Chapter 3: Particle model of matter

Lesson 3.1 Density

1a solid

1b gas

1c liquid

2 The particles in a solid are usually closer together than they are in a liquid or a gas. Therefore, the same mass of material will occupy a smaller volume which makes the density higher.

3 The particles in a gas are far apart. Therefore, the volume of a certain mass of gas is much bigger than the same mass of liquid and solid. This makes the density small.

4a $\rho = m \div V = 5400 \div 2 = 2700$ kg/m^3

4b $m = \rho V = 7700 \times 2 = 15\,400$ kg.

4c Aluminium is less dense than steel. Therefore, aeroplanes made from aluminium are likely to be much lighter.

5 Volume = 5 × 4 × 3 = 60 m^3.

$m = \rho V = 1.3 \times 60 = 78$ kg.

6 Cork is less dense than water so it floats. Iron is denser than water, so it sinks.

7 The mass of the air stays the same but the volume of the air gets less. Since density = mass / volume, this means the density of the air will increase.

8 1 g / cm^3 means that each cm^3 of the substance will have a mass of 1 g. There are 100 × 100 × 100 = 1000 000 cm^3 in 1 m^3, so 1 m^3 of the substance will have a mass of 1000 000 g. 1000 000 g = 1000 kg, so 1 m^3 of the substance has a mass of 1000 kg – giving a density of 1000 kg / m^3.

Lesson 3.2 Required Practical: To investigate the densities of regular and irregular solid objects and liquids

1 The balance would also be recording the mass of the measuring cylinder.

2 Subtract the mass of the empty measuring cylinder to get the mass of the liquid.

3 Density = mass / volume

Coconut oil: 18.5 / 20 = 0.925 g / cm^3

Acetone: 19.6 / 25 = 0.784 g / cm^3

Sea water: 51.3 / 50 = 1.026 g / cm^3

4 Volume of cork = 2.0 × 2.0 × 3.0 = 12 cm^3

5 Density of cork = mass / volume = 3 / 12 = 0.25 g / cm^3

6 Density of oak = mass / volume = 17 / (2.0 × 3.0 × 4.0) = 0.71 g / cm^3

Density of tin = mass / volume = 365 / (2.5 × 2.5 × 8.0) = 7.3 g / cm^3

7 The data is only measured to 2 significant figures. Therefore, the answer can only be given to two significant figures. It is incorrect to give any more significant figures as this suggests that the calculation is more accurate than it actually is.

8 You could half fill a measuring cylinder with water. Record the volume of the water. Then place the necklace into the water and make sure it is fully submerged. Record the new volume of the water. The volume of the necklace is the difference between the two volumes you measured. Then you could find the mass of the necklace by placing it on a balance. Repeat the measurements and find an average to reduce the effects of random errors.

9 You would need to measure the mass of the necklace and the volume of the necklace.

10 Density = mass / volume

11 There are many errors in the experiment such as not reading the measuring cylinder very accurately. Perhaps your eyes weren't lined up with the bottom of the meniscus or you weren't holding the measuring cylinder completely vertically. Also the volume of the necklace is quite small and the measuring cylinder would not be sensitive enough to measure small changes in the volume accurately.

Lesson 3.3 Changes of state

1 Freezing

2 You could place a block of ice in a container and then place the container on a balance. Record the mass and then wait for all of the ice to melt. Record the mass again and see whether the mass has changed.

3 e.g. Dry ice changing from a solid to a gas (sublimating). The material involved is carbon dioxide. (Dry ice is solid CO_2)

4 A freezing temperature is not necessarily a cold temperature. Some materials (e.g. tungsten) freeze at thousands of degrees Celsius. We are really only referring to the temperature at which water freezes.

5 This makes the surface area larger and so more evaporation can take place.

6 The fastest moving particles are the ones which evaporate. When they leave the liquid, the average speed of the remaining particles is less (since the fastest ones have left). The temperature is related to the average speed and so the temperature decreases.

7 When you are burned by steam, the steam transfers energy to your skin when it is condensing. This is extra to the energy transferred to your skin when the hot water cools down.

8 Sweat is no colder than your skin. The cooling effect occurs because the sweat evaporates. Not all of the water molecules in the sweat move at the same speed and it is the ones that move the fastest that evaporate. Therefore, the average speed of the molecules decreases as the sweat evaporates and this results in a lower temperature.

Lesson 3.4 Internal energy

1 They store kinetic energy because they are moving.

2 $E_k = ½\, mv^2$ and the particles have the same kinetic energy at the same temperature. This means that the heavy particles are moving slower than the light particles at the same temperature.

3 The particles store potential energy because they are separated from each other.

4 The Pacific Ocean has more internal energy than the tea. Each particle in the tea does store more kinetic energy (the tea is hotter) and more potential energy (the particles are further apart). However, there are many more particles in the Pacific Ocean so the **total** of the kinetic and potential energies stored by the particles in the Pacific Ocean is a much bigger value.

5 The internal energy increases.

6 The water cools down, freezes and cools down again. All of this results in a decrease in internal energy.

7a The internal energy of steam at 100 ^{0}C is much higher than that of water at the same temperature. The internal energy would also include all of the latent heat of vaporisation.

7b Steam is able to transfer much more energy than water at the same temperature as its internal energy is so much higher.

Lesson 3.5 Specific heat capacity

1 They move faster (gain kinetic energy) and they get further apart (gain potential energy).

2 There is a larger mass of water in the saucepan than there is in the cup. Therefore, more energy is needed.

3 Yes it will. The gain in internal energy of the milk is smaller when it heats up. Therefore, the decrease in internal energy will be smaller when it cools down, so the amount of energy transferred into the surroundings will be less.

4 $\Delta E = mc\Delta\theta = 0.1 \times 4200 \times (40 - 10) = 12\,600$ J

5 e.g. in cooling systems. Water passing through a car engine can stop the engine from heating up by absorbing some of the thermal energy. The water can absorb lots of energy into its thermal energy store without heating up very much.

6a Energy needed = $mc\Delta\theta$ for the copper + $mc\Delta\theta$ for the water

$= (0.5 \times 380 \times 10) + (1 \times 4200 \times 10) = 43\,900$ J

$t = E / P = 43\,900 / 2000 = 21.95$ s = 22 s (to 2 s.f.)

6b I have assumed that all of the energy from the heater has been transferred to the thermal energy stored in the water and in the copper kettle.

7 Copper is a very good conductor of heat – it has a very high thermal conductivity. It also has a low specific heat capacity so not much energy is needed to heat the saucepan up.

8a The temperature of the copper decreases and the temperature of the water increases. Energy is transferred from the mass to the water by heating. Therefore the mass loses internal energy and the water gains internal energy.

8b The final temperature is likely to be closer to 20 ^{0}C. The specific heat capacity of water is much larger than that of copper. Therefore for the same mass (both 50g) and the same amount of energy transfer by heating, the temperature change of the copper will be much larger than the temperature change of the water. So the final temperature will be closer to 20 ^{0}C.

Lesson 3.6 Latent heat

1 The material is changing state.

2 As water turns into steam the particles get further apart. The particles therefore gain potential energy and so they need energy to do this.

3 The particles are only gaining potential energy. The energy in their kinetic energy store remains constant so the temperature remains the same.

4 When particles move from a solid into a liquid they don't move apart from each other very much. However, when they move from the liquid state to a gas they move apart from each other a great deal and gain much more potential energy.

5 $E = mL = 0.1 \times 340\,000 = 34\,000$ J

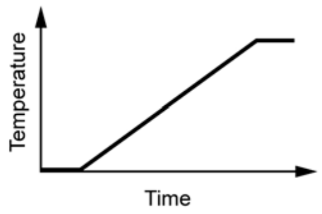
6a Melt the ice at 0 ^{0}C: $E = mL = 0.2 \times 340\,000 = 68\,000$ J

Heat the water to 100 ^{0}C: $E = mc\Delta\theta = 0.2 \times 4200 \times 100 = 84\,000$ J

Boil the water at 100 ^{0}C: $E = mL$ = 0.2 × 2260000 = 452 000 J

Total energy transferred = 68000 + 84000 + 452000 = 604 000 J

6b



7 Energy is needed to heat the ice up to 0 ^{0}C, melt the ice, and then heat the water (the melted ice) up to 5^{0}C. Let the mass of the ice be *m*.

Therefore 7304 = (*m* × 2100 × 2) + (*m* × 340 000) + (*m* × 4200 × 5)

7304 = 4200*m* + 340 000*m* + 21 000*m*

7304 = 365 200*m*

So *m* = 7304 / 365200 = 0.02 kg

Lesson 3.7 Particle motion in gases

1 The molecules move faster.

2 The temperature is related to the average kinetic energy of the molecules. The faster the molecules move, the higher the temperature.

3 The particles collide with the walls of their container. During the collision they exert a force on the walls. Since pressure = force / area, the force exerted by the particles produces a pressure on the container.

4 When you pump more air in a bicycle tyre there are more air particles. Therefore, there are more collisions between the particles and the walls of the tyre, which increases the pressure.

5 No gas can pass in or out of the container.

6 If the gas gets hotter, then the average kinetic energy of the particles increases. This means that the particles will move faster. This makes them collide with the container with a larger force and more often. Therefore, the pressure increases.

7 The temperature of a gas is a related to kinetic energy. So the particles in hot gases have a high kinetic energy. The particles also have a very small mass which means they must move very fast.

8 The pressure can drop by making the gas occupy a larger volume, cooling the gas down and reducing the amount of gas in a given volume.

9 The balloon will change volume until the pressure inside the balloon equals atmospheric pressure. When you heat the air inside a balloon the particles gain kinetic energy and will collide with the walls with more force and more frequently. Both of these increase the pressure inside the balloon. The pressure inside is now bigger than outside so there is a resultant force making the balloon expand. As the balloon expands, the particles inside the balloon collide with the walls of the balloon less often and the pressure drops. Once the pressure becomes the same as the outside pressure again, the balloon stops expanding.

Lesson 3.8 Increasing the pressure of a gas

1 The pressure decreases.

2 The pressure should double.

3 There are more collisions with the walls in a given time because the particles have a smaller distance to travel between each collision. This results in a larger average force on the walls and a higher pressure.

4 $p_1 \times V_1 = p_2 \times V_2$

$200 \times 4 = p_2 \times 3$

P_2 = 800 / 3 = 267 kPa

5 $p_1 \times V_1 = p_2 \times V_2$

$1.8 \times 10^5 \times 80 = 1.2 \times 10^5 \times V_2$

$V_2 = 144 \times 10^5 / 1.2 \times 10^5 = 120$ cm^3

6 When you move the move the pump, the particles of gas colliding with the pump will end up moving faster. This increases the kinetic energy of the particles and so the internal energy increases.

7 The pump is doing work on the gas which heats up the gas. Since gas is not a very good conductor of heat, the region of the gas that gets hot remains near the pump.

8a The internal energy of the gas must decrease since the gas is doing work as it expands. Therefore, the temperature must decrease.

8b An expanding gas reduces the temperature. So you can make the gas expand inside a fridge to reduce the temperature of the fridge.

8c The compressor increases the temperature of the gas. This is used on the outside of the fridge (at the back). As the cold, expanded gas moves inside the fridge, it gains internal energy as the warmer food heats it up a little. Then the gas passes to the outside of the fridge where it is compressed and heats up. The gas is now hotter than the surroundings and it loses internal energy (which has originally come from the food) to the surroundings by heating.

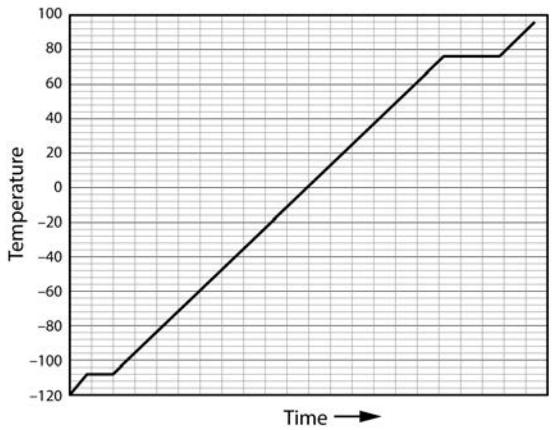
Lesson 3.9 Key Concept: Particle model and changes of state

1 In a solid, the atoms and molecules vibrate around a fixed point. In a liquid the atoms and molecules can move past each other.

2 The particles vibrate with a larger amplitude. Therefore, their average separation increases.

3 The internal energy increases. This is because the potential energy increases from the particles getting further apart and the kinetic energy increases from the particles vibrating with a greater speed.

4

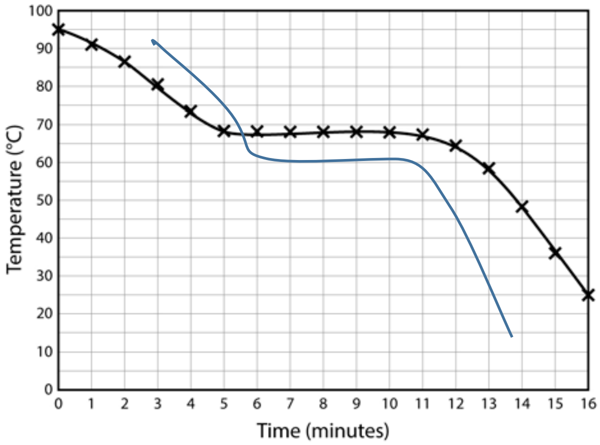


5 The material is cooling down.

Lesson 3.10 Maths Skills: Drawing and interpreting graphs

1 The maximum value of temperature is 95.0 ^{0}C and the minimum value is 25.0 ^{0}C.

2 & 3



4 The line curves when the stearic acid cools from 95.0 ^{0}C to 68.1 ^{0}C. Then the line is horizontal at about 68 ^{0}C indicating that the temperature remains constant. Then the line begins to fall again after about 11 minutes.

5 The specific heat capacity of the wax must be changing.

6 The wax is melting.

7 About 44 ^{0}C.

8 The stearic acid was cooling in liquid form, then it changed state to a solid (as indicated by the horizontal portion of the graph). Once it had completely frozen it continued to cool towards room temperature.

9 The stearic acid is freezing.

10 About 68 ^{0}C

11 When the graph has a negative gradient, both the kinetic energy and the potential energy of the particles is decreasing. When the graph is horizontal only the potential energy of the particles is decreasing. However, the internal energy is decreasing at all parts of the graph.

12 For the stearic acid, both the potential energy and the kinetic energy is decreasing when the stearic acid is cooling. When the acid is freezing, then the kinetic energy remains the same while the potential energy continues to decrease.

For the wax, both the potential and the kinetic energy is increasing when the wax is warming up. When the wax is melting, then the kinetic energy remains the same while the potential energy continues to increase.

13 Same melting point would mean that the horizontal portion of the graph would still be at the same temperature. Lower specific heat capacity would mean less energy would be needed to raise the temperature so the temperature would take less time to change. Therefore the curved regions of the graph would be steeper. A larger latent heat would mean that more energy is needed to melt the substance so this would take longer. So the horizontal part of the graph is longer.

End of Chapter Questions

1 The left hand diagram is a gas, the middle diagram is a solid and the right hand diagram is a liquid. [1 mark]

2 Spacing: In a solid and a liquid the particles are close together and in a gas they are far apart. [1 mark]

Motion: In a solid the particles vibrate about a fixed position, in a liquid the particles slide past each other and in a gas the particles move freely until they collide with each other. [1 mark]

3 It condenses into a liquid [1 mark]

4 Latent heat [1 mark]

5 density = mass / volume [1 mark]

6 mass / volume = 100 / 25 = 4g/cm^{-3} [1 mark]

7 Latent heat of fusion of water is the energy needed to melt 1 kg of ice into water (or the energy given out when 1 kg of water freezes into ice). [1 mark for realising that the change of state is between ice and water and 1 mark for realising that it is for 1 kg]

8 $\Delta E = 2 \times 4200 \times 10 = 84\,000$ J [1 mark]

9 Internal energy [1 mark]

10 There are two latent heats because the energy involved with melting/freezing is different to the energy involved with boiling/condensing. [1 mark]

11 It is the sum of all of the kinetic energies of the particles [1 mark] plus the sum of all of the potential energies [1 mark].

12a The particles are much further apart in steam so the same amount of mass occupies a much bigger volume. [1 mark]

12b Volume = mass / density = 2 / 0.59 = 3.4 m^3 [1 mark]

12c $p_1 \times V_1 = p_2 \times V_2$, so $1.5 \times 10^5 \times 3.4 = 1.0 \times 10^5 \times V_2$, so $V_2 = 5.1$ m^3 [1 mark]

12d $E = mL = 2 \times 2\,260\,000 = 4\,520\,000$ J [1 mark]

13 The internal energy decreases [1 mark]. When the water cools down to 0^0 C both the potential energy and the kinetic energy decreases. When the water is freezing at 0 ^{0}C only the potential energy decreases [1 mark].

14a The mass of a substance is always conserved. [1 mark]

14b It can either increase in temperature or it can change state (melt, boil or sublimate) [1 mark].

15 The particles in the gas move faster [1 mark]. This makes them collide with the walls with a larger force and more often [1 mark]. Which results in a gain of pressure.

16 Level 3: A detailed description is made, which will lead to an accurate measurement of density. All necessary measurements are described together with the measuring instruments and apparatus needed. Consideration of at least two methods of measuring accurately are made. (5-6 marks)

Level 2: A description is made which will lead to a valid measurement of the duck. Measuring the mass and the volume is considered and an attempt at describing a displacement method is made. Some attempt is made to describe procedures to improve the accuracy. (3-4 marks)

Level 1: A simple response is made where it is recognised that the mass and the volume duck need to be measured. (1-2 marks)

Indicative content

- Measure mass of duck by using an electric balance
- Measure volume of duck by using a displacement method
- Displacement method could be by pushing the duck under water in a large measuring cylinder / filling a container full of water, pushing the duck under water and a method of measuring the volume of the water that has spilled / using a displacement/eureka/Archimedes can plus a measuring cylinder.
- Find density by dividing the mass by the volume

Methods to improve accuracy

- Repeat the experiment
- Discard any anomalous results
- Find the mean value of the density (which reduces random error)
- Make sure duck is completely submerged under the water
- When submerging the duck make sure nothing else (e.g. a finger) ends up under the water
- When reading the volume of water in a measuring cylinder make sure that eyes are level with the water.
- Make sure the measuring cylinder is completely vertical

When measuring the mass make sure there is no extra water on the duck.

17 $E = mc\Delta\theta$

So $c = E / (m \times \Delta\theta)$ [1 mark]

= 8880 / (2 × 10) = 444 J / kg^{0}C [1 mark]

18 Since the temperature is constant the speed of the particles remains the same [1 mark]. However, if the volume increases then the particles travel a further distance between collisions with the walls which makes them collide less often [1 mark]. This reduces the pressure.

19 Level 3: A detailed description is made which includes ideas about changing state, latent heat, internal energy and pressure. All descriptions consider the action of the particles in terms of their motion, arrangement and energies and the description forms a logical sequence of steps which lead to an explanation of why the bottle explodes. (5-6 marks)

Level 2: A description is made which considers the action of particles when they are changing state and how they exert a pressure. There is some consideration of energy but it is not clear why the pressure increases and the sequence of steps do not necessarily follow logically on from each other. (3-4 marks)

Level 1: An attempt is made to describe the change of state from liquid to gas in terms of particles and that there is a build-up of pressure. (1-2 marks)

Indicative content

Changing state

- The temperature outside the bottle is much higher than the boiling point of nitrogen so the nitrogen will start boiling very vigorously.
- While the nitrogen is boiling the particles increase their potential energy but their kinetic energy stays the same.
- The nitrogen particles are close together in a liquid but far apart in a gas

Causing pressure

- The internal energy of the gas is much higher than the liquid due to the latent heat that is transferred as the nitrogen is boiling.
- The particles of gas are moving much quicker than the particles in the liquid because the gas is at a much higher temperature
- The gas particles collide with the walls of the bottle and exert a force
- The force creates a pressure

Why the pressure builds up

- As the liquid nitrogen continues to boil then more and more particles are released as gas
- This means that there is an increasing number of collisions with the walls of the bottle
- So the pressure increases

Why the bottle explodes

- The pressure of the nitrogen gas pushes the bottle outwards
- Eventually the pressure inside the bottle becomes so great that the bottle cannot withstand the force and it explodes.