Particle model of matter

Model answers and marking points

GCSE science 6-mark questions

This topic online

1 Haruto takes a tray of ice cubes at -10 °C out of the freezer and heats them steadily in a beaker. He records the temperature every minute. The temperature rises to 0 °C, then stays at 0 °C for several minutes while the ice melts, then rises again.

Explain these observations in terms of particles and internal energy. (6 marks)

Model answer

Internal energy is the total kinetic energy and potential energy of all the particles in a substance.

At the start the ice is a solid. Its particles are held in fixed positions by strong forces and vibrate. Heating gives the particles more kinetic energy, so they vibrate faster and the temperature rises from -10 °C to 0 °C.

At 0 °C the ice is at its melting point. Now the energy supplied is used to weaken and break the bonds holding the particles in place, so they can move past each other as a liquid. This increases the potential energy of the particles but not their kinetic energy. Because temperature depends on the kinetic energy of the particles, the temperature stays at 0 °C while the ice melts, even though the internal energy is still increasing. The energy needed to change the state without changing the temperature is called the latent heat of fusion.

Once all the ice has turned to water, the energy supplied goes back into increasing the kinetic energy of the particles, so they move faster and the temperature starts to rise again.

Marking points (credit any 6 relevant points, linked in a sensible order)

- internal energy is the total kinetic and potential energy of all the particles in a system
- at first, heating increases the kinetic energy of the particles, so the temperature of the ice rises
- in the solid the particles vibrate about fixed positions, held by strong forces of attraction
- at 0 °C the ice reaches its melting point
- while melting, the energy supplied is used to weaken or break the bonds between particles
- this increases the potential energy of the particles, not their kinetic energy, so the temperature stays constant
- the energy needed to melt the ice without a temperature change is the latent heat of fusion
- the internal energy is still increasing while the temperature is constant
- once all the ice has melted, the energy increases the kinetic energy of the water particles again, so the temperature rises

How it is marked

- 5-6 marks: explains all three stages, linking temperature rise to kinetic energy and the flat section to energy breaking bonds and raising potential energy, with internal energy still increasing.
- 3-4 marks: explains that energy is used to break bonds while melting, but does not clearly link the stages to kinetic and potential energy.
- 1-2 marks: describes the temperature changes or says the ice is melting, with little explanation.

What loses marks

- saying no energy is being supplied while the temperature is constant
- saying the particles themselves melt or expand
- confusing temperature with internal energy

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2 A bottle of olive oil is stored in a cold garage, where the oil turns solid. Later it is warmed until it is a liquid, and a few drops are heated in a pan until they become a vapour.

Compare the oil as a solid, a liquid and a gas. Refer to the arrangement and movement of the particles, the forces between them, and the density. (6 marks)

Model answer

In the solid oil the particles are packed closely in a regular, fixed pattern. They cannot move from place to place and only vibrate about fixed positions, because the forces of attraction between them are strong.

In the liquid the particles are still close together, but they are in a random arrangement. The forces between them are weaker than in the solid, so the particles can slide past each other. This is why the liquid can flow.

In the gas the particles are far apart and randomly arranged. The forces between them are very weak, so they move quickly in all directions in straight lines until they collide.

When the oil changes state, the number of particles does not change, so the mass stays the same. Density = mass / volume. The solid and liquid both have high densities, quite close to each other, because their particles are close together. The gas has a far lower density, because the same mass is spread out over a much bigger volume. These are physical changes, so cooling the vapour and the liquid would turn them back into liquid and solid oil again.

Marking points (credit any 6 relevant points, linked in a sensible order)

- in a solid the particles are close together in a regular, fixed arrangement
- in a liquid the particles are still close together but are randomly arranged
- in a gas the particles are far apart and randomly arranged
- solid particles vibrate about fixed positions; liquid particles move around each other; gas particles move quickly in all directions
- forces of attraction are strong in a solid, weaker in a liquid and very weak in a gas
- the mass of the oil stays the same when it changes state, because the number of particles stays the same
- density = mass / volume
- the solid and the liquid have high, similar densities because the particles are close together
- the gas has a much lower density because the same mass takes up a much larger volume
- a change of state is a physical change and can be reversed

How it is marked

- 5-6 marks: compares all three states on arrangement, movement and forces, and explains the difference in density using the spacing of particles and the mass staying the same.
- 3-4 marks: compares two or three features correctly across the states, but the link to density is missing or not explained.
- 1-2 marks: gives a few correct facts about one or two states with little comparison.

What loses marks

- saying the particles get bigger when the oil is heated
- saying the particles in a solid do not move at all
- saying the mass changes during a change of state

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3 Zainab places crushed ice in a funnel with an electric heater pushed into it. A joulemeter records the energy supplied by the heater. She collects and weighs the water that melts. She repeats the test three times.

Trial	Energy supplied in J	Mass of ice melted in kg
1	18,000	0.050
2	27,000	0.075
3	36,500	0.100

The accepted value for the specific latent heat of fusion of ice is 334,000 J/kg.

Use the data to calculate a value for the specific latent heat of fusion of ice. Compare it with the accepted value and suggest reasons for the difference.

(6 marks)

Model answer

The energy needed to change state is E = mL, so L = E / m.

Trial 1: L = 18,000 / 0.050 = 360,000 J/kg.
Trial 2: L = 27,000 / 0.075 = 360,000 J/kg.
Trial 3: L = 36,500 / 0.100 = 365,000 J/kg.

The mean is (360,000 + 360,000 + 365,000) / 3 = about 362,000 J/kg. The three values are very close together, so the results are repeatable.

However, Zainab's value is about 28,000 J/kg higher than the accepted value of 334,000 J/kg, so it is not very accurate. The joulemeter records all of the energy the heater supplies, but not all of that energy went into melting the ice. Some was transferred to the funnel, to the air around it and to the melted water that was in contact with the heater. This means the energy recorded is more than the energy actually used to melt the ice, so the value of L comes out too high.

To get closer to the accepted value she could insulate the funnel and make sure all the ice is at 0 °C before she starts.

Marking points (credit any 6 relevant points, linked in a sensible order)

- energy for a change of state = mass x specific latent heat, so L = E / m
- trial 1: 18,000 / 0.050 = 360,000 J/kg
- trial 2: 27,000 / 0.075 = 360,000 J/kg
- trial 3: 36,500 / 0.100 = 365,000 J/kg
- mean value = about 362,000 J/kg
- the results are close to each other, so they are repeatable
- the calculated value is higher than 334,000 J/kg by about 28,000 J/kg
- some of the energy from the heater was transferred to the surroundings, the funnel or the melted water instead of melting ice
- so more energy was recorded than was used to melt the ice, giving a value that is too high
- insulating the funnel, or making sure the ice is all at 0 °C and that drips are collected for the full time, would improve accuracy

How it is marked

- 5-6 marks: calculates L for each trial and a mean correctly, notes that it is higher than the accepted value, and explains why energy transferred elsewhere makes the value too high.
- 3-4 marks: calculates at least one value correctly and gives a reasonable reason for the difference, without explaining which way it affects the result.
- 1-2 marks: recalls E = mL or gives a vague reason such as human error.

What loses marks

- dividing mass by energy
- saying energy lost to the surroundings would make the value too low

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- using the word 'error' without saying what caused it

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4 Callum seals some air inside a large syringe attached to a pressure gauge. He pushes the plunger in slowly, waiting each time before taking a reading, so the temperature stays the same.

Volume in cm^3	60	50	40	30	25	20
Pressure in kPa	100	120	150	200	230	300

Callum says: *My results show that the pressure of a gas is inversely proportional to its volume.*

Evaluate Callum's claim. Use the data and the particle model in your answer.

Separate science only

(6 marks)

Model answer

If pressure is inversely proportional to volume, then pressure x volume should stay the same when the temperature is constant.

For 60 cm^3: 60 x 100 = 6,000. For 50 cm^3: 50 x 120 = 6,000. The results for 40, 30 and 20 cm^3 also give 6,000. For example, halving the volume from 60 to 30 cm^3 doubles the pressure from 100 to 200 kPa. These results strongly support Callum's claim.

However, at 25 cm^3 the product is 25 x 230 = 5,750. The expected pressure is 6,000 / 25 = 240 kPa, so this reading is anomalous. He has probably misread the gauge or written the value down wrongly. A leak is unlikely, because the reading at 20 cm^3 fits the pattern again. He should repeat this reading.

The pattern matches the particle model. When the volume is smaller, the same number of particles are in less space, so they hit the walls of the syringe more often. This means a larger force on each area, so the pressure is greater.

Overall, Callum's claim is supported, but only for a fixed mass of air at constant temperature, and he has tested just one gas over a small range.

Marking points (credit any 6 relevant points, linked in a sensible order)

- if pressure is inversely proportional to volume, pressure x volume should be constant at constant temperature
- pV for 60, 50, 40, 30 and 20 cm3 is 6,000 each time
- pV for 25 cm3 is 25 x 230 = 5,750, which does not fit
- the expected pressure at 25 cm3 is 6,000 / 25 = 240 kPa, so 230 kPa is an anomaly
- the low reading at 25 cm3 is most likely a misread gauge or a recording mistake; a leak is unlikely because the 20 cm3 reading fits the pattern again
- halving the volume from 60 to 30 cm3 doubles the pressure from 100 to 200 kPa, which supports the claim
- with a smaller volume the particles hit the walls more often, so the pressure is greater
- the claim only holds for a fixed mass of gas at constant temperature
- the data covers only one gas over a limited range, so the conclusion should be limited to air over this range unless repeated
- overall the data supports the claim apart from one anomalous reading

How it is marked

- 5-6 marks: tests the claim by working out pV or a similar check, identifies the anomaly, explains the pattern using particle collisions, and reaches a conclusion that notes its limits.
- 3-4 marks: uses the data to show that pressure rises as volume falls, with some calculation or a mention of the anomaly, and a basic conclusion.
- 1-2 marks: describes the trend, for example pressure goes up as volume goes down, without testing the claim.

What loses marks

- describing the trend without testing whether it is inversely proportional
- ignoring the anomalous result at 25 cm3

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- explaining the pressure rise by saying the particles move faster
- blaming the low reading on the air still being warm, which would make the pressure higher, not lower

5 **Higher tier | Separate science only**

Leah pumps up her bike tyre quickly with a hand pump. After a minute of pumping she notices that the end of the pump near the valve feels warm. When she pumps the same tyre slowly, the pump warms up much less.

Suggest why the pump gets warm and why the speed of pumping makes a difference. Use ideas about work, internal energy and particles.

(6 marks)

Model answer

When Leah pushes the handle, she applies a force that moves the piston through a distance, so she is doing work on the air inside the pump. Doing work on a gas transfers energy to it, which increases its internal energy.

As the piston moves in, air particles bounce off it and move away faster, so they gain kinetic energy. Since the temperature of a gas depends on the average kinetic energy of its particles, the temperature of the air rises. The air is also squashed into a smaller volume, so the particles hit the walls more often and the pressure rises until air is pushed into the tyre.

The warm air then transfers energy to the walls of the pump by heating, so the end of the pump feels warm. A small amount of warming may also come from friction between the piston and the barrel.

When she pumps quickly, she does work on the air faster than energy can be transferred away to the surroundings, so the temperature builds up. When she pumps slowly, there is more time between strokes for energy to be transferred from the air and pump to the surroundings, so the temperature rise is much smaller.

Marking points (credit any 6 relevant points, linked in a sensible order)

- pushing the handle applies a force over a distance, so Leah does work on the air in the pump
- doing work on a gas transfers energy to it
- this increases the internal energy of the air
- the particles gain kinetic energy, so the temperature of the air rises
- the moving piston hits particles and they bounce off faster
- the hot air transfers energy to the metal or plastic of the pump by heating, so the pump feels warm
- the air is also squashed into a smaller volume, so particles hit the walls more often and the pressure rises, allowing air into the tyre
- when she pumps quickly, energy is transferred in faster than it can escape to the surroundings, so the temperature rises more
- when she pumps slowly, there is more time for energy to be transferred away to the surroundings, so the temperature stays closer to room temperature
- friction between the piston and the pump wall may also warm the pump a little

How it is marked

- 5-6 marks: links work done on the gas to increased internal energy and particle kinetic energy, explains why the pump warms, and explains the effect of speed using rate of energy transfer to the surroundings.
- 3-4 marks: states that work done on the gas raises its temperature and gives some particle explanation, but the effect of pumping speed is missing or unclear.
- 1-2 marks: gives friction as the only reason or says the air gets hot without explanation.

What loses marks

- giving friction as the main or only cause
- saying pressure itself makes the pump hot without linking to work and energy
- not explaining the difference between fast and slow pumping

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