LEARNERS' ALLEY
Designed by Khow Willard

1 Matter, Mixtures and Separation

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Chemistry is the study of matter: what it is made of and how it changes. This chapter starts from the particles in every substance, sorts substances into elements, compounds and mixtures, then separates mixtures and tests how pure the result is.

Learning objectives

By the end of this chapter, you can:

Foundation O LEVEL

- tell elements, compounds and mixtures apart, and read a simple chemical formula
- use the terms solute, solvent, solution, solubility, saturated, miscible and immiscible
- describe the kinetic particle theory, the three states of matter, changes of state and diffusion
- match separation methods to mixtures
- read chromatograms and R_f values
- use melting and boiling points to judge purity

Prerequisites

None. These lessons assume no prior knowledge, and each later chapter builds on the chapters before it. Fill in the blanks as the lesson goes. After every chapter there is a Kahoot quiz to check everyone's understanding, and the top three win a prize.

1.1 Elements, compounds and mixtures

All matter is made of tiny particles. An **atom** is the smallest particle of an element. Atoms can be joined together into a **molecule**. Every substance is an element, a compound or a mixture (Figure 1.1).

An **element** is a pure substance that cannot be broken down into two or more simpler substances by _____ methods. A **compound** is a pure substance containing two or more elements chemically combined in a _____ ratio. A **mixture** contains two or more elements or compounds that are _____ chemically combined.

- An element can exist as single atoms, such as helium and argon, or as molecules, such as oxygen, O_2.
- Each element has a symbol of one or two letters, such as H for hydrogen, O for oxygen and Na for sodium. A **chemical formula** shows the atoms in one particle. In H_2O the small 2 counts the hydrogen atoms, so a

water molecule always has _____ hydrogen atoms and one oxygen atom.

- A molecule can be an element or a compound. H_2 is an element because both atoms are hydrogen. CO_2 is a compound because it holds carbon and oxygen.
- Air is a mixture of nitrogen, N_2, oxygen, O_2, carbon dioxide, CO_2, and other gases. Its make-up varies: air at the top of a mountain holds less oxygen than air at sea level.

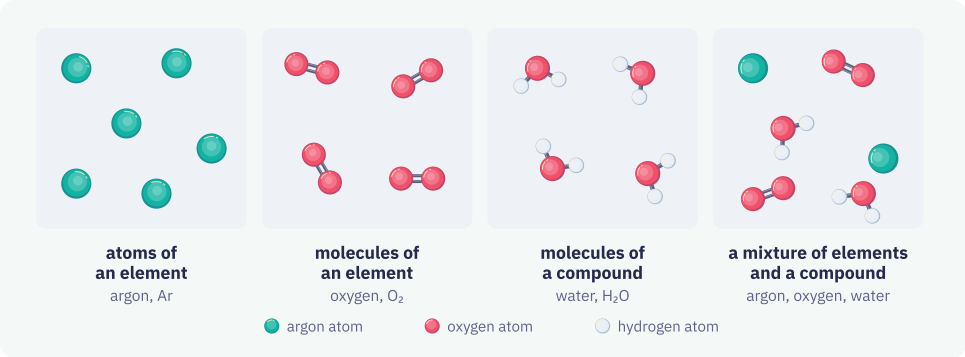


Figure 1.1 Particles in an element, a compound and a mixture. Positions and sizes are drawn for illustration.

	compound	mixture
how it forms	by a chemical reaction	by mixing, with no reaction
ratio of its parts	fixed	can _____
properties	different from those of its elements	similar to those of its parts
melting and boiling	at fixed temperatures	over a _____ of temperatures
energy change	usually a large one when it forms or breaks down	little or none when it is mixed or separated
how it is separated	only by chemical methods, such as strong heating or passing electricity through it	by _____ methods, such as filtration, distillation and chromatography (1.3 and 1.4)

1.1.1 Solutions

When sugar is stirred into tea it seems to disappear, but it is still there. It has dissolved, and the tea is now a mixture called a solution.

> A **solvent** is a liquid that dissolves a substance. The substance that dissolves is the **solute**, and the mixture formed is a **solution**. **Solubility** is how much of a solute can dissolve in a solvent at a given temperature.

- A substance that dissolves is _____. One that does not is _____. A substance can be soluble in one solvent and insoluble in another.
- A **saturated solution** is one in which no more solute can dissolve at that temperature. An **aqueous** solution is one in which the solvent is water.
- **Miscible** liquids mix completely to form one liquid, such as ethanol and water. **Immiscible** liquids do not mix, such as oil and water, and form separate layers.
- The **density** of a substance is its mass in a given volume. In layers of immiscible liquids the least dense liquid floats on top and the densest sinks to the bottom.

- An **impurity** is any unwanted substance mixed into another. A sample with no impurity is pure.

Check your understanding

1. Sparkling water consists of water and carbon dioxide. Is it a compound or a mixture? Explain.
2. Air contains argon, nitrogen and carbon dioxide. Name one element in air that exists as single atoms, one element that exists as molecules and one compound.
3. Salt dissolves in water. Name the solute and the solvent, and say why the solution is called aqueous.

1.2 Particles and the states of matter

The **kinetic particle theory** states that all matter is made of tiny _____ in constant, _____ motion. The particles may be atoms or molecules (1.1).

How the particles are arranged and how fast they move decide whether a substance is a solid, a liquid or a gas (Figure 1.2).

	solid	liquid	gas
arrangement	very closely packed, in an orderly pattern	closely packed, disorderly	very far apart, disorderly
movement	vibrate and rotate about fixed positions	slide past one another	move quickly and randomly in any direction
forces of attraction	very _____	strong	very _____
volume and shape	definite volume and shape	definite volume, takes the shape of its container	no definite volume or shape, fills its container

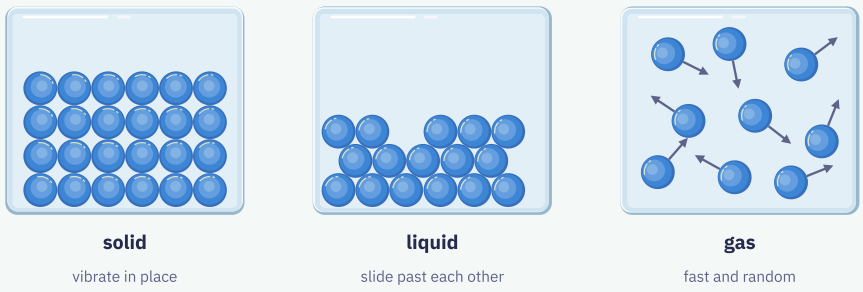


Figure 1.2 Particles in a solid, a liquid and a gas. Arrows show the direction of motion.

1.2.1 Changes of state and energy

Heating transfers thermal energy to a substance. The energy becomes kinetic energy of the particles, so they move faster and the temperature rises. At the melting point and the boiling point, the energy is used to overcome the forces of attraction instead, so the _____ stays constant until the change of state is complete (Figure 1.3).

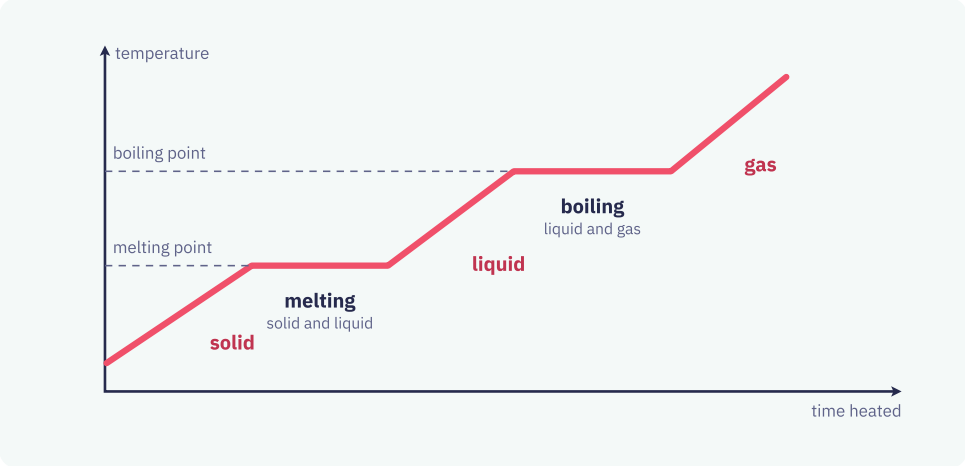


Figure 1.3 Heating curve of a pure substance. The two flat sections are melting and boiling.

change	from, to	energy
melting	solid, liquid	absorbed
boiling and evaporation	liquid, gas	absorbed
sublimation	solid, gas	absorbed
freezing	liquid, solid	released
condensation	gas, liquid	released
vapour deposition	gas, solid	released

- **Evaporation** happens at the surface of a liquid at any temperature. **Boiling** happens throughout the liquid, as bubbles of gas, at the boiling point only.
- A solid below its melting point **expands** when heated: the particles vibrate harder and sit slightly further apart. It contracts when cooled.
- A gas takes up far more space than the same substance as a liquid because its particles are far apart: liquid nitrogen shrinks about 700 times when it forms from the gas. The space between the particles is why a gas is easy to compress, and a liquid or a solid is not.

1.2.2 Diffusion

Diffusion is the net movement of particles from a region of _____ concentration to a region of _____ concentration.

It happens in liquids and gases because their particles move randomly. A drop of ink spreads through water, and a smell spreads through a room. Dust specks in a beam of light jump about because moving air particles keep hitting them. Diffusion ends in an even mixture, but the particles carry on moving.

- A higher temperature gives the particles more kinetic energy, so diffusion is _____.
- Heavier particles need more energy to move at the same speed, so they diffuse _____.
- Questions often give the mass of a particle as its **relative molecular mass**, M_r. The larger the M_r, the heavier the particle. Chapter 4 shows how M_r is worked out.

Figure 1.4 shows the second point. Ammonia and hydrogen chloride gases diffuse towards each other along a tube and form white ammonium chloride where they meet. The ring forms nearer the hydrogen chloride end, because the lighter ammonia particles travelled further in the same time.

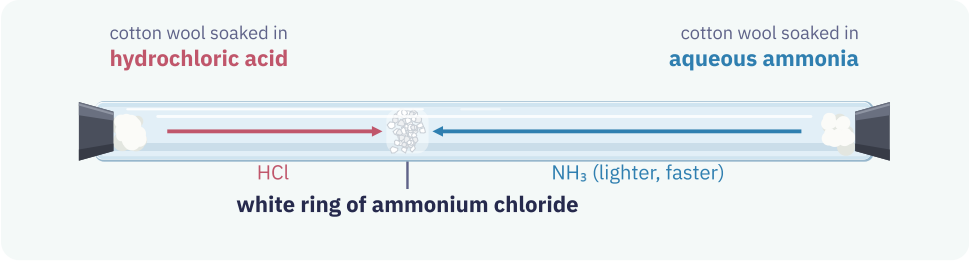


Figure 1.4 Ammonia and hydrogen chloride diffusing along a tube.

Check your understanding

1. Use the kinetic particle theory to explain why a liquid takes the shape of its container but a solid does not.
2. Dry ice, solid carbon dioxide, sublimes at room temperature. Describe what happens to its particles, and why the gas takes up much more space.
3. Why does the smell of cooking spread faster in a warm kitchen?

1.3 Separating mixtures

The method depends on a physical property in which the components differ: particle size, solubility, or melting and boiling points.

Mixture	Method	Property used and how it works
solid and solid	**magnet**	one solid is magnetic (iron, cobalt, nickel)
	sieving	the solids have different _____
	suitable solvent	only one solid dissolves, such as salt from sand in water, then filter
	sublimation	one solid changes straight to a gas on heating, such as iodine from salt. The gas deposits on a cool surface as the sublimate.
solid and liquid	**filtration**	an _____ solid stays on the filter paper as the residue. The liquid passes through as the filtrate.
	evaporation to dryness	heat until all the solvent has vaporised, leaving the dissolved solid
	crystallisation	for a solute that decomposes on heating, such as sugar. Heat to a saturated solution, cool, then filter off the crystals.
	simple distillation	the solvent has a lower boiling point than the solute. It is vaporised, condensed and collected as the distillate.
liquid and liquid	**separating funnel**	for _____ liquids. They form layers, the least dense on top, and each is run off through the tap.
	fractional distillation	for _____ liquids with different boiling points, such as ethanol and water, using a fractionating column. It also separates crude oil and liquid air

NOTE Evaporation to dryness separates the solid but it may not be pure. Sea water, for example, contains several minerals. Crystallisation gives a pure solid. Separating and purifying are not the same thing.

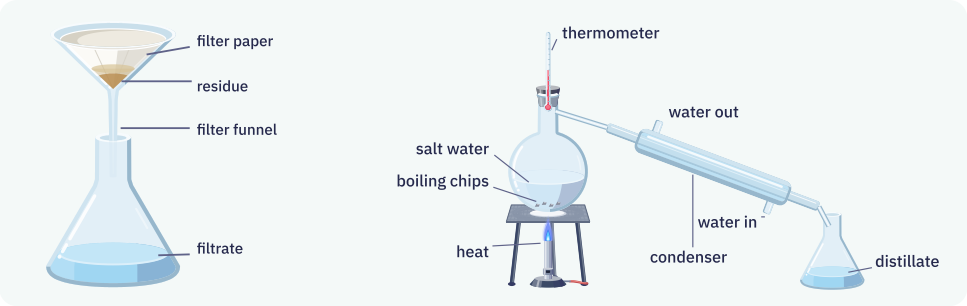


Figure 1.5 Filtration and simple distillation. In the condenser, cooling water enters at the lower end, so it flows against the vapour.

1.3.1 Distillation in detail

- Add _____ for smooth boiling. The thermometer bulb sits at the side arm, so it reads the temperature of the vapour leaving.
- In fractional distillation the lower-boiling liquid leaves the column first (ethanol at 78 °C). Remove the receiver once the thermometer rises above that temperature, or the distillate is contaminated.
- The column's glass beads give a large surface for the higher-boiling vapour to condense on and fall back. Liquids with close boiling points need a _____ column.

WORKED EXAMPLE A mixture holds four substances. W and X are immiscible liquids and X is denser. Y is a solid that dissolves in W but not in X. Z is a solid that dissolves in neither liquid. Outline how to separate all four.

1. Filter the mixture. Z stays on the paper as the residue.	*Z is the only _____ solid.*
2. Pour the filtrate into a separating funnel and run off X, the lower layer.	*W and X are _____, so they form layers.*
3. Evaporate or crystallise the solution of Y in W to recover Y.	*Y is dissolved in W.*

Check your understanding

1. Name two separation methods in which a component changes state.
2. How do you decide which method to use to separate two substances?

1.4 Chromatography

A purple food colouring can be a mixture of a pure blue dye and a pure red dye. Filtration cannot separate dissolved substances, and distillation only removes the liquid. Chromatography separates the dyes by a property they do not share: how well they dissolve in a given solvent.

Chromatography separates a mixture of substances that have different _____ in a given _____.

1. Place a drop of the mixture on the **start line**, drawn in pencil near one edge of the paper.
2. Dip that edge in the solvent, keeping the spot above the liquid.

3. The solvent rises and carries the substances with it. A more soluble substance moves _____ and ends _____ on the paper.

The finished paper is the **chromatogram**. The highest point the solvent reached is the **solvent front**.

NOTE The start line is pencil because graphite does not dissolve. An ink that dissolves would run up the paper and confuse the result.

To identify the dyes, run the pure dyes in the same solvent (Figure 1.6). A spot that lines up with a pure dye has moved the _____, so it is that dye. A pure substance gives _____ spot. More than one spot means a _____.

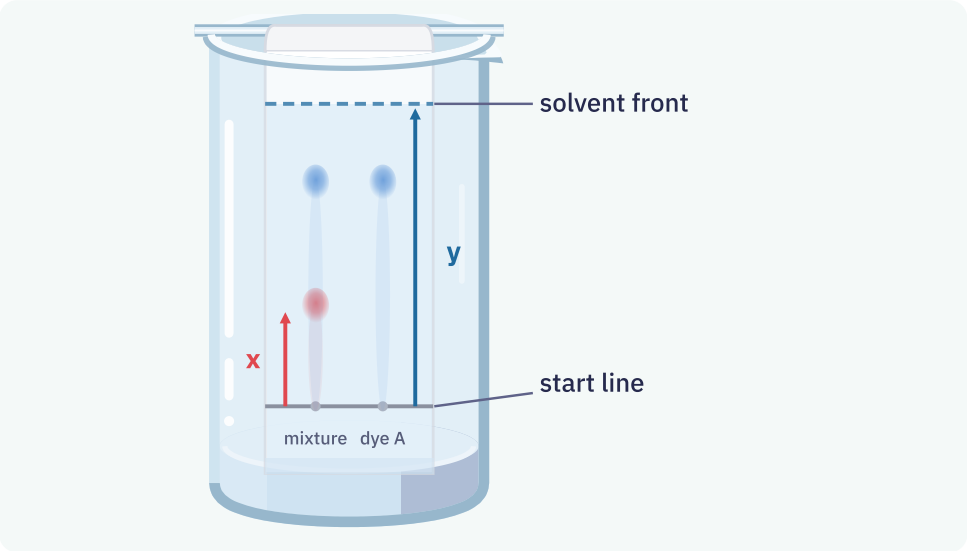


Figure 1.6 A spot of the mixture that lines up with a pure dye has moved the same distance, so it is that dye.

1.4.1 The retention factor

Runs of different lengths put the same substance at different heights, so heights cannot be compared directly. Compare each spot with its own solvent front instead.

The **retention factor**, R_f, is the distance moved by the _____ divided by the distance moved by the _____, both measured from the start line.

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

- R_f has no _____ and lies between _____ and _____.
- A very soluble substance has an R_f close to 1. One that hardly dissolves stays near the start line, close to 0.
- R_f is constant only for the same _____ and temperature. Never compare R_f values found in different solvents.

In Figure 1.7 the longer run carries the spot higher, but the solvent front rises in proportion. Both runs give $R_f = 0.5$.

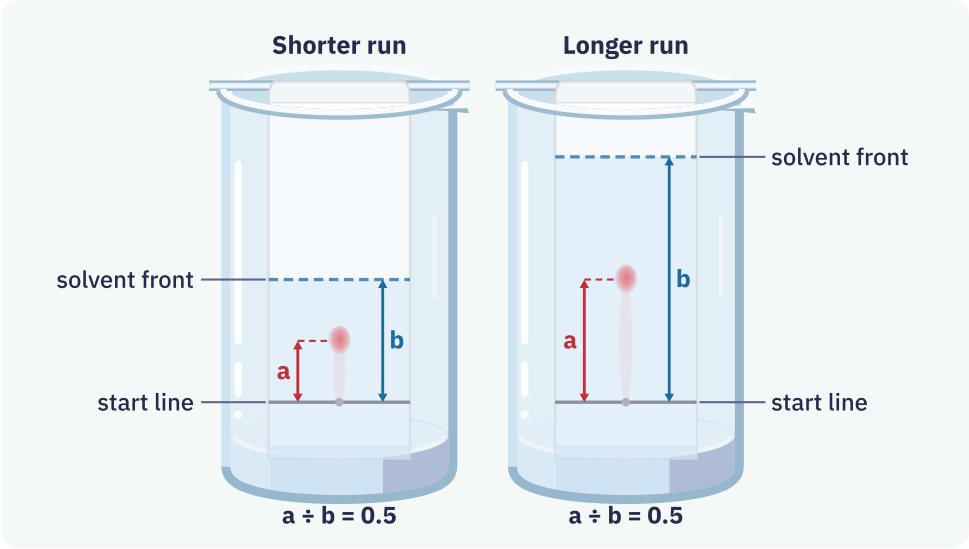


Figure 1.7 The same substance run for two different times. **a** is the distance moved by the spot and **b** the distance moved by the solvent front, both from the start line.

1.4.2 Colourless substances

Amino acids and sugars are colourless. Their spots are made visible with a **locating agent** or by viewing the paper under _____. Some need both.

> A **locating agent** is a chemical that _____ with a colourless substance to form a _____ spot.

Chromatography is used to detect pesticides and poisons in food, banned substances in an athlete's urine or blood, and DNA fragments in forensic samples.

Check your understanding

1. Why is the start line drawn in pencil and not in ink?
2. The same substance is run in the same solvent at the same temperature for 10 minutes and for 20 minutes. Will the R_f values differ? Explain.
3. Why can an R_f found using ethanol not be compared with one found using water?

1.5 Judging purity

Impurities can make a medicine harmful, and some products must reach a certain purity to work. Chromatography is one test. Melting and boiling points are another.

> A **pure substance** has a specific _____ and _____ under fixed conditions. A mixture melts or boils over a _____. An impurity _____ the melting point and _____ the boiling point, and more impurity changes them further.

Salt raises the boiling point of water and lowers its freezing point from 0 °C. This is why salt is spread on icy roads.

WORKED EXAMPLE The melting points of water (H_2O), tridecane ($C_{13}H_{28}$) and tetradecane ($C_{14}H_{30}$) are 0 °C, −5 °C and 5 °C. A solid X melts at 0 °C. A solid Y melts over −5 °C to 5 °C.
(a) State whether X and Y are pure or mixtures.
(b) Identify the solids.

1. X melts at one temperature. Y melts over a range.	*A pure substance has a _____ melting point. A mixture has a _____.*
(a) X is pure. Y is a mixture.	*From step 1.*
2. 0 °C is the melting point of water.	*A pure substance is identified by its melting point.*
3. −5 °C and 5 °C are the melting points of tridecane and tetradecane.	*Y melts between the two.*
(b) X is ice. Y could be a mixture of tridecane and tetradecane.	*"Could", because the range alone does not prove it.*

Check your understanding

1. Liquid P boils over 130 °C to 140 °C. What does this tell you about its purity?

2. Name two ways to test whether a solid is pure.

Answers to Check your understanding

1.1

1. A mixture. The water and carbon dioxide are not chemically combined, and the amount of carbon dioxide can vary.
2. Argon exists as single atoms. Nitrogen, N_2, exists as molecules. Carbon dioxide, CO_2, is a compound.
3. Salt is the solute and water is the solvent. The solution is aqueous because its solvent is water.

1.2

1. In a liquid the particles are closely packed but slide past one another, so the liquid flows into the shape of the container. In a solid they are held in fixed positions by strong attractions and can only vibrate, so it keeps its own shape.
2. The particles gain energy and overcome the forces of attraction, so they move far apart and move quickly and randomly. In the gas the particles are far apart, so it takes up much more space than the solid, where they are closely packed.
3. A warmer kitchen gives the particles more kinetic energy, so they move faster and diffuse faster.

1.3

1. Any two of: evaporation, crystallisation, simple distillation, fractional distillation, sublimation.
2. By the physical properties in which the components differ, such as particle size, solubility, and melting and boiling points.

1.4

1. Graphite does not dissolve in the solvent, so the line stays put. A dissolving ink would run up the paper and its colours would confuse the result.

2. No. The spot and the solvent front both move further in the longer run, in the same proportion, so the ratio stays the same.
3. The R_f of a substance changes with the solvent, so values from different solvents must not be compared.

1.5

1. A pure substance boils at one temperature. Liquid P boils over a range, so it is a mixture.
2. Chromatography (a pure substance gives one spot) and melting or boiling point (a pure substance has a specific value).