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IB DIPLOMA PROGRAMME · CHEMISTRY (2023 SYLLABUS)

Structure 1.1.1 Elements, Compounds & Mixtures

Complete revision notes, original particle diagrams, worked examples, exam-style practice & full mark-scheme guidance

SL + HL

No separate AHL content in Structure 1.1.1 — this whole booklet is common to SL and HL.

0 How to use these notes

Structure 1.1.1 is short in the syllabus but highly testable because it links **classification**, **particle models** and **practical separation**. Learn the definitions precisely, then practise choosing a separation method from the physical properties given.

Syllabus focus	Level	What you should be able to do	Section
Elements, compounds, mixtures	SL + HL	Distinguish them using atom type, chemical bonding, fixed/variable composition and method of separation.	1–2
Particle-level models	SL + HL	Interpret diagrams for pure elements, molecular elements, pure compounds and different types of mixtures.	2
Types of mixture	SL + HL	Distinguish homogeneous from heterogeneous mixtures and recognise solutions and alloys as mixtures.	3
Physical separation	SL + HL	Understand solvation, filtration, recrystallization, evaporation, distillation and paper chromatography.	4–6
Choosing a method	SL + HL	Select a technique from solubility, particle size, volatility/boiling point and differing affinities; plan purification steps.	4–7

SYLLABUS FOCUS

The examinable skill is not just naming apparatus. You should be able to explain **which physical property is being exploited** and why that method separates the components.

Core idea: compounds are chemically bonded in a fixed ratio; mixtures are not, so their components can be separated physically.

1 Elements, compounds and mixtures SL + HL

1.1 The three definitions you must know

Element

A pure substance containing only one **type of atom**. An element cannot be chemically broken down into a simpler substance.

Examples: He, Fe, O₂, S₈.

Compound

A pure substance made from atoms of **different elements chemically bonded in a fixed ratio**.

Examples: H₂O, CO₂, NaCl, MgO.

Mixture

Two or more elements and/or compounds present in no fixed ratio and not chemically bonded to each other.

Examples: air, seawater, brass, muddy water.

1.2 Compare them directly

Feature	Element	Compound	Mixture
Composition	One type of atom	At least two different elements	At least two substances
Ratio of components	Not applicable	Fixed by the chemical formula	Variable
Chemical bonding between components	Atoms may or may not be bonded to identical atoms	Yes — different elements are chemically bonded	No chemical bonds joining one component to another
Pure substance?	Yes	Yes	No
Can be separated into components by physical methods?	No	No	Yes
Properties	Characteristic of that element	Often very different from constituent elements	Components largely retain their own characteristic properties

REMEMBER — MOLECULE ≠ COMPOUND

O₂ is a molecule but it is still an **element** because both atoms are oxygen. H₂O is both a molecule and a compound. NaCl is a compound, but in the solid it is an extended ionic lattice, so we describe **formula units** rather than discrete NaCl molecules.

WORKED EXAMPLE 1 — CLASSIFY AND JUSTIFY

Q. Classify each sample: (i) oxygen gas, O₂; (ii) pure water, H₂O; (iii) air; (iv) brass.

A. (i) **Element** — one atom type, even though atoms are bonded in O₂. (ii) **Compound** — H and O atoms are chemically bonded in a fixed ratio. (iii) **Mixture** — several gases in variable proportions. (iv) **Mixture (alloy)** — composition can vary; it is not described by one fixed chemical formula.

CLASSIC EXAM ERROR

"A compound contains more than one type of particle" is not a safe definition. A pure compound can contain only **one particle type** — for example, identical H₂O molecules. The key is **different elements bonded in a fixed ratio**.

2 Reading particle diagrams SL + HL

IB questions often replace chemical names with circles or spheres. Treat each colour/shading as a different atom type and look first at **how many particle types are present**, then at **whether different atom types are bonded together**.

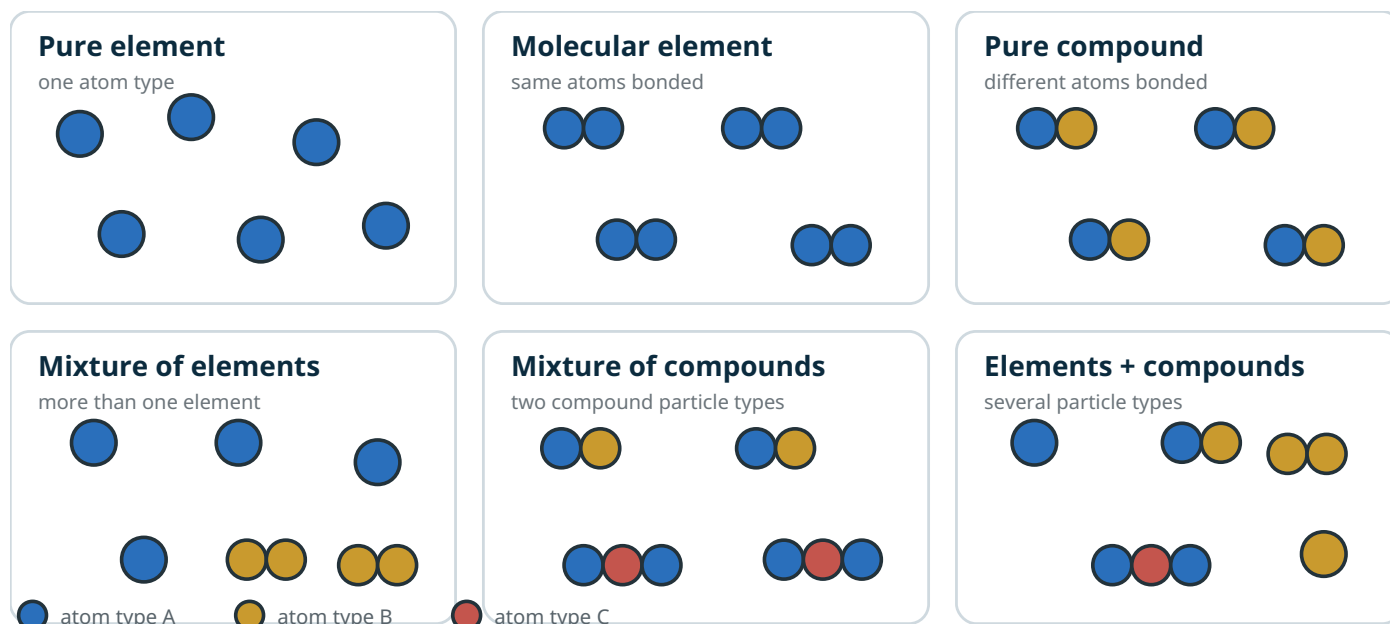


Figure 1 · Original particle-level models. Bonded circles form one particle; colour represents atom type, not physical state.

2.1 A reliable three-step decoding routine

Step	Ask yourself	What it tells you
1	Are all particles identical?	If yes, the sample is a pure substance . If no, it is a mixture .
2	Does each particle contain only one atom type?	If yes, the pure substance is an element (monatomic or molecular).
3	Does each identical particle contain different atom types bonded together?	If yes, the pure substance is a compound .

EXAM TIP

If two colours are merely close together but **not joined in the diagram**, do not assume a chemical bond. In particle questions, the drawing convention matters.

REMEMBER

A mixture can contain **elements only**, **compounds only**, or **both elements and compounds**.

WORKED EXAMPLE 2 — PARTICLE MODEL REASONING

Q. A box contains only identical particles. Each particle consists of one blue atom bonded to two gold atoms. Is the sample an element, compound or mixture?

A. It is a **pure compound**. There is only one particle type, so it is pure; each particle contains two different elements bonded together in the same fixed ratio.

COMMON ERROR

"Different colours means mixture." Not necessarily. If different atom types are **bonded into identical particles**, the sample is a compound. A mixture requires more than one substance/particle type present together.

3 Pure substances and types of mixture SL + HL

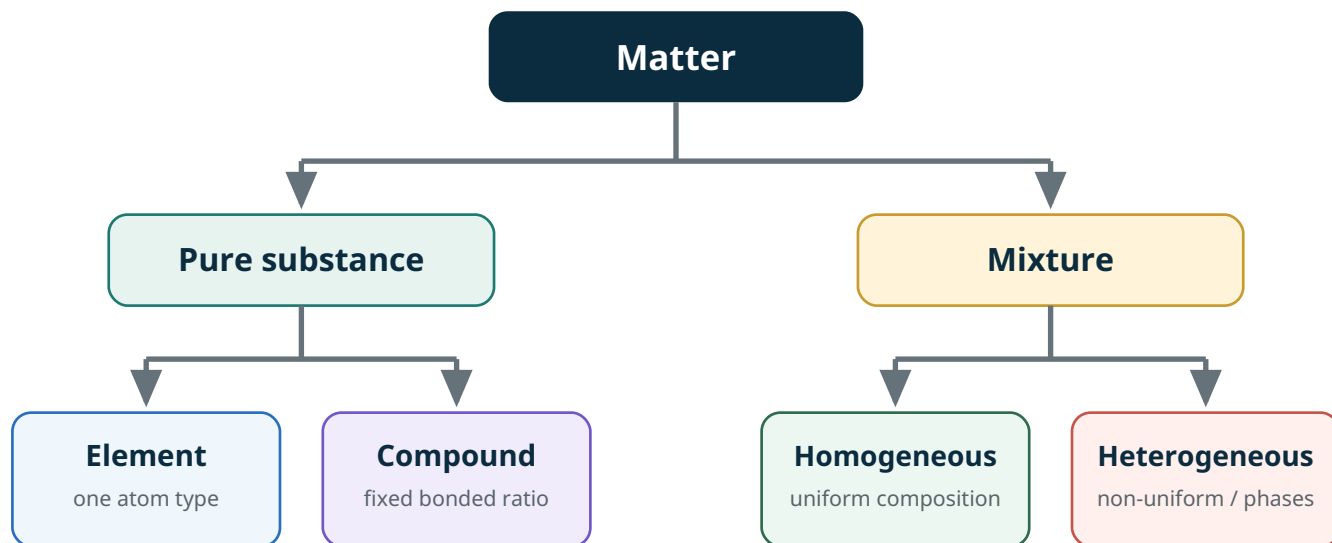


Figure 2 · Classification map for matter used in Structure 1.1.1.

3.1 Homogeneous vs heterogeneous mixtures

Feature	Homogeneous mixture	Heterogeneous mixture
Composition	Uniform throughout the sample at the scale being considered.	Not uniform throughout; visibly different regions or phases may be present.
Typical examples	Air, salt solution, sugar solution, many alloys.	Sand in water, oil and water, granite.
Useful model	One phase with components evenly distributed.	Two or more distinguishable phases/regions.

SOLUTION LANGUAGE

A **solution** is a homogeneous mixture. The substance dissolved is the **solute**; the medium doing the dissolving is the **solvent**. "Aqueous" means water is the solvent.

3.2 Why alloys are mixtures

Alloys contain a metal together with other metal(s) or non-metal(s). Their atoms may participate in metallic bonding, but an alloy usually has **variable composition** rather than one fixed whole-number ratio. That is why alloys are classified as **mixtures**, not compounds.

EXAM CONNECTION

Structure 2 later explains metallic bonding and alloy properties. In Structure 1.1.1, the classification argument is simpler: **variable composition** → **mixture**.

3.3 Pure substance vs "looks pure"

A clear, colourless sample is not automatically pure. Air and salt water can look completely uniform but are mixtures. A pure substance has a **fixed composition**; under fixed pressure, a pure substance also typically shows a characteristic melting/boiling point rather than the broader behaviour often seen in mixtures.

WORKED EXAMPLE 3 — THE "CLEAR LIQUID" TRAP

Q. A clear liquid contains water and dissolved sodium chloride. A student calls it a compound because it is uniform. Explain the mistake.

A. Uniform appearance makes it a **homogeneous mixture**, not a compound. The amount of NaCl can vary, NaCl is not chemically bonded to water in a fixed ratio, and the components can be separated physically, for example by distillation or evaporation/recrystallization.

4 Choosing a separation method SL + HL

Mixtures can be separated because their components have **different physical properties**. The separation method must match the property difference.

Method	Physical property exploited	Use it when...	Key exam words
Solvation	Difference in solubility in a chosen solvent	One component dissolves while another does not, or components have very different solubilities.	selective dissolution / soluble / insoluble
Filtration	Particle size + insolubility	An insoluble solid is suspended in a liquid.	residue / filtrate
Evaporation	Volatility of solvent	You want the dissolved solid and do not need to collect the solvent.	remove solvent / leave solute
Recrystallization	Solubility changes with temperature	You want to purify a soluble solid.	hot solvent / cool / crystals / mother liquor
Distillation	Difference in boiling point / volatility	You want to collect a volatile liquid from a mixture.	vaporize / condense / distillate
Paper chromatography	Different affinities for stationary and mobile phases	You need to separate/compare small amounts of dissolved substances.	stationary phase / mobile phase / spots

4.1 The selection logic

Solid + liquid

- **Solid insoluble?** → filtration.
- **Solid dissolved?** → evaporation or recrystallization if the solid is wanted.
- **Liquid wanted?** → distillation.

Several dissolved components

- Different affinities and small sample? → paper chromatography.
- Different boiling points and liquid components? → distillation.
- One component selectively soluble? → solvation, followed by another recovery step.

PHYSICAL SEPARATION DOES NOT BREAK CHEMICAL BONDS WITHIN A COMPOUND

When salt water is distilled, the process separates **water molecules from dissolved ions**; it does not chemically decompose H_2O or NaCl into their elements. By contrast, splitting a compound into simpler substances requires a **chemical change**.

HOW TO SCORE THE EXPLANATION MARK

Do not write only "use filtration". Add the property: "Use filtration because the solid is **insoluble** and its particles are retained by the filter paper while the liquid passes through."

5 Solvation, filtration, evaporation & recrystallization SL + HL

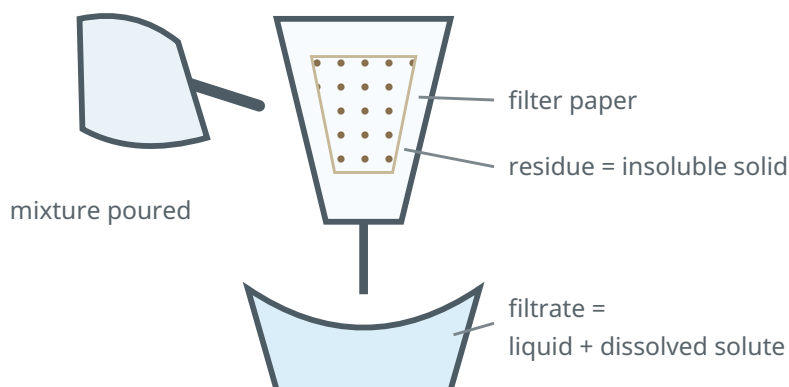
5.1 Solvation — dissolve selectively

Solvation is the interaction of solvent particles with a solute that allows the solute to disperse through the solvent. As a separation strategy, choose a solvent that dissolves one component much better than another.

WORKED EXAMPLE 4 — SALT + SAND

A mixture contains sodium chloride and sand. Add water: NaCl dissolves but sand does not. Filter to collect sand as the residue. The NaCl remains in the filtrate and can then be recovered by evaporation of the water.

Filtration: separate an insoluble solid from a liquid



IB language

- Insoluble solid stays as residue.
- Liquid passes through as filtrate.
- Dissolved solutes also pass through.
- It cannot remove a dissolved solute.

Figure 3 · Filtration separates an insoluble solid from a liquid; dissolved solutes pass through with the filtrate.

5.2 Evaporation vs recrystallization

Evaporation

Heat the solution so solvent escapes as vapour, leaving dissolved solid behind. Appropriate when the solid is stable to heating and maximum purity/large crystal formation is not the main goal.

Recrystallization

Used to **purify** a soluble solid. Make a hot concentrated solution, then cool it so the desired substance crystallizes while many soluble impurities remain in solution.

Recrystallization: purify a soluble solid



Why it works: the desired solid is much more soluble in hot solvent than in cold solvent; many soluble impurities remain in the mother liquor.

Figure 4 · A typical recrystallization sequence. Exact details depend on the substance and solvent.

COMMON ERRORS

Filtration cannot separate dissolved NaCl from water. Also, “evaporate all the water” is not the best wording when asked to prepare pure crystals by recrystallization: concentrate the solution, cool to crystallize, then filter, wash and dry the crystals.

6 Distillation and paper chromatography SL + HL

6.1 Distillation

In distillation, the more volatile component vaporizes preferentially. The vapour is cooled in a condenser and collected as the **distillate**. The method therefore exploits a difference in **boiling point / volatility**.

Simple distillation: exploit a difference in boiling point / volatility

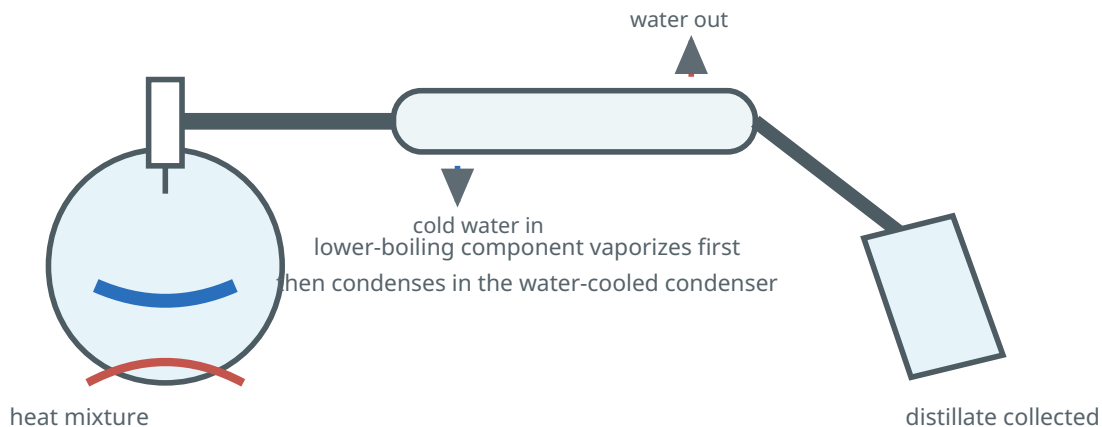


Figure 5 · Simplified simple-distillation apparatus. The thermometer is positioned to measure vapour temperature near the side arm.

EXAM TIP

If asked why distillation works, write the full causal chain: **different boiling points** → **one component vaporizes more readily** → **vapour passes into condenser** → **vapour condenses and is collected**.

6.2 Paper chromatography

Paper acts as the **stationary phase**; the solvent is the **mobile phase**. Components travel different distances because they have different relative attractions to the stationary phase and the moving solvent.

Paper chromatography: separate dissolved components by different affinities

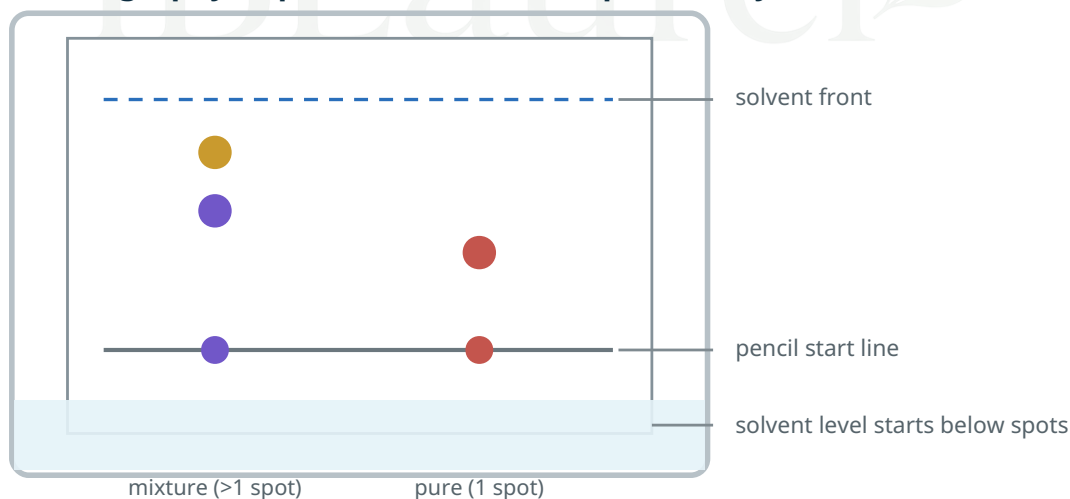


Figure 6 · Paper chromatography. A pure component ideally gives one spot; a mixture can give two or more spots under the chosen conditions.

COMMON SETUP ERROR

The start line must begin **above the solvent level**; otherwise the sample dissolves directly into the solvent reservoir.

WHY PENCIL?

A pencil line uses graphite, which is insoluble in the solvent and does not usually travel up the paper. Ink could separate and create extra spots.

7 Planning purification & exam technique SL + HL

7.1 Purifying a reaction product — think in a sequence

WORKED EXAMPLE 5 — COPPER(II) SULFATE CRYSTALS

A reaction mixture contains **aqueous copper(II) sulfate** and some **excess insoluble copper(II) oxide**. Describe how to obtain pure copper(II) sulfate crystals.

1. **Filter** to remove excess insoluble CuO as the residue.
2. Gently **evaporate some water** from the filtrate to make a concentrated solution.
3. Allow the solution to **cool** so CuSO₄ crystals form.
4. **Filter** the crystals, wash with a small amount of cold solvent and **dry** them.

Why this scores well: each operation is linked to a physical property — insolubility first, then temperature-dependent solubility.

7.2 What the command term is asking for

If the question says...	Your answer must contain...
"Distinguish element, compound and mixture"	Atom type + fixed/variable composition + bonding/separation.
"Explain why X is a mixture"	More than one substance, no fixed ratio, not chemically bonded to each other, physically separable.
"Identify the separation method"	Correct technique matched to the physical property in the stem.
"Explain how method X works"	Name the physical property difference and the step that exploits it.
"Describe how to purify..."	Give a sensible sequence; use terms such as filtrate, residue, concentrate, crystallize, distillate where relevant.

7.3 One-page revision checklist

Classification

- Element = one atom type.
- Compound = different elements bonded, fixed ratio.
- Mixture = variable ratio, components not chemically bonded.
- Molecule and compound are not synonyms.
- Alloys are mixtures.

Separation

- Filtration → insoluble solid.
- Evaporation/recrystallization → dissolved solid.
- Distillation → collect volatile liquid.
- Chromatography → dissolved components, different affinities.
- Always state the property exploited.

Fast test: fixed bonded ratio = compound · variable unbonded composition = mixture.

8 Practice questions

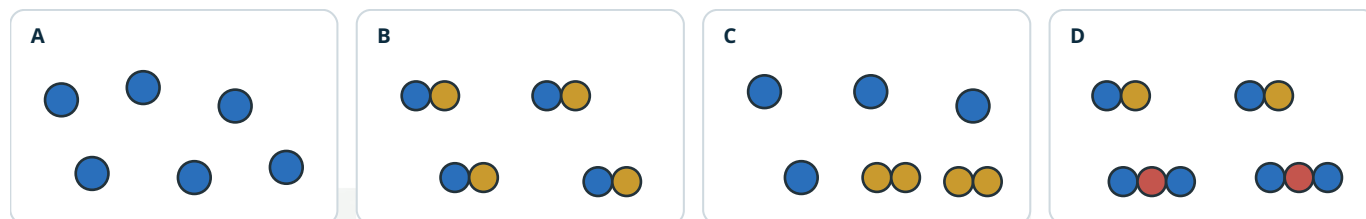
Attempt without looking back. The structured section contains **25 marks**. Full answers and mark-scheme notes follow in Section 9.

Part A — Multiple choice SL + HL

- Which sample is a pure substance containing more than one element?
A. air B. pure water C. brass D. salt solution
- Which is the best classification of $O_2(g)$?
A. monatomic element B. molecular element C. molecular compound D. mixture
- Which statement correctly distinguishes a mixture from a compound?
A. Mixtures contain only elements. B. Mixtures always contain visible phases.
C. Mixture composition can vary and components can be separated physically. D. Compounds can be separated by filtration.
- Which is most likely a homogeneous mixture?
A. oil + water B. air C. sand + water D. granite
- Which method is best for separating an insoluble solid from a liquid?
A. filtration B. paper chromatography C. distillation D. recrystallization
- In paper chromatography, why should the start line be drawn in pencil above the solvent level?
A. Pencil makes the solvent move faster. B. Graphite is normally insoluble and the sample must not begin submerged.
C. Pencil attracts all solutes equally. D. The line must dissolve to carry the sample.

Part B — Structured questions SL + HL

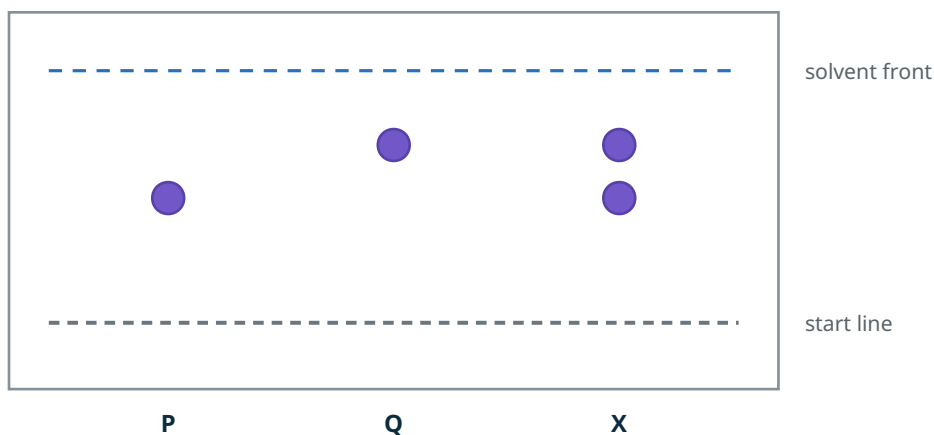
- Distinguish between an **element** and a **compound**. [2]
- The four boxes below show particle-level representations. Classify each as **element, compound or mixture**. [4]



- Seawater can be clear and uniform. Explain why it is nevertheless a **mixture** rather than a compound. [3]
- Stoichiometric amounts of powdered iron and sulfur are mixed together. Before heating, the iron can still be removed physically. After strong heating they react completely to form iron sulfide. Explain the classification of the material **before** and **after** the chemical reaction. [3]

8 Practice questions — continued

11. A dry mixture contains **sodium chloride and sand**. Describe how to obtain **dry sodium chloride crystals** and **dry sand** using water and standard laboratory separation methods. Your answer should name the key products at each stage. [5]
12. The chromatogram below shows two known substances, P and Q, and an unknown sample X. [4]



- (a) State whether X is pure or a mixture. [1]
- (b) Deduce which known substance(s), P and/or Q, are present in X. [2]
- (c) State one reason the start line should be drawn in pencil rather than ink. [1]

13. Use the data below to select and justify suitable separation methods. [4]

Mixture	Relevant data
A: solid R + water	R is insoluble in water.
B: liquids S + T	S and T are miscible; boiling points are 58 °C and 101 °C respectively.

- (a) Name a method for separating R from water and explain why it works. [2]
- (b) Name a method for obtaining the lower-boiling liquid from mixture B and explain why it works. [2]

TIMED-PRACTICE SUGGESTION

Allow about 1–1.5 minutes per structured mark. In explanation questions, underline the physical property in the stem before choosing the method.

9 Answers & mark-scheme notes

Part A — Multiple choice

1. **B** — pure H_2O contains two elements chemically bonded in a fixed ratio. Air, brass and salt solution are mixtures.
2. **B** — O_2 contains only oxygen atoms, so it is an element; two atoms are bonded, so it is molecular.
3. **C** — mixtures have variable composition and can be separated by physical methods.
4. **B** — air is a uniform mixture of gases under ordinary conditions.
5. **A** — filtration retains an insoluble solid as residue while liquid passes through.
6. **B** — graphite normally remains on the paper and the sample must not dissolve into the solvent reservoir at the start.

Part B — Structured

7. [2]

- An element contains only **one type of atom** and cannot be chemically broken down into a simpler substance. [1]
- A compound contains atoms of **different elements chemically bonded in a fixed ratio**. [1]

Marker's note: "element = one molecule" is incorrect; elements such as Fe are not molecular, while O_2 is.

8. [4]

- A = **element**. [1]
- B = **compound**. [1]
- C = **mixture** (mixture of elements). [1]
- D = **mixture** (mixture of compounds). [1]

9. [3]

- Seawater contains more than one substance (water plus dissolved salts/other solutes). [1]
- The proportions are **not fixed**; salinity can vary. [1]
- The components are not chemically bonded to each other in one fixed formula and can be separated by **physical methods**, e.g. distillation. [1]

Common lost mark: "It is a mixture because it has two things" is incomplete without fixed/variable composition or physical separability.

10. [3]

- Before heating: **mixture** because Fe and S are present together without being chemically bonded and can be separated physically. [1]
- Heating causes a **chemical reaction** forming iron sulfide. [1]
- After reaction: iron sulfide is a **compound** because Fe and S are chemically bonded in a fixed stoichiometric ratio in the product. [1]

9 Answers & mark-scheme notes — continued

11. [5]

- Add water and stir so the sodium chloride **dissolves** (solvation) while sand remains insoluble. [1]
- **Filter** the mixture. Sand remains as the **residue**; sodium chloride solution is the **filtrate**. [1]
- Wash the sand residue with a little water to remove adhering salt solution, then **dry** it. [1]
- Heat the filtrate so the water **evaporates** and sodium chloride crystals are left/formed. [1]
- Collect the sodium chloride crystals and **dry** them. [1]

Marker's note: For this salt-and-sand separation, evaporation is an appropriate recovery step for NaCl. Recrystallization is reserved for a solid whose solubility changes sufficiently with temperature.

12. [4]

- (a) X is a **mixture** because it produces two spots. [1]
- (b) X contains **P and Q**: one spot is at the same height as P and the other is at the same height as Q. [2]
- (c) Pencil graphite is normally **insoluble in the solvent** / will not travel and produce extra spots. [1]

Marker's note: "P and Q because the colours match" is not supported by this diagram. The evidence is the matching **positions** under the same conditions.

13. [4]

- (a) **Filtration**. [1] R is insoluble, so its solid particles are retained by the filter while water passes through. [1]
- (b) **Distillation**. [1] S has the lower boiling point, so it vaporizes preferentially and can be condensed/collected as distillate. [1]

Final exam checklist

Before you finish a classification answer

- Did I say **one atom type** for an element?
- Did I say **chemically bonded + fixed ratio** for a compound?
- Did I say **variable ratio + physical separation** for a mixture?

Before you finish a separation answer

- Did I name the technique?
- Did I name the **physical property** it exploits?
- Did I use terms such as residue/filtrate, crystals or distillate correctly?

End of Structure 1.1.1 · Elements, Compounds & Mixtures

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