"**: write both parts (distance moved by the substance; distance moved by the solvent).
- **Work backwards**: solvent distance $=$ spot distance $\div R_f$, or spot distance $= R_f \times$ solvent distance.

- **Which two substances are the same?** Work out each R_f from the table and look for two equal values. The distances alone can differ if the runs lasted different times.
- **True or false statements**: R_f is always less than 1; a higher R_f means it travelled further and is more soluble in the solvent; two different substances **can** share an R_f value.
- **Which substance is most soluble in the solvent?** The one with the largest R_f (the spot that moved furthest).

5. Separation words: residue, filtrate, solute, solvent, mixture (15 questions)

1. **Residue**: the solid left in the filter paper. **Filtrate**: what passes through.
2. The filtrate still contains **everything that was dissolved**, so it is a solution, not pure water.
3. **Solute**: what dissolves; **solvent**: what it dissolves in; **solution**: the mixture they make.

Variations you will meet:

- **Fill the gaps** in a method: the mixture is added to a suitable **solvent**, and the insoluble solid collected on the filter paper is the **residue**.
- **Name X and Y** on a filtration diagram: the solid in the paper is the residue, the liquid in the flask is the filtrate.
- **Sugar dissolved away from broken glass** (or salt from sand): the filtrate is the **sugar solution**, not pure water and not the glass.
- **"Which statement is correct?"** about a rock-salt style method: the salt is the solute; the water is the solvent; the filtrate is salt solution; the residue is the insoluble part, not the salt.
- **Is the starting sample a mixture or a compound?** Two substances that can be separated by dissolving and filtering, with no reaction, make a **mixture**.
- **Paper 3 definitions**, in your own words: the **solvent** is the liquid that does the dissolving; a **solution** is what you get when a solute dissolves in a solvent (a mixture, not a new substance). For two features of a **mixture**, say that its substances are only mixed, with no bonds formed between them; that you can get them apart again without a chemical reaction (by filtering or distilling, say); that their amounts can vary; or that each one behaves as it does on its own.

6. Purity from melting and boiling points (12 questions)

1. **Compare** the measured value with the pure substance's value.
2. **Impure**: melting point **lower** and over a **range**; boiling point **higher** (and over a range).
3. **Pure**: melts or boils sharply at one temperature, the known value.

Variations you will meet:

- **Which values could belong to the impure sample?** Melting point below the pure value **and** boiling point above it. For water, a melting point of -2 °C with a boiling point of 101 °C, not $+2$ °C or 99 °C.
- **Which row shows the change?** Boiling point **increases**, melting point **decreases**.
- **"Melts from 45 °C to 49 °C"** means impure; "boils at 141 °C and stays there" means pure.

- **Paper 3, 2 marks: "Describe how to test whether a sample of water is pure using its boiling point (or melting point)."**
  1. **Measure** its boiling point (heat it until it boils and read the thermometer), or its melting point (freeze it, let it warm, and read the temperature as it melts) **(1)**.
  2. **Compare**: pure water boils at exactly 100 °C (melts at exactly 0 °C); if it boils higher, or melts lower, or over a range, it is impure **(1)**.
- **Which methods test purity?** Melting point, boiling point **and** chromatography, all three.
- **Which substance must be pure?** A medicine (drug) or a food; not limestone for a furnace, petroleum for distillation or water for washing a car.
- **"Why is distilled water used in practical chemistry rather than tap water?"** It contains fewer impurities (tap water has dissolved substances that could interfere).

7. Apparatus diagrams: identify, draw or label (10 questions)

1. **Recognise the set-up**: funnel and filter paper, filtration; flask, thermometer and condenser, distillation (with a column packed with beads, fractional distillation); paper in a solvent, chromatography.
2. **For "what is the mixture?"** pick the one the method can separate. Filtration needs an **undissolved solid** with a liquid or solution (a metal or hydroxide precipitate with a salt solution; not two solutions, or two solids, or two liquids). A heated flask with a fractionating column needs **two liquids**, such as two alcohols.
3. **To label**: residue (in the filter paper), filtrate (in the flask), condenser (the jacketed tube), fractionating column (the tall packed tube).

Variations you will meet:

- **Draw filtration apparatus** (Paper 3, 3 marks): a filter funnel with the filter paper drawn **inside** it, over a flask or beaker **(1)**; label the **filtrate** in the flask **(1)** and the **residue** in the paper **(1)**. Use the first diagram in "Understand it" as your model.
- **Which set of apparatus separates liquids with different boiling points?** The one with heat, a fractionating column and a condenser.
- **Name the method shown**: distillation (a flask with a condenser) or chromatography (paper in a solvent).

8. Planning a separation from solubility information (8 questions)

1. **Sort each substance**: which solvent does it dissolve in, and which does it not?
2. **Add the solvent** that dissolves only one of them, **stir**, then **filter**. The dissolved one is in the filtrate; the other is the residue.
3. **Get the dissolved one back** by **crystallisation** of the filtrate (or evaporation). Wash and dry the residue.
4. For **three** substances, repeat with a second solvent. Add it to **whichever part still holds two substances**, often the residue.

You need to know which common substances dissolve in water (from Preparation of salts): all sodium, potassium, ammonium and nitrate salts dissolve; chlorides do, except silver and lead chlorides; sulfates do, except barium, calcium and lead sulfates; carbonates and hydroxides don't, except sodium, potassium and ammonium ones. Metals and sand don't dissolve.

Variations you will meet:

- **Which pair of solids can be separated by adding water, stirring and filtering?** Exactly one must dissolve. An ammonium salt with silver chloride works; two nitrates (both dissolve) or two hydroxides (neither dissolves) don't.
- **Put stages in order**: add water and stir → filter → crystallise the filtrate.
- **Data including boiling points you don't need**: if one solid dissolves in water and the other doesn't, water, stir and filter is the answer. Fractional distillation is only for liquids, and a solvent that dissolves neither solid (such as kerosene for two salts) is no use.
- **A reaction as the "solvent"**: to separate copper from copper(II) oxide, add dilute acid; the oxide reacts to make a soluble salt, and the copper (which doesn't react) is filtered off.
- **Two solvents, three solids**: for example, a mixture of a salt (dissolves only in water), a solid that dissolves only in an organic solvent, and sand (dissolves in neither). Water → filter (salt in the filtrate) → add the organic solvent **to the residue** → filter again (sand is the residue).

9. Explaining simple distillation (1 question)

1. **Heating makes the water boil** (evaporate), and the dissolved solid stays in the flask **(1)**.
2. **The steam condenses** (turns back to liquid) **in the condenser**, and the pure water is collected **(1)**.

Say **where** each change happens: boiling in the flask, condensing in the condenser.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

A student has a mixture of zinc oxide and potassium sulfate. Zinc oxide is insoluble in water. Potassium sulfate is soluble in water.

(a) Describe how the student can obtain a dry sample of zinc oxide from the mixture. **[3]**

(b) Describe how the student can then obtain crystals of potassium sulfate. **[3]**

(c) Name the solid collected in the filter paper and the liquid that passes through it. **[2]**

(d) The student wants to collect pure water from some potassium sulfate solution. Name the method and explain how it separates the water. **[3]**

(a) Add water to the mixture and stir, so the potassium sulfate dissolves **B1**. Filter; the zinc oxide stays in the filter paper **B1**. Wash it with a little distilled water and dry it between filter papers (or in a warm oven) **B1**.

(b) Heat the filtrate to evaporate some of the water until crystals start to form on a cold glass rod (the crystallisation point) **B1**. Leave the solution to cool so crystals form **B1**. Filter off the crystals and dry them between sheets of filter paper **B1**. (Boiling it all away to dryness would not earn the first mark.)

(c) The zinc oxide in the filter paper is the **residue B1**; the potassium sulfate solution that passes through is the **filtrate B1**.

(d) Simple distillation B1. The water boils and leaves the flask as steam, while the potassium sulfate stays behind **B1**. The steam is cooled and condenses back to liquid water in the condenser, and is collected **B1**.

Example 2

A student wants to know which dyes were used on a T-shirt. The dye is dissolved and spotted on chromatography paper, next to four known dyes, K, L, M and N. The table shows how far each spot moved from the baseline. The solvent moved 7.5 cm.

Sample	Distances moved by its spots / cm
T-shirt dye	1.2, 3.9, 6.0
K	3.9
L	2.4
M	6.0
N	0

(a) Explain why the baseline is drawn in pencil. **[1]**

(b) State why the solvent level must be below the baseline at the start. **[1]**

(c) How many substances are in the T-shirt dye? Which of the known dyes does it contain? **[2]**

(d) What does the result for N show? **[1]**

(e) **Extended:** Calculate the R_f value of the spot that moved furthest in the T-shirt dye. **[1]**

(f) **Extended:** In this solvent, dye Z has an R_f value of 0.16. Show that Z could be the third substance in the T-shirt dye. **[2]**

(a) Pencil does not dissolve in the solvent, so it won't run up the paper and mix with the spots **B1**.

(b) Otherwise the spots would dissolve into the solvent in the beaker instead of moving up the paper **B1**.

(c) Three spots, so **three** substances **B1**. It contains **K and M**: their spots are at 3.9 cm and 6.0 cm, the same as two of its spots **B1**.

(d) N did not move, so it is **insoluble** in this solvent **B1**.

(e) $R_f = \dfrac{6.0}{7.5} = 0.80$ **B1**

(f) Its R_f is $\dfrac{1.2}{7.5} = 0.16$ **M1**, the same as dye Z's in this solvent, so it could be Z **A1**.

Example 3

A mixture of hexane (boiling point 69 °C) and octane (boiling point 126 °C) is separated.

(a) Name the method used. **[1]**

(b) Explain which liquid is collected first, and state the thermometer reading while it is collected. **[3]**

(c) Two samples are then tested.

Sample	Result
sample 1	boils at 69 °C and stays at 69 °C while it boils
sample 2	starts to boil at 128 °C and the temperature keeps rising to 133 °C

Deduce which sample is pure, and identify it. Explain your answers. **[3]**

(d) A white solid is thought to be one of three substances:

Substance	Melting point / °C
A	114
B	122
C	135

The solid melts at exactly 122 °C. Identify it and state whether it is pure. **[2]**

(a) Fractional distillation B1. (Just "distillation" is not enough for two liquids.)

(b) Hexane is collected first **B1**, because it has the **lower boiling point**, so its vapour reaches the top of the fractionating column while octane vapour condenses in the column and runs back **B1**. The thermometer reads 69 **°C B1**.

(c) Sample 1 is **pure hexane**: it boils sharply at hexane's boiling point **B1 B1**. Sample 2 is **impure**: it boils above octane's boiling point (126 °C) and over a range (128 to 133 °C) **B1**.

(d) B B1; it is **pure**, because it melts sharply at exactly B's melting point **B1**.

Example 4

This question is about **Extended** content.

Fruit juice contains sugars, which are colourless. A student runs a chromatogram of the juice. The solvent moves 9.0 cm. The table gives the R_f values of three sugars in this solvent.

Sugar	R_f
sucrose	0.18
glucose	0.33
fructose	0.38

(a) State what the student must do to see the spots. **[1]**

(b) The juice gives two spots, 1.62 cm and 2.97 cm above the baseline. Identify the two sugars. **[3]**

(c) The student says the juice cannot contain fructose, because there is no spot for it. Suggest why this might be wrong, and how to check. **[2]**

(d) In a second solvent, fructose has an R_f value of 0.58 and the solvent moves 9.0 cm. Calculate how far fructose moves. **[1]**

(a) Let the paper dry, then spray it with a **locating agent B1**.

(b) $\frac{1.62}{9.0} = 0.18$ and $\frac{2.97}{9.0} = 0.33$ **M1** (both R_f values worked out). The spots are **sucrose A1** and **glucose A1**.

(c) Glucose (0.33) and fructose (0.38) have similar R_f values, so a fructose spot could overlap the glucose spot **B1**. Run the chromatogram again with a **different solvent**, in which they move different distances **B1**.

(d) $0.58 \times 9.0 = 5.22$, so about 5.2 cm **B1**.

Common mistakes

- **Filtration diagrams without the filter paper in the funnel.** Examiners see the paper drawn flat across the top of the funnel, or the funnel missing. Draw the paper as a V lining the inside of the funnel.
- **Mixing up residue and filtrate.** The residue stays **in** the paper; the filtrate goes **through**. And a filtrate is not "pure water" if something was dissolved.
- **"Distillation" when fractional distillation is needed.** Two or more liquids need a fractionating column. Petroleum, liquid air and ethanol from water are all **fractional** distillation.
- **Heating to dryness instead of crystallising.** Heat only to the crystallisation point, then leave to cool. "Crystallise the solution" alone does not describe how; and "dry the crystals" should say how (with filter paper).

- **Forgetting to filter off an excess solid first**, or then using the residue instead of the filtrate for the crystals.
- **Explaining distillation without places.** Say the water **boils in the flask** and **condenses in the condenser**; "the water comes off" earns nothing.
- **Solvent above the baseline.** In drawings of the start of a chromatogram, the solvent is often drawn covering the spots. It must be below them.
- **Counting spots, not substances.** Two red spots at the same height in two samples are one dye, not two.
- **Melting a solid sample for chromatography.** Dissolve it in a solvent instead.
- **Getting the impurity effect half right.** Many candidates know the boiling point goes up but choose a melting point that also goes up. The melting point goes **down**.
- **Vague purity tests.** "Check the melting point" is not enough: say you measure it and compare it with the pure value (0 °C for water), and what an impure result looks like.
- **Extended: R_f upside down**, or measured from the bottom of the paper instead of the baseline. The answer must be below 1.

How to get the marks

- **"Name the process/method"** wants the exact term: filtration, crystallisation, (simple) distillation, fractional distillation, chromatography. One word, spelt so it can be recognised.
- **"Describe how"** (a separation) wants the steps in order with the key word for each: dissolve (in a named solvent) and stir → filter → heat to the crystallisation point → cool → filter → dry (with filter paper). Each step is usually a mark.
- **"Explain"** (distillation, chromatography) wants the reason as well as the step: the water **boils** and the salt doesn't; pencil **doesn't dissolve** in the solvent.
- **Drawing marks** come from what the examiner can recognise: a funnel with filter paper inside it, and the words filtrate and residue on the right parts. Label with lines that touch the part.
- **Purity answers** have two marks: the measurement, and the comparison with the pure value, including which way an impure sample differs (melting point lower, boiling point higher, or over a range).
- **Reading chromatograms**: use the heights, not the colours. In "which statements are correct?" questions, test every statement separately.
- **Extended, R_f**: give the value to two decimal places unless told otherwise, without units, and show the division. For "complete the equation", both the top and the bottom are marked.
- **Multiple choice**: look for the one difference between the substances; that tells you the method.

Quick check

1. Name the method used to:
   - (a) obtain crystals of zinc sulfate from aqueous zinc sulfate;
   - (b) remove unreacted solid zinc carbonate after it has reacted with an acid;
   - (c) obtain water from aqueous potassium manganate(VII);

- (d) separate propanone (boiling point 56 °C) from water;
- (e) find out whether a green food colouring is a single dye.

2. **Extended:** (a) A spot moves 2.1 cm and the solvent moves 7.0 cm. Calculate the R_f value. (b) A substance has an R_f value of 0.55. The solvent moves 6.0 cm. How far does the substance move?
3. A sample of water freezes at -1.5 °C and boils at 100.4 °C. Is it pure? Explain, and name a method that would give pure water from it.
4. Describe how to obtain a dry sample of each substance from a mixture of magnesium carbonate and potassium chloride.
5. A student draws the baseline in ink and puts the paper in the beaker so that the solvent covers the spots. Give the effect of each mistake.

Answers

1. (a) Crystallisation. (b) Filtration. (c) Simple distillation. (d) Fractional distillation. (e) Chromatography: one spot means a single dye.
2. (a) $R_f = \frac{2.1}{7.0} = 0.30$. (b) $0.55 \times 6.0 = 3.3$ cm.
3. No. Pure water freezes at exactly 0 °C and boils at exactly 100 °C; this sample freezes lower and boils higher, so it contains a dissolved impurity. Simple distillation would give pure water.
4. Add water and stir: potassium chloride dissolves, magnesium carbonate doesn't. Filter. Wash the residue (magnesium carbonate) with distilled water and dry it. Heat the filtrate to the crystallisation point, leave it to cool, filter off the potassium chloride crystals and dry them between filter papers.
5. The ink dissolves in the solvent and runs up the paper, giving extra spots that confuse the result. The spots dissolve into the solvent in the beaker, so they don't travel up the paper and no chromatogram forms.

Past questions to try

- **0620/43/M/J/24 Q1**: naming processes, including filtration, chromatography and fractional distillation.
- **0620/41/O/N/24 Q6**: parts (e) and (f), the R_f equation, pencil baselines, a locating agent and two amino acids with the same R_f.
- **0620/21/O/N/22 Q3**: separating three solids with two solvents.
- **0620/31/O/N/23 Q2**: part (a), explaining how distillation separates water from a solution.