

Structure 1.1.2

The Kinetic Molecular Theory

Particles, states of matter and changes of state — notes, worked examples, practice questions & full answers

Covers: Structure 1.1.2 in full, with the parts of Structure 1.1.3 (temperature and kinetic energy) needed to explain heating curves.

Level coding used throughout: SL + HL = examinable for everyone | LINK = context from a later topic, not examinable here

Prerequisite: Structure 1.1.1 — elements, compounds and mixtures.

0 Syllabus map and how to use these notes

READ THIS FIRST — THERE IS NO HL-ONLY CONTENT IN STRUCTURE 1.1

The whole of Structure 1.1 is **common core**. Every section in this booklet is examinable at **both SL and HL**, so there is nothing here an SL student may skip. Purple LINK blocks point forward to Structure 1.5 (ideal gases) and Reactivity 1.2 (energy changes); they are there to make the ideas cohere, and are *not* assessed as part of Structure 1.1.

IB syllabus point	Level	What you must be able to do	Section here
Structure 1.1.2	SL + HL	Use the kinetic molecular theory as a model to explain the physical properties of solids, liquids and gases, and to explain changes of state. Distinguish between the properties of the three states.	1–4
Structure 1.1.2 (guidance)	SL + HL	Name and use all six changes of state: melting, freezing, vaporization, condensation, sublimation, deposition .	4
Structure 1.1.3 (the part needed here)	SL + HL	Recognise that temperature in kelvin is a measure of the average kinetic energy of particles, and interpret temperature–time (heating) curves.	5–7

KEY DEFINITION — THE THEORY ITSELF

The **kinetic molecular theory** is a model which states that all matter is made of very small particles that are in **constant, random motion**, and whose **average kinetic energy depends only on the absolute temperature**. The state of a substance is determined by the balance between the kinetic energy of its particles and the strength of the **forces of attraction** between them.

A note on the name: the syllabus says *molecular*, but the particles may equally be atoms (Ar, Fe) or ions (in molten NaCl). Write "particles" in your answers unless the substance is genuinely molecular.

1 The four assumptions of the model SL + HL

Almost every mark in this topic comes from applying one of four ideas. Learn them as a numbered list, because a question asking you to "explain, using the kinetic molecular theory" is really asking which of these four you are using.

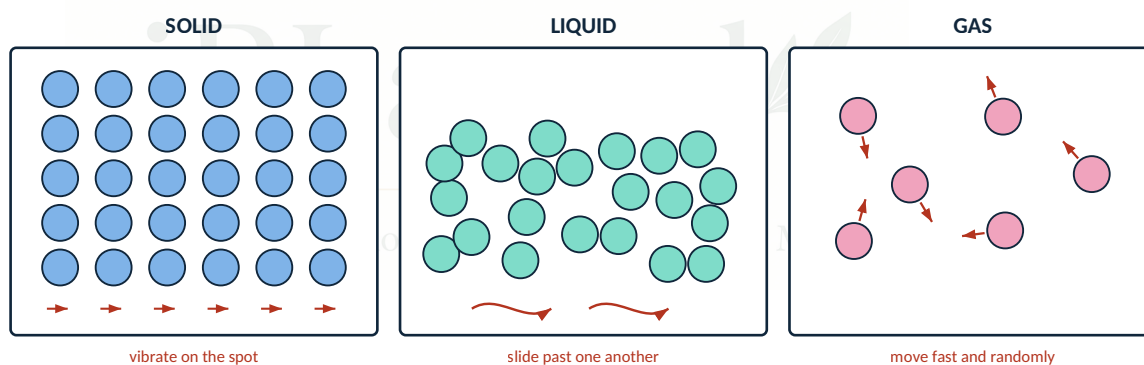
#	Assumption	What it lets you explain
1	Matter is made of discrete particles separated by empty space.	Why gases can be compressed; why a solid has a fixed volume
2	The particles are in constant, random motion .	Diffusion; gas pressure; why liquids flow
3	Particles have a range of kinetic energies ; the average kinetic energy is proportional to the temperature in kelvin .	Why heating makes particles move faster; why evaporation happens below the boiling point
4	There are forces of attraction between particles, and energy must be supplied to overcome them.	Why substances exist as solids, liquids or gases; why melting and boiling absorb energy

THE ONE SENTENCE THAT UNLOCKS THE WHOLE TOPIC

State = a tug-of-war between kinetic energy (which separates particles) and forces of attraction (which hold them together).
Heating adds kinetic energy, so attraction loses ground: solid → liquid → gas. Cooling does the reverse.

2 The three states at particle level SL + HL

FIGURE 1 • PARTICLE ARRANGEMENT, MOVEMENT AND ENERGY IN THE THREE STATES



Arrangement	regular, ordered	close, disordered	far apart, random
Forces of attraction	strong	moderate	negligible
Average kinetic energy	lowest	intermediate	highest

The particles themselves are identical in all three states — only their **arrangement, motion and energy** change. Heating never makes a particle bigger.

2.1 The comparison table — learn this line by line

Feature	Solid	Liquid	Gas
Arrangement	Closely packed in a regular, ordered lattice	Closely packed but random / disordered	Far apart and completely random
Separation	Touching	Touching, but slightly further apart than in the solid	Roughly ten times the particle diameter apart
Movement	Vibrate about fixed positions — they cannot move past one another	Slide past one another while staying in contact	Move rapidly and randomly in all directions
Forces of attraction	Strong	Moderate (weaker than in the solid)	Negligible
Average kinetic energy	Lowest	Intermediate	Highest

Feature	Solid	Liquid	Gas
Shape	Fixed	Takes the shape of the container	Takes the shape of the container
Volume	Fixed	Fixed	Not fixed — fills the container completely
Compressibility	Almost none	Almost none	Easily compressed
Density	High	High (usually slightly below the solid)	Very low (roughly 1000× less)
Rate of diffusion	Negligible	Slow	Fast

EXAM TIP — HOW THE MARK SCHEME IS WRITTEN

Questions in this topic almost always award marks in the pattern **observation + particle-level reason**. Never stop at the observation.

✗ "A gas can be compressed." → 0 marks (that is the question restated).

✓ "A gas can be compressed **because its particles are far apart with large spaces between them**, so they can be pushed closer together." → full marks.

2.2 Water: the important exception to remember

For almost every substance the solid is denser than the liquid, so the solid sinks. **Water is the standard exception:** ice is *less* dense than liquid water and floats, because hydrogen bonding forces the molecules into an open lattice with more empty space than in the liquid. If a question asks for an anomaly of the kinetic model, this is the one to quote.

3 Explaining the properties

SL + HL

3.1 The four explanations you are most likely to be asked for

Property	Explanation in terms of the model
Gases are easily compressed; solids and liquids are not	In a gas the particles are separated by large empty spaces , so an applied pressure can push them closer together. In a solid or liquid the particles are already in contact , so there is almost no space to remove.
Liquids and gases flow; solids do not	In a liquid and a gas the particles have enough kinetic energy to move past one another . In a solid the forces of attraction are strong enough to hold each particle in a fixed position , so it can only vibrate.
A gas fills its container but a liquid does not	Attractive forces between gas particles are negligible , so nothing holds the particles together and they spread out until they meet the walls. In a liquid the attractions are strong enough to keep the particles together, giving a fixed volume and a surface.
Gases have very low densities	Density = mass ÷ volume. The same number of particles occupies a far larger volume in the gas state, so the mass per unit volume is much smaller.

3.2 Diffusion

DEFINITION

Diffusion is the spreading out of particles from a region of higher concentration to a region of lower concentration, as a result of their **random motion**.

Diffusion is fastest in gases (particles move quickly and there is plenty of empty space to move through), slow in liquids (particles move more slowly and constantly collide with neighbours) and effectively zero in solids (particles cannot change position). Two further points are worth having ready:

- **Raising the temperature speeds diffusion up**, because the particles have a greater average kinetic energy and therefore move faster.

- At the same temperature, **lighter particles diffuse faster** than heavier ones. All particles have the same average kinetic energy, and since $E_k = \frac{1}{2}mv^2$, a smaller mass must mean a higher average speed.

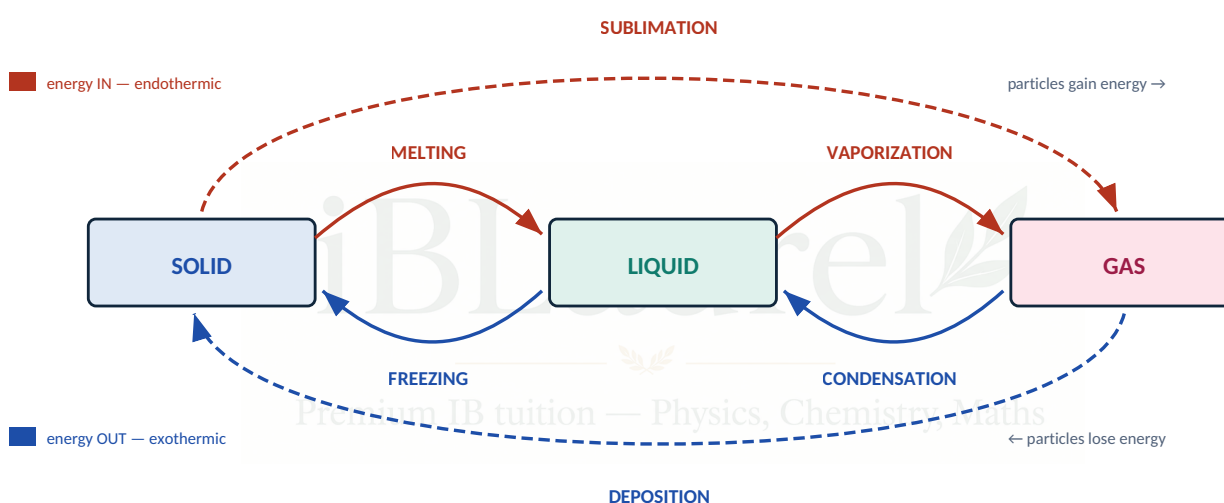
WORKED EXAMPLE 1 — A CLASSIC APPLICATION QUESTION

Q. A drop of bromine liquid is placed at the bottom of a sealed gas jar. After a few minutes the whole jar is uniformly orange-brown. Explain this observation using the kinetic molecular theory. [3]

A. Some bromine molecules at the surface have enough kinetic energy to overcome the forces of attraction holding them in the liquid, so the bromine **evaporates** to form a gas. [1] The gaseous bromine molecules are in **constant, random motion** and there are negligible forces of attraction between them. [1] They therefore **diffuse**, spreading from the high concentration at the bottom throughout the jar until the concentration is uniform. [1]

4 The six changes of state SL + HL

FIGURE 2 • THE SIX CHANGES OF STATE AND THEIR ENERGY CHANGES



Reading upwards (left to right) always means **energy in** and **endothermic**; reading downwards always means **energy out** and **exothermic**.

Change	Name	Energy	What happens to the particles
Solid → liquid	Melting (fusion)	In — endothermic	Vibrations become vigorous enough to partly overcome the attractive forces; particles leave their fixed positions and can slide past one another
Liquid → solid	Freezing (solidification)	Out — exothermic	Particles lose kinetic energy, slow down and are pulled into fixed positions in a regular lattice
Liquid → gas	Vaporization (boiling or evaporation)	In — endothermic	Particles gain enough energy to overcome the attractive forces completely and escape from the liquid
Gas → liquid	Condensation	Out — exothermic	Particles lose kinetic energy; attractions become significant and pull them together into a liquid
Solid → gas	Sublimation	In — endothermic	Particles escape directly from the solid surface without ever forming a liquid
Gas → solid	Deposition	Out — exothermic	Gas particles lose energy and are captured directly into the solid lattice

EXAMPLES WORTH QUOTING IN AN EXAM

Sublimation: solid carbon dioxide ("dry ice") at room temperature and pressure; solid iodine gently warmed to give a violet vapour.

Deposition: frost forming directly on a cold window from water vapour in the air; iodine vapour re-forming shiny crystals on a cool surface.

COMMON ERROR — THE THREE THAT COST MOST MARKS

1. "The bonds break when water boils." For a molecular substance, boiling overcomes the **intermolecular forces** *between* molecules. The covalent bonds *within* each H_2O molecule stay intact — steam is still H_2O .
2. "The particles get bigger / expand when heated." Particles never change size. The **spacing between them** increases.
3. "Particles in a solid don't move." They **vibrate** about fixed positions. They cannot *translate*, which is not the same thing.

5 Energy and temperature during a change of state SL + HL

This is the highest-value idea in Structure 1.1, and the one examiners return to most often.

THE TWO KINDS OF ENERGY A PARTICLE HAS

Kinetic energy (E_k) — the energy of motion. The **average** kinetic energy of the particles is what a thermometer measures, and it is proportional to the temperature **in kelvin**.

Potential energy (E_p) — the energy stored because of the positions of the particles relative to one another. Separating particles against their mutual attraction **increases** their potential energy.

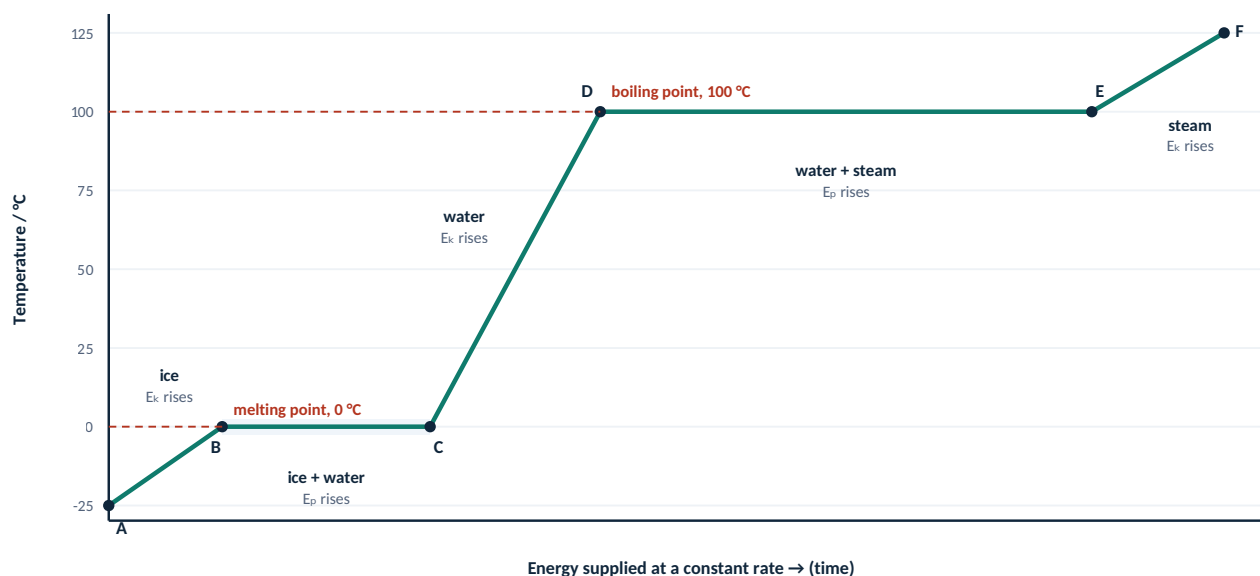
WHY THE TEMPERATURE STAYS CONSTANT WHILE SOMETHING MELTS OR BOILS

During a change of state, all the energy supplied is used to **overcome the forces of attraction between the particles** — that is, to increase their **potential** energy.

The **average kinetic energy therefore does not change**, so the **temperature stays constant**.

Say all three parts. A single sentence such as "the energy is used to break the forces" usually scores only one of the two or three marks available.

FIGURE 3 • HEATING CURVE FOR WATER HEATED AT A CONSTANT RATE



On the sloping sections the kinetic energy (E_k) rises, so the temperature rises. On the flat sections the potential energy (E_p) rises, so the temperature does not.

The horizontal axis is **not** drawn to scale. In reality, boiling 1 g of water requires about **6.8×** as much energy as melting it (2260 J g^{-1} against 334 J g^{-1}), so the upper plateau would be far longer still.

5.1 Reading the curve segment by segment

Segment	What is present	Temperature	Energy supplied is used to...
A-B	Solid only (ice)	Rises	increase the kinetic energy — the particles vibrate faster
B-C	Solid + liquid together	Constant at the melting point	increase the potential energy — partly overcoming the forces holding the lattice together
C-D	Liquid only (water)	Rises	increase the kinetic energy — the particles move faster
D-E	Liquid + gas together	Constant at the boiling point	increase the potential energy — completely overcoming the forces between the particles
E-F	Gas only (steam)	Rises	increase the kinetic energy

TWO DETAILS THAT SEPARATE A 6 FROM A 7

Why is the boiling plateau longer than the melting plateau? Melting only *loosens* the attractions — the particles stay in contact. Boiling must **overcome them completely** and separate the particles to a large distance, which takes much more energy.

What is present during a plateau? **Both** states, coexisting. At B-C the sample is a mixture of ice and water, not one or the other.

WORKED EXAMPLE 2 — AN EXAM-STANDARD EXPLANATION

Q. A sample of a pure solid is heated at a constant rate. Its temperature rises steadily, then remains constant for several minutes before rising again. Explain, in terms of the kinetic molecular theory, why the temperature remains constant. **[3]**

A. During this period the solid is **melting**, so solid and liquid are both present. **[1]** The energy supplied is used to **overcome the forces of attraction between the particles**, increasing their potential energy. **[1]** The **average kinetic energy of the particles therefore does not increase**, and since temperature is a measure of average kinetic energy, the temperature stays constant. **[1]**

COOLING CURVES

A cooling curve is the same graph reversed: the plateaus occur at the same temperatures, but energy is now **released** to the surroundings and the changes are **exothermic**. The temperature stays constant during a plateau because the potential energy is falling as attractions re-form, while the average kinetic energy is unchanged.

6 Evaporation and boiling are not the same thing SL + HL

Both are vaporization, and students routinely lose marks by treating them as interchangeable.

Feature	Evaporation	Boiling
Where it happens	At the surface of the liquid only	Throughout the liquid — bubbles of vapour form in the bulk
Temperature	At any temperature below the boiling point	Only at the boiling point , a fixed temperature for a pure substance
Which particles escape	Only the small fraction with above-average kinetic energy	The great majority have enough energy
Effect on the liquid left behind	It cools — the most energetic particles have left, lowering the average kinetic energy	Temperature stays constant at the boiling point

FIGURE 4 • EVAPORATION HAPPENS AT THE SURFACE; BOILING HAPPENS THROUGHOUT

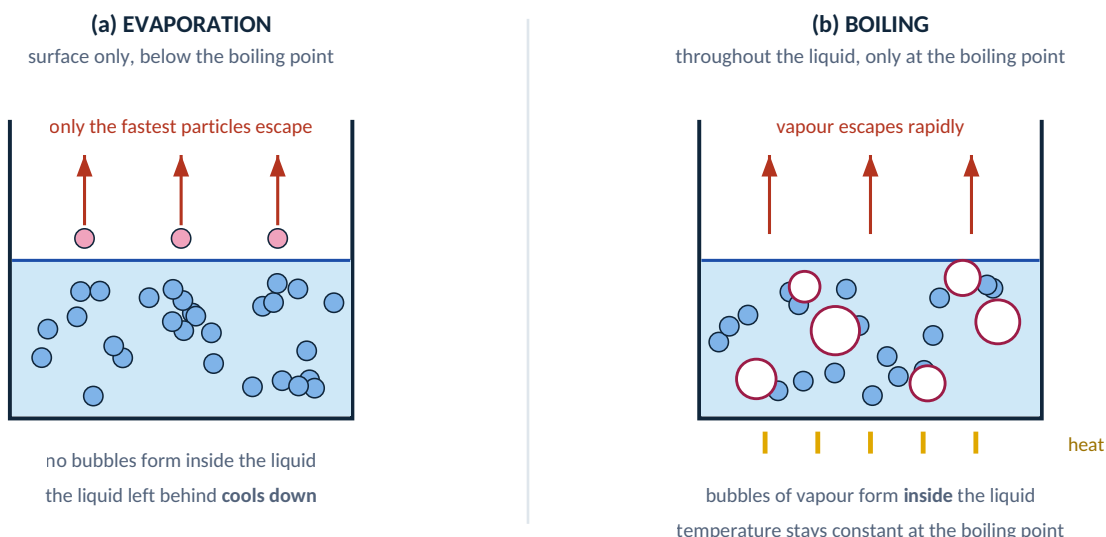
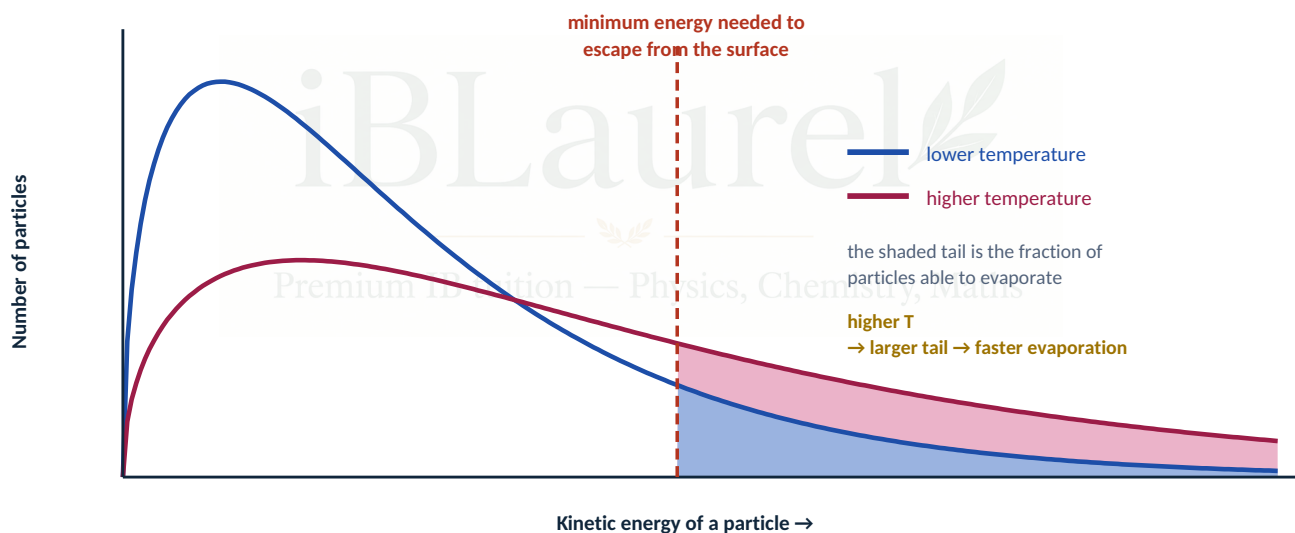


FIGURE 5 • WHY EVAPORATION HAPPENS BELOW THE BOILING POINT



At any temperature the particles have a **range** of kinetic energies. Only those in the shaded tail have enough energy to escape from the surface — and raising the temperature enlarges that tail, which is why warm liquids evaporate faster.

THREE EVERYDAY APPLICATIONS EXAMINERS LIKE

Sweating cools you because the water molecules that evaporate are the most energetic ones, so the average kinetic energy — and therefore the temperature — of the liquid left on your skin falls.

Washing dries faster on a warm, windy day: higher temperature means a larger fraction of molecules have enough energy to escape, and the wind removes vapour from above the surface so fewer molecules return.

Food cooks more slowly at high altitude: the lower external pressure lowers the boiling point of water, so the food is cooked at a lower temperature.

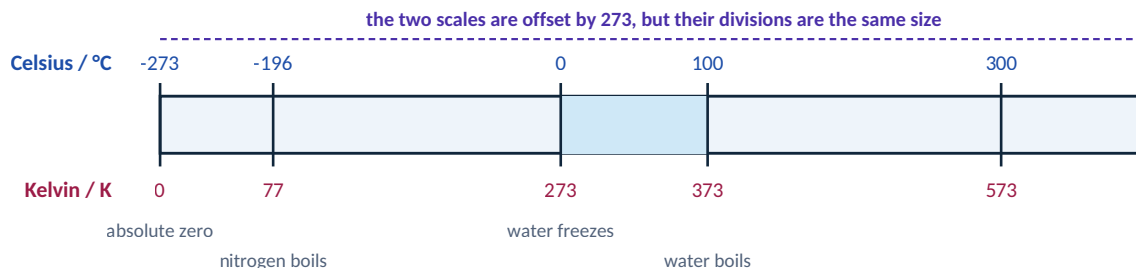
7 Temperature, kelvin and average kinetic energy SL + HL

Everything in Section 5 rests on the link between temperature and kinetic energy, so it is set out properly here. It is formally syllabus point Structure 1.1.3.

$$T / \text{K} = T / ^\circ\text{C} + 273$$

The kelvin is the SI unit of temperature. One kelvin is exactly the same size as one degree Celsius, so a *difference* of 10°C is a difference of 10 K.

FIGURE 6 • THE CELSIUS AND KELVIN SCALES



- **Absolute zero (0 K, -273°C)** is the temperature at which particles have the **minimum possible kinetic energy**. It cannot be reached in practice, and there are no negative kelvin temperatures.
- The **average kinetic energy of the particles is directly proportional to the absolute temperature**, $E_k \propto T(\text{K})$. This is why the kelvin scale is used: it starts at true zero, so ratios are meaningful.
- At a given temperature, **all substances have the same average kinetic energy** — but not the same average speed, because $E_k = \frac{1}{2}mv^2$ and their particles have different masses.

THE PROPORTIONALITY TRAP

Doubling the temperature **in kelvin** doubles the average kinetic energy. Doubling the temperature **in Celsius** does not. From 20°C to 40°C the Celsius value doubles, but in kelvin the change is $293\text{ K} \rightarrow 313\text{ K}$ — an increase of only about **7%**. Always convert to kelvin before comparing.

WORKED EXAMPLE 3 — A SHORT CALCULATION

Q. A gas sample is warmed from 27°C to 327°C . Determine the factor by which the average kinetic energy of its particles increases. **[2]**

Convert both temperatures to kelvin:

$$T_1 = 27 + 273 = 300\text{ K} \quad T_2 = 327 + 273 = 600\text{ K} \quad \text{[1]}$$

Since $E_k \propto T(\text{K})$:

$$\text{ratio} = 600 / 300 = 2 \text{ — the average kinetic energy doubles. [1]}$$

Trap avoided: using Celsius would have given $327/27 = 12.1$, which is wrong by a factor of six.

Looking ahead [LINK](#)

Two later topics build directly on this model, and it is worth knowing where it is heading — though neither is examined as part of Structure 1.1.

- **Structure 1.5 — the ideal gas model.** An *ideal* gas is defined by taking assumption 1 to its limit: the particles are treated as having **no volume** and **no intermolecular attractions**, and all collisions are perfectly elastic. Real gases deviate from this at **high pressure and low temperature**, where the particles are close enough for both to matter.
- **Reactivity 1.2 — enthalpy changes.** The energy absorbed in the two plateaus of Figure 3 has formal names: the enthalpy of **fusion** (melting) and the enthalpy of **vaporization** (boiling).

8 Nature of science: this is a model SL + HL

Structure 1.1.2 explicitly calls the kinetic molecular theory a **model**, and IB questions sometimes ask you to comment on that. A model is a deliberate simplification that is judged by how well it explains and predicts, not by whether it is literally true.

What the model explains well	Where the simplification shows
The three states and the six changes of state	It treats particles as simple spheres, ignoring molecular shape
Compressibility, diffusion, density and flow	It says nothing about why the attractive forces exist — that needs bonding theory (Structure 2)
Why heating causes changes of state	It does not predict the anomaly of water, where the solid is less dense than the liquid
Why gases exert pressure	The ideal-gas version fails at high pressure and low temperature

9 One-page summary SL + HL

If the question says...	Your answer must contain...
"Explain why a gas can be compressed"	Particles are far apart / large spaces between them → they can be pushed closer together
"Explain why a solid has a fixed shape"	Strong forces of attraction hold the particles in fixed positions → they can only vibrate, not move past one another
"Explain why the temperature stays constant during melting"	Energy overcomes the forces of attraction → potential energy increases → average kinetic energy unchanged → temperature constant
"Explain why boiling needs more energy than melting"	Melting only partly overcomes the attractions (particles stay in contact); boiling overcomes them completely and separates the particles
"Distinguish evaporation from boiling"	Surface vs throughout; any temperature below the boiling point vs at the boiling point only
"Explain why an evaporating liquid cools"	The most energetic particles escape → the average kinetic energy of those remaining falls → temperature falls
"Name the change of state"	Melting / freezing / vaporization / condensation / sublimation / deposition — and say endothermic or exothermic
"Compare average kinetic energies"	Convert to kelvin first; $E_k \propto T(K)$

10 Practice questions

Attempt these under timed conditions: roughly 1.5 minutes per mark. Part B and Part C together carry 28 marks. Full answers with mark-scheme wording follow in Section 11.

Part A — Multiple choice

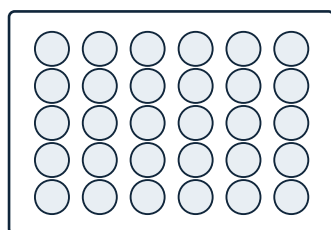
SL + HL

- Which change of state is exothermic?
A. Melting B. Sublimation C. Deposition D. Vaporization
- Which statement about the particles in a solid is correct?
A. They are stationary. B. They vibrate about fixed positions.
C. They slide past one another. D. They move rapidly in all directions.
- A sealed syringe containing a gas is compressed to half its volume. Which best explains why this is possible?
A. The gas particles become smaller. B. The gas particles move more slowly.
C. There are large spaces between the gas particles. D. The forces between the particles increase.
- The temperature of a gas is raised from 25 °C to 50 °C. The average kinetic energy of its particles is multiplied by approximately:
A. 1.08 B. 2.00 C. 2.16 D. 4.00
- Solid carbon dioxide changes directly to a gas at room temperature. This change is called:
A. evaporation B. deposition C. condensation D. sublimation
- During the plateau of a heating curve at the boiling point, which quantities are increasing?
I. The potential energy of the particles II. The average kinetic energy of the particles III. The temperature
A. I only B. I and II only C. II and III only D. I, II and III
- Ammonia ($M_r = 17$) and hydrogen chloride ($M_r = 36.5$) diffuse towards each other along a tube. Ammonia diffuses faster because, at the same temperature, its molecules have:
A. a greater average kinetic energy. B. a greater average speed.
C. stronger forces of attraction. D. a larger volume.

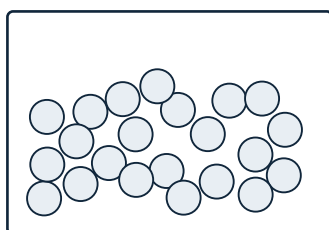
Part B — Structured questions

SL + HL

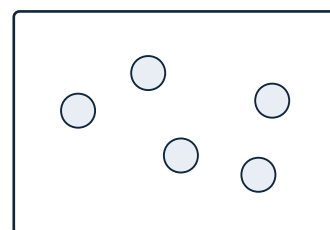
- Compare the arrangement, the movement and the relative forces of attraction between the particles in a liquid and in a gas. [3]
- Explain, in terms of the kinetic molecular theory, why a liquid has a fixed volume but takes the shape of its container. [2]
- The diagram below shows particles of three pure substances at room temperature. [4]



X



Y



Z

- Identify the state of matter shown in each of the boxes X, Y and Z. [3]
 - State which box shows the substance with the highest average kinetic energy per particle. [1]
- Name the change of state occurring in each case and state whether it is endothermic or exothermic. [3]
 - Water vapour in the air forms frost directly on a cold surface.
 - Molten iron in a mould turns solid.
 - Solid iodine crystals are warmed and a violet vapour appears above them.
 - A pure solid is heated at a constant rate from below its melting point. Sketch the shape of the resulting temperature–time graph up to just above the boiling point, labelling the melting point, the boiling point, and the region where solid and liquid coexist. [3]

13. Explain why the temperature of a pure substance remains constant while it is boiling, even though energy is being supplied continuously. [3]
14. Explain why more energy is required to boil 1 g of water than to melt 1 g of ice. [2]
15. A student claims: "When water boils, the covalent bonds in the water molecules break." Explain why this statement is incorrect and state what actually happens. [3]

Part C — Application and data SL + HL

16. Distinguish between evaporation and boiling, and explain why a liquid left in an open dish becomes cooler as it evaporates. [3]
17. The table gives the melting and boiling points of four substances. [3]

Substance	Melting point / °C	Boiling point / °C	State at 25 °C
Nitrogen	-210	-196	?
Ethanol	-114	78	?
Sodium chloride	801	1413	?
Substance W	-39	357	?

- (a) Deduce the state of each substance at 25 °C. [2]
- (b) State and explain which substance has the strongest forces of attraction between its particles. [1]
18. Convert 78 °C to kelvin, and determine by what factor the average kinetic energy of the particles of a gas increases when it is heated from 27 °C to 227 °C. [2]
19. A sealed rigid container holds a fixed amount of gas. Explain, in terms of the kinetic molecular theory, why the pressure inside the container increases when the gas is heated. [2]
20. The kinetic molecular theory is described as a *model*. [3]
- (a) State one physical property of matter that the model explains successfully, and give the explanation. [2]
- (b) State one limitation of the model. [1]

11 Answers & mark-scheme notes

Part A

1. **C** — deposition is gas $\rightarrow$ solid, so the particles lose energy to the surroundings. A, B and D all require energy to be supplied.
2. **B** — A is the classic error: particles in a solid are never stationary, they vibrate about fixed positions. C describes a liquid and D a gas.
3. **C** — particles never change size (A) and their speed depends only on temperature (B). Compression works because the empty space between particles is reduced.
4. **A** — convert first: 298 K $\rightarrow$ 323 K, so the ratio is $323/298 = 1.08$. Answer B is the trap for anyone dividing 50 by 25.
5. **D** — solid to gas directly, with no liquid formed, is sublimation. Evaporation is from a *liquid* surface.
6. **A** — the temperature is constant during a plateau, so by definition the average kinetic energy is constant too. Only the potential energy rises.
7. **B** — at the same temperature both gases have the **same** average kinetic energy, which rules out A. Since $E_k = \frac{1}{2}mv^2$, the lighter NH_3 molecules must have the higher average speed.

Part B

8. [3]

- **Arrangement:** in a liquid the particles are close together / touching but randomly arranged; in a gas they are far apart with large spaces between them. [1]
- **Movement:** in a liquid the particles slide past one another while remaining in contact; in a gas they move rapidly and randomly in all directions. [1]
- **Forces:** the forces of attraction are moderate in a liquid but negligible in a gas. [1]

Marker's note: the question says *compare*, so each mark needs a statement about **both** states. A description of liquids alone scores nothing.

9. [2]

- The forces of attraction between the particles are **strong enough to hold them in contact**, so the total volume they occupy cannot change. [1]
- The particles still have enough kinetic energy to **slide past one another**, so the liquid can flow and take the shape of the container. [1]

10. [4]

- (a) **X = solid** (particles closely packed in a regular, ordered arrangement) [1]; **Y = liquid** (particles close together but disordered) [1]; **Z = gas** (particles far apart and randomly distributed). [1]
- (b) **Z**, the gas. [1]

Marker's note: in (a) the reason is not required, but naming the state is. Do not write "X is ice" — the substances are unidentified.

11. [3]

- (a) **Deposition** — **exothermic**. [1]
- (b) **Freezing** (solidification) — **exothermic**. [1]
- (c) **Sublimation** — **endothermic**. [1]

Each mark requires the correct name **and** the correct energy term. "Condensation" for (a) is a common wrong answer — no liquid is formed at any stage.

12. [3]

- Correct overall shape: a rising line, a horizontal plateau, a rising line, a second horizontal plateau, a rising line — five segments in that order. [1]
- The **second plateau drawn at a higher temperature** than the first, and clearly **longer** than it. [1]
- Correct labels: melting point at the first plateau, boiling point at the second, and "solid + liquid" for the first plateau region. [1]

Marker's note: sloping "plateaus" lose the first mark. The plateaus must be horizontal because the substance is pure.

13. [3]

- The energy supplied is used to **overcome the forces of attraction between the particles**. [1]
- This increases the **potential** energy of the particles, not their kinetic energy. [1]
- Temperature is a measure of the **average kinetic energy**, which is unchanged, so the temperature remains constant. [1]

Marker's note: "the energy is used to break bonds" is not accepted for a molecular substance — write "forces of attraction between particles/molecules".

14. [2]

- Melting only **partly** overcomes the forces of attraction: the particles leave their fixed positions but remain close together / in contact. [1]
- Boiling must overcome the forces of attraction **completely** and separate the particles to a much greater distance, which requires more energy. [1]

15. [3]

- The statement is incorrect because the covalent bonds are **within** each H₂O molecule and are **not** broken on boiling. [1]
- Evidence: steam is still composed of H₂O molecules — boiling is a **physical** change, not a chemical one. [1]
- What actually happens is that the **intermolecular forces of attraction between** the water molecules are overcome, allowing the molecules to separate. [1]

Part C**16. [3]**

- Evaporation occurs only at the **surface** of the liquid and at **any temperature below the boiling point**; boiling occurs **throughout** the liquid and only **at the boiling point**. [1]
- Only the particles with the **highest kinetic energies** have enough energy to overcome the attractive forces and escape from the surface. [1]
- Those particles leave, so the **average kinetic energy of the particles remaining** in the liquid falls, and the temperature of the liquid therefore falls. [1]

17. [3]

(a) Nitrogen: **gas** (25 °C is above its boiling point of -196 °C); ethanol: **liquid**; sodium chloride: **solid**; W: **liquid** (25 °C lies between -39 °C and 357 °C). [2] (award [1] for two or three correct)

(b) **Sodium chloride**, because it has by far the highest melting and boiling points, so the most energy is needed to overcome the forces between its particles. [1]

W is mercury. The general rule is worth memorising: if 25 °C is below the melting point the substance is a solid; between the two values, a liquid; above the boiling point, a gas.

18. [2]

- $78 + 273 = 351 \text{ K}$ [1]
- $27^\circ\text{C} = 300 \text{ K}$ and $227^\circ\text{C} = 500 \text{ K}$, so the average kinetic energy increases by a factor of $500/300 = 1.67$. [1]

Using Celsius would give $227/27 = 8.4$, which scores zero.

19. [2]

- Heating increases the **average kinetic energy** of the particles, so they move **faster**. [1]
- They therefore collide with the container walls **more frequently and with greater force**, so the pressure increases. [1]

Both parts of the second mark are needed — "they hit the walls more often" alone is usually only worth partial credit.

20. [3]

(a) Any one property with a valid particle-level explanation, for example: **gases are easily compressed** [1] because their particles are far apart with large spaces between them that can be reduced. [1]

Other acceptable answers: solids have a fixed shape; liquids and gases flow; gases have low density; gases diffuse rapidly.

(b) Any one limitation, for example: it treats particles as simple spheres and ignores their shape; it does not explain **why** the forces of attraction exist; it does not account for water being less dense as a solid than as a liquid; the ideal-gas form of the model fails at high pressure and low temperature. [1]

End of Structure 1.1.2 • Next: **Structure 1.1.3 — Temperature, kelvin and the kinetic energy of particles**, followed by Structure 1.2 (the nuclear atom).