

States of matter

Mark scheme and worked solutions for 30 questions: 15 multiple choice, 15 structured.

1 Core Solids, liquids and gases [1]

Answer: C

Explanation

A liquid has no fixed shape (it takes the shape of its container), has a fixed volume, and flows easily — row C. A describes a solid (fixed shape, fixed volume, does not flow). B describes a gas (no fixed shape, no fixed volume, flows easily). D does not match any real state (fixed shape but no fixed volume, and does not flow) and is a distractor combining properties that do not occur together.

2 Core Solids, liquids and gases [1]

Answer: C

Explanation

Gas particles are much further apart than liquid particles and move faster, in random directions, than liquid particles. A and B wrongly keep the particles "closer together" as in a liquid. D gets the separation right but the speed wrong.

3 Core Solids, liquids and gases [1]

Answer: D

Explanation

Water vapour (gas) turning into liquid droplets is condensing. A (boiling) and B (evaporating) are liquid → gas changes, the reverse direction. C (freezing) is liquid → solid, not the change happening here.

4 Core Solids, liquids and gases [1]

Answer: D

Explanation

Particles in a solid vibrate about fixed positions and have the least average energy; particles in a liquid move more freely and have more energy; particles in a gas move fastest and have the most energy. So solid < liquid < gas. The other options put the states in an order that does not match this.

5**Core**

Solids, liquids and gases

[1]

Answer: B

Explanation

Heating a fixed mass of gas while its pressure stays roughly constant makes the particles move faster and spread out, increasing the volume. A gives the opposite change; C ignores the effect of temperature; D is incorrect because the effect of temperature on volume at constant pressure is a standard, predictable relationship.

6**Core**

Solids, liquids and gases

[1]

Answer: A

Explanation

Decreasing the volume of a fixed mass of gas at constant temperature squeezes the same number of particles into a smaller space, so they collide with the syringe/pump walls more often, increasing the pressure. B is the opposite effect. C ignores the effect of volume on pressure. D is not physically possible for a sealed system.

7**Supplement**

Solids, liquids and gases

[1]

Answer: C

Explanation

On melting, particles gain enough energy to overcome some of the forces holding them in fixed positions and break free, becoming able to move around each other — this is melting. A describes freezing (the reverse). B describes boiling/evaporating (liquid → gas), not melting into a liquid. D is incorrect; particles never stop moving completely.

8**Supplement**

Solids, liquids and gases

[1]

Answer: B

Explanation

The temperature stays constant at 69 °C from minute 3 to minute 5 while the substance is being heated — this plateau shows the solid is melting (energy is going into breaking up the solid structure rather than raising the temperature). Before minute 3 and after minute 5 the temperature is still rising, showing the solid or the liquid warming up, not changing state.

9**Supplement**

Solids, liquids and gases

[1]

Answer: A

Explanation

Heating the fixed mass of gas in a container of fixed volume makes the particles move faster (higher average kinetic energy). Faster particles hit the container walls more often and with greater force per collision, so the pressure increases. B and C are wrong because the number and size of particles do not change. D is wrong because in a rigid, sealed container of fixed volume the average particle separation cannot decrease.

10**Core**

Solids, liquids and gases

[1]

Answer: B

Explanation

Evaporation happens only at the surface of a liquid and can occur at any temperature below the boiling point; boiling happens throughout the whole liquid, but only at one fixed temperature (the boiling point). A and C reverse these facts. D is incorrect — evaporation and boiling are different processes.

11**Supplement**

Solids, liquids and gases

[1]

Answer: A

Explanation

As the football warms up, its air particles gain kinetic energy and move faster on average. Faster particles collide with the inside surface of the ball more often and with greater force, increasing the pressure of the trapped air (the mass and volume of air are essentially unchanged). B, C and D describe changes that do not happen in this situation.

Mark scheme

(a)

[2]

- melting point = 0 °C (1)
- boiling point = 100 °C (1)

ALLOW values read correctly from the table even if expressed as "0" and "100" without units

(b)

[2]

- between 4 and 8 minutes: melting (solid → liquid) (1)
- between 18 and 22 minutes: boiling (liquid → gas) (1)

REJECT "evaporating" for 18–22 minutes unless boiling is also given, since the whole liquid is changing state at a fixed temperature here

(c)

[2]

- the energy supplied is used to weaken/overcome the forces of attraction between the particles (increasing their potential energy), allowing the fixed structure to break down (1)
- it is not used to increase the particles' kinetic energy at this point, so the temperature (which depends on kinetic energy) does not rise until melting is complete (1)

ALLOW reference to "latent heat" being absorbed for the change of state

Worked solution

Reading the table, the temperature is constant at 0 °C from 4 to 8 minutes — this is the melting point, so the solid is melting into a liquid during this time. The temperature is constant again at 100 °C from 18 to 22 minutes — this is the boiling point, so the liquid is boiling into a gas here. Between these plateaus (8–18 minutes) the liquid water is simply warming up, and before 4 minutes the solid ice is warming up.

During a change of state, all the energy being supplied is used to pull the particles further apart against the forces of attraction holding them together (for example, breaking down the rigid structure of the solid). None of this energy goes into speeding the particles up further, so their average kinetic energy — and therefore the temperature — stays the same until every particle has changed state. Once melting (or boiling) is complete, further heating goes back into increasing kinetic energy, and the temperature starts rising again.

Mark scheme

(a)

[1]

- liquid (1)

(b)

[4]

- particles are close together (touching), but not held in a fixed, regular pattern like a solid (1)
- particles are arranged randomly (1)
- particles can move/slide past each other (are not fixed in position) (1)
- this random movement and close packing gives a substance that flows and takes the shape of its container, while the particles being close together (with little empty space) gives it a fixed volume (1)

ALLOW "particles vibrate and move about, changing neighbours" as equivalent to "can move/slide past each other"

Worked solution

No fixed shape but a fixed volume are the defining properties of a liquid, so substance R is a liquid. In a liquid, the particles are close together, almost as close as in a solid, which is why liquids (like solids) have a fixed volume and cannot easily be compressed. However, unlike in a solid, the particles in a liquid are arranged randomly rather than in a fixed, regular pattern, and they are free to move around and slip past one another. This freedom to move lets a liquid flow and change shape to fill the bottom of whatever container it is placed in, while staying the same overall volume.

Mark scheme

(a) [1]

- atmospheric pressure decreases as altitude increases (1)

(b) [2]

- the volume of the gas inside the balloon increases as it rises (1)
- because as the external (and internal) pressure falls, the same fixed mass of gas spreads out to occupy a larger space at the lower pressure (1)

(c) [2]

- because the gas inside will expand considerably as the balloon rises into lower pressure (1)
- if the balloon were fully inflated at ground level, it would not have room to expand and could burst before reaching a useful altitude; launching it partly inflated leaves room for this expansion (1)

ALLOW "so it does not burst / to stop it bursting" as the core idea

Worked solution

The table shows that atmospheric pressure falls steadily as altitude increases — from 100 kPa at ground level to only 6 kPa at 20 km. Since the gas inside the balloon is assumed to be at the same pressure as the air outside, the pressure of the balloon's gas also falls as it rises. For a fixed mass of gas at constant temperature, a lower pressure means the same particles need more space to produce that lower pressure, so the gas expands and the balloon's volume increases. Because the pressure drops so much between the ground and 20 km, the balloon would expand hugely — if it were fully inflated at launch it would have no room left to expand and would burst well before reaching altitude. Launching it only partly inflated leaves space for this large expansion.

Mark scheme

(a) [3]

- the gas particles gain kinetic energy as they are heated (1)
- they move faster / their average speed increases (1)
- they collide with each other and with the walls of the can more often (1)

ALLOW "particles move more vigorously" for the second mark**IGNORE** "particles vibrate more" (gas particles do not vibrate about fixed positions)

(b) [2]

- the faster-moving particles hit the inside walls of the can more often and with greater force each time (1)
- the volume of the can is fixed, so this greater total force on each unit area of wall means a higher pressure (1)

(c) [2]

- if the pressure inside becomes greater than the can is designed to withstand (1)
- the can will burst/rupture suddenly, releasing its contents (1)

ALLOW "the walls of the can cannot withstand the force/pressure and split open"**Worked solution**

Heating the gas inside the sealed can increases the average kinetic energy of its particles, so they move around faster. Because the can is sealed and rigid, the volume available to the gas cannot change, so these faster particles hit the inside walls of the can more frequently and with greater force each time they collide. Since pressure is the total force from these collisions acting on each unit area of the wall, the pressure inside the can rises as the temperature rises. Aerosol cans are designed to withstand normal pressures, but if they are heated too much the pressure can exceed what the metal walls can safely contain, causing the can to burst suddenly and forcefully — which is why the warning label tells people not to heat it.

Mark scheme

(a)

[2]

- melting (1)
- evaporating (1)

ALLOW answers only if given in the correct order (melting first, then evaporating)

(b)

[3]

- the particles move slightly further apart (separation increases) (1)
- the fixed, regular arrangement of the solid breaks down and the particles become arranged randomly (1)
- the particles are no longer held in fixed positions and become free to move/slide past each other (1)

Worked solution

Solid wax first melts into liquid wax, and continued heating then makes some of the liquid wax evaporate into a vapour — melting happens before evaporating here. When the solid wax melts, the particles gain enough energy to partly overcome the forces holding them in their fixed positions. They move slightly further apart, lose their fixed, regular (ordered) arrangement, and become able to move around and slide past one another, which is why the liquid can flow and take the shape of the bottom of the tube while still having a fixed volume.

Mark scheme

(a) [3]

- a very large number of air particles are squeezed into a small, fixed volume, so the particles are close together (1)
- this means the particles collide with the cylinder walls very often (1)
- and with a large total force, giving a high pressure (1)

(b) [2]

- the volume occupied by this fixed mass of air increases (1)
- because at the much lower pressure in the lungs, the same particles need to spread out over a larger space to produce that lower pressure (1)

(c) [2]

- as a diver rises, the surrounding (and lung) pressure decreases, so any air remaining in the lungs will expand to occupy a larger volume (1)
- if the diver holds their breath, this expanding air cannot escape and can over-expand and damage the lungs; breathing out steadily lets the expanding gas escape safely (1)

Worked solution

Compressing a large mass of air into the small, rigid volume of a cylinder forces the gas particles much closer together than they would be at normal atmospheric pressure. With so many particles in such a small space, they collide with the cylinder walls extremely frequently and with a large total force, which is measured as a very high pressure. When some of this air is breathed in and reaches the diver's lungs, it is now at ordinary atmospheric (or slightly higher, underwater) pressure, which is much lower than the pressure inside the cylinder — so the same mass of air particles spreads out and occupies a much larger volume. As a diver swims towards the surface, the pressure around them keeps falling, so any air in their lungs keeps expanding. If they held their breath, this expanding air would have nowhere to go and could stretch and damage the lungs; breathing out continuously allows the expanding air to escape safely instead.

Mark scheme

(a)

[1]

- both change liquid into gas/vapour (1)

ALLOW "both involve a liquid turning into a gas" or equivalent

(b)

[3]

- evaporation can happen at any temperature (below the boiling point) (1)
- boiling happens only at one fixed temperature, the boiling point (1)
- evaporation happens only at the surface of the liquid whereas boiling happens throughout the whole liquid (1)

ALLOW "bubbles of gas/vapour form inside the liquid during boiling" for the third mark

IGNORE references to speed/rate as a "difference" unless linked to temperature or location

Worked solution

Both processes turn a liquid into a gas, so that is their similarity. The differences are about where and at what temperature they happen. Evaporation only happens at the exposed surface of a liquid, and it can happen at any temperature — this is why damp washing dries even on a cool, windy day, well below 100 °C. Boiling, on the other hand, happens throughout the whole liquid (bubbles of vapour form inside the liquid, not just at the surface), but only once the liquid reaches its fixed boiling point — 100 °C for pure water at normal atmospheric pressure, which is why the kettle must heat the water all the way to that temperature before it boils.

Mark scheme

(a)

[3]

- A: solid (1)
- B: liquid (1)
- C: gas (1)

(b)

[2]

- the particles in C (a gas) are far apart, with large gaps of empty space between them (1)
- because they move around at high speed in random directions (rather than being packed together), these gaps can be reduced by pushing the particles closer together, so the gas is easily compressed (1)

Worked solution

A keeps its own shape and cannot be poured or compressed, so it is a solid. B has no fixed shape, can be poured, but cannot easily be compressed, so it is a liquid (liquids, like solids, have particles close together, so there is little empty space to squeeze out). C has no fixed shape, can be poured, and is easily compressed, so it is a gas. Gases can be compressed because their particles are spread far apart with a lot of empty space between them; pushing on a gas simply reduces this empty space and forces the particles closer together, without needing to overcome the strong particle-to-particle forces present in a solid or liquid.

Mark scheme

(a) [1]

- freezing (1)

(b) [3]

- the particles lose kinetic energy and slow down (1)
- the forces of attraction between the particles hold them in a fixed, regular (ordered) arrangement / lattice (1)
- the particles are no longer free to move past one another and only vibrate about fixed positions (1)

IGNORE statements about the particles moving closer together (water expands on freezing, so do not credit or penalise)

(c) [2]

- the energy being removed is taken from the particles' potential energy as they form the fixed, ordered structure (bonds/attractions between particles becoming fixed), not from their kinetic energy (1)
- because temperature depends on the particles' kinetic energy, the temperature does not fall until freezing is complete and there is no more potential energy of this kind left to remove (1)

ALLOW reference to "latent heat" being released during freezing

Worked solution

The water turning from a liquid into a solid is freezing. As freezing happens, the water particles lose energy, slow down, and are pulled into a fixed, regular arrangement, where they can only vibrate about fixed positions rather than move around freely — this is the structure of ice. While this change is taking place, the energy removed by the freezer is being taken from the energy associated with the particles locking into this ordered structure, not from their kinetic energy. Since temperature is a measure of the particles' average kinetic energy, and that kinetic energy is not changing during the plateau, the temperature stays at 0 °C throughout freezing. Only once every particle has become part of the solid structure does further cooling start to lower the kinetic energy — and the temperature — again.

Mark scheme

(a) [1]

- the volume decreases (1)

(b) [1]

- the pressure increases (1)

(c) [2]

- the volume increases (1)
- because at constant pressure, heating a fixed mass of gas makes it expand/occupy a larger volume (1)

ALLOW a particle-level reason (particles move faster and need more space to keep the pressure the same) for the second mark

Worked solution

Pushing the plunger in squeezes the same fixed mass of trapped air into a smaller volume, and because temperature stays constant, this smaller volume means more frequent collisions with the syringe walls, so the pressure increases. When the plunger is instead left free to move and the pressure is kept constant while the air is warmed, the trapped air expands — its volume increases — because a gas needs a bigger volume to keep the same pressure once its particles are moving faster (a warmer gas at the same pressure always takes up more space than a cooler one).

22**Supplement**

Solids, liquids and gases

[5]

Mark scheme

(a)

[1]

- 327 °C (1)

(b)

[1]

- freezing (the lead is changing from liquid to solid) (1)

(c)

[3]

- while freezing is taking place, the particles are losing kinetic energy and coming together into a fixed, regular arrangement (1)
- energy is being released as the particles form this fixed structure (bonds/attractions between particles), and this release balances the energy being removed by the surroundings (1)
- so there is no net loss of kinetic energy during this time, and the temperature (which depends on kinetic energy) stays constant until freezing is complete (1)

Worked solution

The plateau in the table, at 327 °C, is the freezing point of lead — this is where the molten lead is solidifying. Even though the surroundings keep removing energy from the lead throughout this stage, the temperature does not fall, because the energy being removed is matched by energy released as the particles slow down and lock into the fixed, ordered arrangement of solid lead. This release of energy as the particles form a solid structure exactly offsets the energy loss to the surroundings, so the particles' average kinetic energy — and hence the temperature — stays constant at 327 °C until all of the lead has solidified. After that, with no more freezing left to release energy, the solid lead's temperature falls steadily again, as shown after 8 minutes.

23**Core**

Diffusion

[1]

Answer: C

Explanation

The scent spreading through the room without any stirring, fan or draught is diffusion — the random movement of particles from a region of higher concentration to a region of lower concentration. Osmosis (A) applies to solvent movement across a membrane, not gas particles spreading through air. Evaporation (B) only describes the perfume liquid turning into vapour at the bottle, not the vapour then spreading across the room. Convection (D) needs currents caused by temperature/density differences, not random particle motion.

24**Core**

Diffusion

[1]

Answer: D

Explanation

Diffusion is the random, continuous movement of particles in all directions, which results in a net movement from a region of higher concentration to a region of lower concentration until the particles are evenly spread out — this matches D. A and C wrongly require an external cause (wind currents, opening a door) for the spreading to happen at all. B incorrectly claims the fumes sink and only spread along the floor.

25**Supplement**

Diffusion

[1]

Answer: A

Explanation

$\text{Mr}(\text{NH}_3) = 14 + (3 \times 1) = 17$; $\text{Mr}(\text{Cl}_2) = 2 \times 35.5 = 71$. The gas with the smaller relative molecular mass diffuses faster, so ammonia diffuses faster than chlorine. B and D wrongly link "diffuses faster" to a larger or a smaller Mr in the wrong direction, and C states the wrong Mr comparison for ammonia.

26**Supplement**

Diffusion

[1]

Answer: B

Explanation

At a given temperature, all gas particles have the same average kinetic energy, regardless of their mass. Since kinetic energy depends on both mass and speed, particles with a smaller mass (smaller Mr) must, on average, move faster to have the same kinetic energy as heavier particles — and faster-moving particles diffuse more quickly. A, C and D describe effects (stronger attractive forces, fewer particles, smaller physical size) that are not the reason relative molecular mass affects diffusion rate.

Mark scheme

(a)

[2]

- the orange colour gradually spreads upward from the lower jar into the upper jar (1)
- after some time, both jars appear a uniform, evenly coloured (paler) orange throughout (1)

ALLOW "the colour becomes paler / less intense than the original bromine gas" as part of describing the final appearance

(b)

[3]

- bromine gas particles move randomly and continuously in all directions at high speed (1)
- particles move from the region of higher bromine concentration (the lower jar) to the region of lower concentration (the upper jar) (1)
- this continues until the bromine particles are evenly spread throughout both jars; the upward movement happens because of this random particle motion, not because of stirring or convection (1)

Worked solution

Bromine gas starts concentrated in the lower jar. Once the cover slip is removed, the bromine particles, which are moving randomly and continuously in every direction, gradually spread into the upper jar as well as staying in the lower one. Over time, this random motion carries more and more bromine particles upward than air particles carry bromine downward (since there are initially many more bromine particles below than above), so there is a net movement of bromine into the upper jar. Eventually the bromine particles become evenly distributed between the two jars, so both jars appear the same, paler, orange colour. This happens even though bromine gas is denser than air, showing that diffusion — the random spreading of particles from high to low concentration — does not depend on stirring, shaking or convection currents.

Mark scheme

(a)

[2]

- purple colour spreads out (slowly) from the crystal through the water, for example in streaks or a spreading cloud (1)
- the crystal becomes smaller / dissolves OR the water eventually becomes (pale) purple throughout (1)

ALLOW "the water gradually becomes (partly) coloured purple" for the first mark; do not require the colour to become completely even throughout the beaker within the hour, since diffusion in a liquid is slow

IGNORE references to rate

(b)

[2]

- particles of the purple compound move randomly and continually in all directions (1)
- they move from the region of higher concentration (near the crystal) to regions of lower concentration, gradually spreading out through the water even without stirring (1)

Worked solution

As the crystal slowly dissolves, particles of the purple compound spread out from it into the surrounding water. Even though nobody stirs the beaker, these dissolved particles are moving randomly and continuously in all directions, and this random motion causes a net movement of particles away from the crystal, where their concentration is highest, towards the rest of the water, where their concentration is lower. Over the hour this produces a slowly spreading, streaky purple colour. Diffusion happens much more slowly in a liquid than in a gas, because liquid particles are much closer together and collide with each other far more often, so it is normal for the colour not to have spread completely evenly through the whole beaker after only an hour.

Mark scheme

(a) [2]

- $\text{Mr}(\text{NH}_3) = 14 + (3 \times 1) = 17$ (1)
- $\text{Mr}(\text{HCl}) = 1 + 35.5 = 36.5$ (1)

(b) [1]

- ammonia, NH_3 (1)

ECF allow consistent with an incorrect Mr calculated in (a), provided the comparison is made correctly from that value

(c) [2]

- the ring forms nearer the hydrogen chloride end (1)
- because ammonia has the smaller Mr, so it diffuses faster and travels further along the tube in the same time, meeting the (slower) hydrogen chloride closer to the hydrogen chloride end (1)

(d) [2]

- at the same temperature, gas particles of any Mr have the same average kinetic energy (1)
- so particles with a smaller Mr must move faster, on average, than particles with a larger Mr, allowing them to spread out (diffuse) more quickly (1)

Worked solution

Using the given Ar values, $\text{Mr}(\text{NH}_3) = 14 + 3(1) = 17$ and $\text{Mr}(\text{HCl}) = 1 + 35.5 = 36.5$, so ammonia has the smaller relative molecular mass. Because both gases are at the same temperature, their particles have the same average kinetic energy, which means the lighter ammonia particles must be moving faster, on average, than the heavier hydrogen chloride particles. Faster-moving particles diffuse — spread out — more quickly, so the ammonia travels further along the tube than the hydrogen chloride does in the same time. The two gases meet and react to form the white ammonium chloride ring at the point they reach at the same time, which is therefore closer to the hydrogen chloride end of the tube (since the slower hydrogen chloride has travelled a shorter distance).

Mark scheme

(a) [2]

- as the relative molecular mass increases, the time taken to detect the gas increases (1)
- so gases with a larger Mr diffuse more slowly (take longer to travel the same distance) (1)

(b) [2]

- the time for chlorine would be somewhat longer than 220 s (1)
- because chlorine has a larger Mr (71) than sulfur dioxide (64), so it diffuses more slowly and takes longer to travel the same distance (1)

ALLOW any specific time greater than 220 s (e.g. "around 230–250 s") provided the reasoning is correct; no exact value is required

(c) [2]

- at the same temperature, gas particles of different Mr have the same average kinetic energy (1)
- so gases with a larger Mr have particles that move more slowly, on average, and slower-moving particles diffuse (spread out) more slowly (1)

Worked solution

The table shows a clear pattern: as relative molecular mass increases (hydrogen, 2, up to sulfur dioxide, 64), the time taken to detect the gas 2 m away also increases, from 40 s up to 220 s. This means heavier gas particles take longer to diffuse the same distance — they diffuse more slowly. Chlorine has an even larger Mr (71) than sulfur dioxide (64), so it would be expected to diffuse a little more slowly still, taking somewhat longer than 220 s to be detected (the syllabus does not require an exact calculated value, only the correct trend and reasoning). The underlying reason is that, at a fixed temperature, all gas particles share the same average kinetic energy regardless of their mass; since heavier particles need to move more slowly to have the same kinetic energy as lighter ones, gases made of heavier particles diffuse more slowly than gases made of lighter particles.