Knowledge

P12 Kinetic theory and energy transfer

Kinetic theory

Kinetic theory explains the states of matter, and what happens in changes of state.

State	Arrangement	Movement	Properties
gas	particles are spread out; almost no forces of attraction between particles	particles move randomly at high speed	low density; no fixed volume; can be compressed or flow; fill available space
liquid	particles are in contact with each other; forces of attraction between particles are weaker than in solids	particles are free to move randomly around each other	usually lower density than solids; fixed volume; can flow
solid	particles held next to each other in fixed positions by strong forces of attraction	particles vibrate about fixed positions	high density; fixed volume; fixed shape (unless distorted by external forces)

Internal energy

Heating a substance increases its **internal energy**.

Internal energy is the sum of the total kinetic energy due to the particles' motion and the total potential energy due to the particles' positions.

Specific heat capacity

When a substance is heated or cooled the temperature change depends on: the substance's mass, the type of material, and how much energy is transferred to it.

Every type of material has a **specific heat capacity** – the amount of energy needed to raise the temperature of 1 kg of the substance by 1 °C.

The energy change can be calculated using:

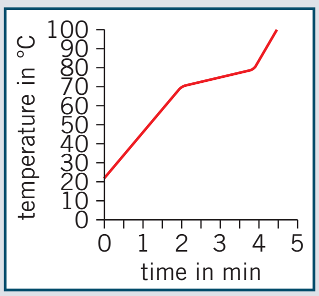
change in thermal energy (J) = mass (kg) × specific heat capacity (J/kg°C) × temperature change (°C)

$$\Delta E = m\ c\ \Delta\theta$$

Change of state and impurities

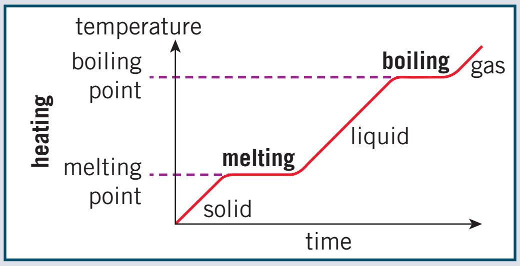
Only a pure substance produces a horizontal line on a temperature–time graph of change of state.

Melting points and boiling points are affected by **impurities**.



Latent heat

The graph shows the temperature change over time, when a substance is heated or cooled. While the substance is changing state, the energy transfered does not change the temperature, but it does change the internal energy. So these show as flat sections on the graph.



The energy transferred when a substance changes state is called the **latent heat**.

Specific latent heat – the energy required to change 1 kg of a substance with no change in temperature.

This can be calculated using:

thermal energy for a change in state (J) = mass (kg) × specific latent heat (J/kg)

$$E = m \times L$$

Specific latent heat of fusion – the energy required to melt 1 kg of a substance with no change in temperature.

This can be calculated using: $E = m \times L_F$

Specific latent heat of vaporisation – the energy required to evaporate 1 kg of a substance with no change in temperature.

This can be calculated using: $E = m \times L_V$

Key terms

Make sure you can write a definition for these key terms.

condensation conduction convection evaporation expansion impurities insulator internal energy kinetic theory latent heat specific heat capacity

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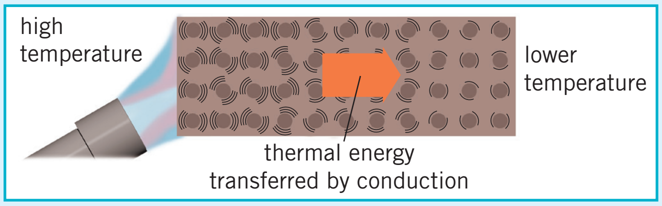
P12

Energy transfer – conduction

In solids, energy is mainly transferred by **conduction**.



In a metal, energy is transferred by the movement of free electrons. Metals are **conductors**.

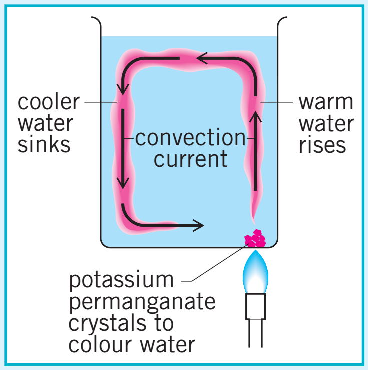
Insulators do not have electrons that can move easily.

Energy transfer – convection

When a fluid (liquid or gas) is heated, the particles move further apart and the density of the fluid decreases.

Warm fluid floats above cooler fluid.

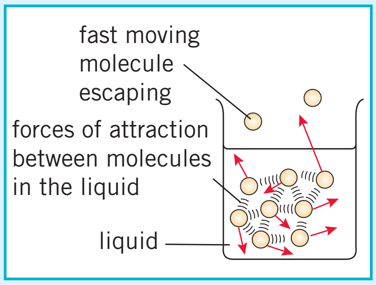
This is **convection**.



Energy transfer – evaporation and condensation

When a liquid **evaporates**, the faster moving molecules escape. This reduces the average energy per molecule in the liquid. The temperature decreases. Energy is transferred *from* the liquid *to* the surroundings. The surroundings heat up.

Evaporation is used in systems to cool houses, and cools the human body when we sweat.



When a gas **condenses** to a liquid, the molecules slow down and move closer together. Energy is transferred *from* the gas *to* the surroundings. The surroundings heat up.

Rate of evaporation

A liquid will evaporate faster if:

- the temperature difference between the liquid and the surroundings is greater
- the surface area of the liquid is larger
- there is wind or air movement near the surface
- the liquid has a low boiling point.

Rate of energy transfer

Hot objects transfer energy to the surroundings. The rate of transfer depends on:

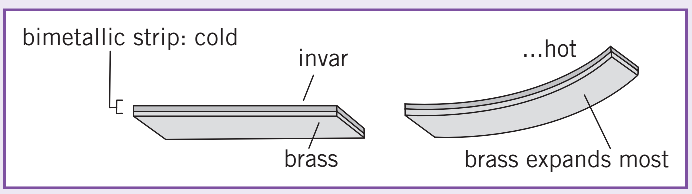
- the surface area and volume of the object
- the material from which the object is made
- the nature of the surface with which the object is in contact.

Elephants have large ears to increase the surface area available for cooling. Engines and computers have devices with 'cooling fins' to increase the surface area.

Moving a liquid over a surface, or blowing air over a surface, will allow it to cool more quickly.

Heating and expansion

Most solids expand when they are heated. The amount of **expansion** for each increase of 1 °C in temperature can be different. This can be useful. Bimetallic strips can be used in systems that control temperature. The strip consists of two metals stuck together.



Thermal expansion can cause bridges, roofs, and railway lines to buckle.

Expansion joints enable sections to move together safely.

Retrieval

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many as you can. Check and repeat.

	P12 questions	Answers
1	Give the spacing and movement of particles in solids, liquids, and gases.	solids: touching, vibrating; liquids: touching, moving around; gases: moving fast, far apart
2	What happens to the particles in a substance if its temperature is increased?	they move faster and the kinetic energy increases
3	What is the internal energy of a substance?	the total kinetic energy and potential energy of all the particles in the substance
4	What is specific heat capacity of a substance?	the amount of energy needed to raise the temperature of 1 kg of the substance by 1 °C
5	Why is the mass of a substance conserved when it changes state?	the number of particles does not change
6	On a graph showing the change in temperature of a substance as it cools, why is the section when the substance is changing state flat?	the energy transferred during a change in state causes a change in the internal energy of the substance
7	What is the name given to the energy transferred when a substance changes state?	latent heat
8	What is the specific latent heat of a substance?	the energy required to change the state of 1 kg of the substance with no change in temperature
9	What is the specific latent heat of fusion of a substance?	the energy required to change 1 kg of the substance from solid to liquid at its melting point, without changing its temperature
10	What is the specific latent heat of vaporisation of a substance?	the energy required to change 1 kg of the substance from liquid to vapour at its boiling point, without changing its temperature
11	On a graph of temperature against time for a substance being heated up or cooled down, what do the flat (horizontal) sections show?	the time when the substance is changing state and the temperature is not changing
12	How is energy transferred by conduction in metals?	free electrons move through the metal
13	How is energy transferred by convection?	hot gas or liquid is less dense and floats above colder gas or liquid
14	What happens to the temperature of a liquid as it evaporates?	it decreases
15	Describe four factors that affect the rate of evaporation of a liquid.	surface area, temperature difference, boiling point, air movement across surface
16	Describe three factors that affect the rate of transfer of energy.	surface to volume ratio, type of material, type of surface
17	Describe one use of thermal expansion.	bimetallic strips
18	Describe one situation where thermal expansion is a problem.	buckling of roads/bridges/railway tracks

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Now use the questions below to check your knowledge from previous chapters.

Previous questions | Answers

	Previous questions	Answers
1	According to Newton's Second Law, what is the acceleration of an object inversely proportional to?	mass
2	Name the four ways in which energy can be transferred.	heating, waves, electric current, mechanically (by forces)
3	What do electromagnetic waves transfer from their source to an absorber?	energy
4	What is a virtual image?	an image that cannot be put on a screen
5	Which parts of the eye control the shape of the lens?	ciliary muscles and suspensory ligaments

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Required Practical

Practise answering questions on the required practicals using the example below. You need to be able to apply your skills and knowledge to other practicals too.

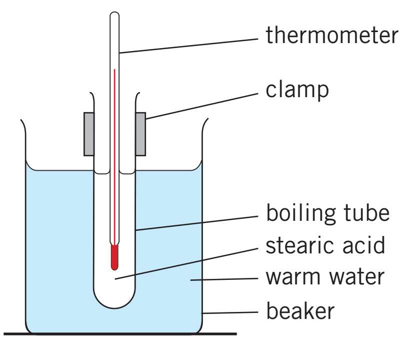
Melting point

To determine the melting point of stearic acid, you need to measure the temperature of stearic acid as it is heated.

To do this, you use a thermometer and a timer.

In the experiment, you need to:

- use a thermometer that is already in a boiling tube of stearic acid
- clamp the tube so the stearic acid is surrounded by water in a beaker
- use a Bunsen burner to heat the water, and stir the water to maintain an even temperature
- plot the data as you go until the temperature reaches 70 °C
- wear eye protection.

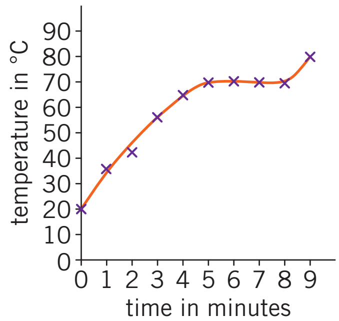


If there are impurities in the stearic acid, the line on the graph when the stearic acid is melting will not be horizontal.

Worked example

A student heats a boiling tube of stearic acid in a water bath.

They measure the temperature of the stearic acid as it is heated, and plot this graph.



1 Write down the time interval between measurements.

Answer: The measurements are one minute apart.

2 Estimate the melting point of stearic acid. Explain how you arrived at your answer.

Answer: 70 °C

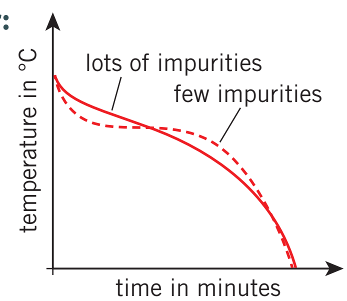
This is the horizontal section of the graph.

3 Sketch the graph for freezing a sample of stearic acid, with:

a a few impurities

b lots of impurities.

Answer:



Practice

A student wants to work out if a sample of water contains impurities.

1 Describe the experimental procedure that would enable them to do this.

2 Sketch a temperature–time graph for a sample of pure water.

3 Describe how the student will use the temperature–time graph for the sample to decide if it is pure.

Practice

Exam-style questions

01 A block of aluminium has a mass of 1.2 kg.

It is at room temperature, which is 20 °C.

A student uses a heater to increase the temperature to 50 °C.

01.1 Calculate the difference between the initial and final temperatures. **[1 mark]**

____

Temperature change = ______________

01.2 The specific heat capacity of aluminium is 900 J/kg °C.

Calculate the energy transferred to the aluminium to raise its temperature.

Use the correct equation from the *Physics Equations Sheet.* **[2 marks]**

______________ J

Exam Tip

The first thing you must do is write down the equation.

This is a key skill and you need to get into the habit of always writing that down first.

01.3 A student does this experiment and finds that the energy they need to transfer is bigger than the energy calculated in **01.2**.

Suggest why. **[1 mark]**

____

____

02 A student is learning about internal energy.

They draw two diagrams, **A** and **B**, as shown in **Figure 1**.

02.1 Complete the sentences using the words in the box. **[4 marks]**

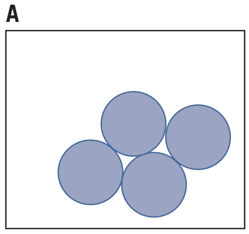
kinetic	vibrating	moving fast
potential	gravitational	moving slowly

In diagram **A**, the particles are ______________. Most of the internal energy is due to the ______________ energy of the particles.

In diagram **B**, the particles are ______________. Most of the internal energy is due to the ______________ energy of the particles.

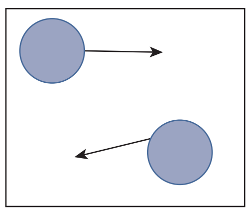
Figure 1

A



The particles in a solid.

B



The particles in a gas.

02.2 The sample shown in **Figure 1 A** is heated for a long time.

Describe how the internal energy of the sample changes. **[2 marks]**

____

____

____

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02.3 The sample shown in **Figure 1 B** is heated.

The student decides to use the particle model to describe and explain what happens.

Which statement is correct? **[1 mark]**

Tick **one** box.

As the gas is heated, the average kinetic energy of the molecules decreases.	☐
The average kinetic energy of the molecules is independent of the temperature of the gas.	☐
If the temperature of a gas increases, the pressure that the gas exerts decreases (if the volume stays the same).	☐
The particles in a gas are in random motion.	☐

Exam Tip

Only tick *one* box; if you tick more boxes you won't get any marks!

03 A swimming pool is heated by the Sun.

A paddling pool next to the swimming pool is also heated by the Sun.

A student notices that the temperature of the paddling pool is higher than the temperature of the swimming pool.

The student makes the estimates shown in **Table 1**.

Table 1

	Swimming pool	Paddling pool
energy transferred by the Sun	88 000 MJ	28.8 MJ
temperature of pool	25 °C	28 °C
starting temperature	18 °C	18 °C
specific heat capacity of water	4200 J/kg °C	4200 J/kg °C

Exam Tip

Don't let these big numbers worry you. Just plug the numbers (carefully) into your calculator and you'll be fine!

03.1 Use **Table 1** to find the ratio of the mass of water in the paddling pool to the mass of water in the swimming pool.

Use the correct equation from the *Physics Equations Sheet*.

Use an appropriate number of significant figures. **[6 marks]**

Exam Tip

Put the numbers in first before you rearrange the equation.

03.2 At the end of the day the pool owner puts an identical cover over each pool.

If energy transfer is only through the cover, suggest why:

- the swimming pool might take longer to cool down
- the paddling pool might take longer to cool down. **[2 marks]**

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04 A student is comparing the specific heat capacities of two liquids **A** and **B**. Both liquids have the same mass. They use a heater to change the temperature of the liquids, and an energy meter to measure the energy transferred to each liquid by the electric current.

It takes 1.8 kJ of energy to raise the temperature of 10 g of liquid **A** by 50 °C. Calculate the specific heat capacity of liquid **A**. Use the correct equation from the *Physics Equations Sheet*.

Liquid **B** has a specific heat capacity that is twice that of liquid **A**. Suggest **two** differences that the student would observe if they heat the 10 g of liquid **B** using the same heater. Justify your answer.

[6 marks]

Exam Tip

Pull all the key information out of the text first, for example:

Liquid A

mass =

energy used =

temperature change =

05.1 What quantities do you need to find to work out kinetic energy? Choose **one** answer. **[1 mark]**

mass and speed	mass and time	speed and time

05.2 Car **A** and car **B** are both moving in different ways. Car **A** accelerates under a constant force for three seconds at the start of a race. During the same three seconds car **B** is travelling at a steady speed on a motorway.

Compare:

- the ways energy is stored for each car at the start and end of the three seconds
- the way energy is transferred. **[6 marks]**

Exam Tip

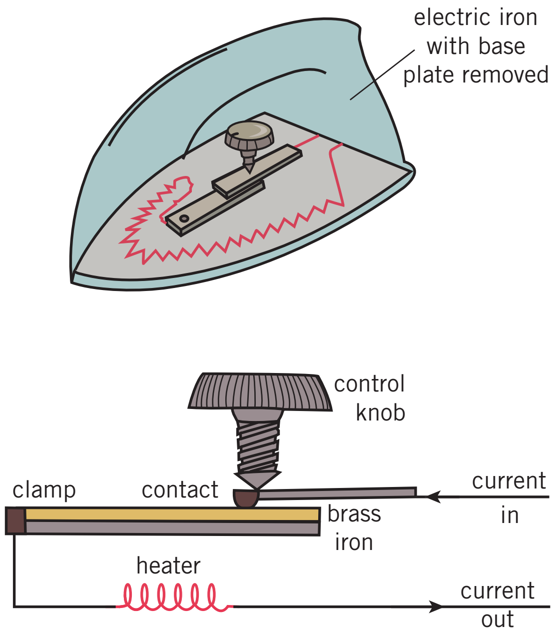
Break your answer up into two paragraphs – one paragraph for each bullet point mentioned in the question.

05.3 All cars require that you add oil to the engine. Suggest **one** benefit of adding oil to the engine. Use the idea of energy to explain your answer. **[2 marks]**

06 An electric iron switches off when it gets to the required temperature. The iron contains a bimetallic strip.

In **Figure 2**, a current is flowing and the heater is on.

Figure 2



06.1 Describe what happens to materials when they are heated. **[1 mark]**

06.2 Explain how the bimetallic strip ensures that the iron turns off at the correct temperature. **[2 marks]**

06.3 The control knob is turned so that it pushes the contact down and bends the bimetallic strip.

Suggest what happens to the temperature at which the circuit is switched off. Explain your answer. **[2 marks]**

07 A student is investigating the purity of an unknown solid. They are given a boiling tube with the solid and a temperature probe embedded in it. The temperature probe is connected to a data logger that records the temperature every minute. The student places the tube in a beaker of water on top of a hot plate. They turn the hot plate on and start the data logger.

07.1 Name the type of energy transfer between the hot plate and water. **[1 mark]**

07.2 Explain why the water at the bottom of the beaker will rise. **[2 marks]**

07.3 Describe the observation that will indicate to the student that the solid is pure. **[1 mark]**

07.4 At the end of the experiment, the student notices that water level in the beaker is lower even though the water has not boiled.

Explain why, in terms of particles. **[2 marks]**

07.5 Which of the following statements are correct?

Choose **two** answers. **[2 marks]**

If the water was at a lower temperature, the evaporation rate would be higher.

If the room temperature was higher, the evaporation rate would be higher.

If the liquid had a lower boiling point, the evaporation rate would be higher.

If the surface area of the liquid was higher, the evaporation rate would be higher.

Exam Tip

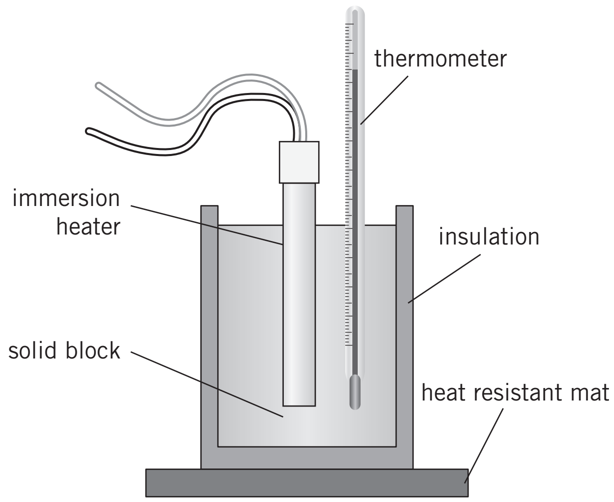
Lots of the words in this topic sound very similar, its important that things are spelt correctly and that your handwriting is clear so the examiner can see exactly which word you mean.

08 A student set up an experiment to measure the specific heat capacity of a 1 kg solid block of an unknown material, as shown in **Figure 3**.

The immersion heater was connected to a power supply.

> **Exam Tip**
> You might be familiar with this practical but you may not have seen it drawn like this before.
> Here we show you what is going on inside the practical.

Figure 3



The student measured the starting temperature of the solid block. Then they turned on the power supply and started a stopwatch.

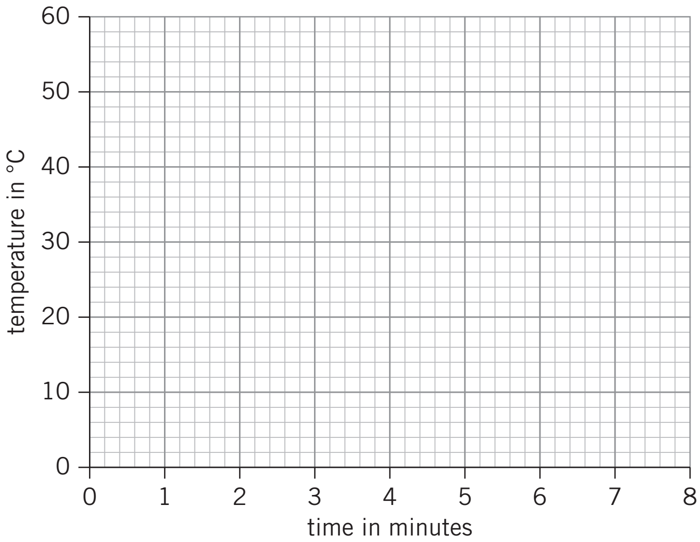
The results are shown in **Table 2**.

Table 2

Time in minutes	Temperature in °C
0	20
2	35
4	45
6	50
8	52

08.1 Plot a graph of temperature against time on **Figure 4**. **[3 marks]**

Figure 4



> **Exam Tip**
> Always use crosses to plot points, and draw a line of best fit.

08.2 Describe the change in the rate of temperature increase over time. Explain your answer. **[2 marks]**

08.3 After 8 minutes, the energy transferred to the block was 15 800 J. Use the data in **Table 2** to calculate the specific heat capacity of the block. Use the correct equation from the *Physics Equations Sheet*. Give your answer to **three** significant figures. **[3 marks]**

Exam Tip

The first step is to write the equation down.

08.4 **Table 3** lists the specific heat capacity of some materials.

Table 3

Material	Specific heat capacity in J/kg °C
aluminium	900
iron	452
magnesium	1020
nickel	440
zinc	390

Use **Table 3** to identify which material the block is most likely to be made of. **[1 mark]**

Exam Tip

Use your answer from **08.3**.

09 A teacher is showing a class a method for finding the specific latent heat of vaporisation of water. The teacher puts a kettle containing water on a set of digital scales and measures its mass.

The kettle is turned on to allow the water to boil. At the same time, the teacher turns on a stopwatch. After two minutes the kettle is turned off and the teacher notes the new reading on the scales (see **Table 4**).

Table 4

Mass at the start of the two minutes	1.276 kg
Mass at the end of the two minutes	1.180 kg

The power of the kettle is 2 kW.

09.1 Calculate the energy transferred from the kettle to the water. **[4 marks]**

Exam Tip

Make sure you use the correct equation from the *Physics Equations Sheet*.

09.2 Use the correct equation from the *Physics Equations Sheet* to calculate the specific latent heat of vaporisation of water.

Give your answer in kJ/kg. **[5 marks]**

Exam Tip

Look at the difference in values in **Table 4**.

09.3 The textbook value for the specific latent heat of vaporisation of water is 2265 kJ/kg. Suggest a reason for the difference between the value that you have calculated and the textbook value.

Explain your answer. **[3 marks]**

10 A student noticed that when they finished having a shower, the mirror is 'fogged up'.

10.1 Explain in terms of energy why the mirror is covered by a thin layer of water. **[3 marks]**

10.2 The student estimates that the mirror is a square with sides measuring 60 cm. The density of water is 1×10^3 kg/m^3. The specific latent heat of vaporisation of water is 2265 kJ/kg. While the fog was forming, a total of 730 kJ of energy was transferred.

Calculate the thickness of the layer of water on the mirror. **[6 marks]**

Exam Tip

First use the equation for specific latent heat of vaporisation to find the mass of water.

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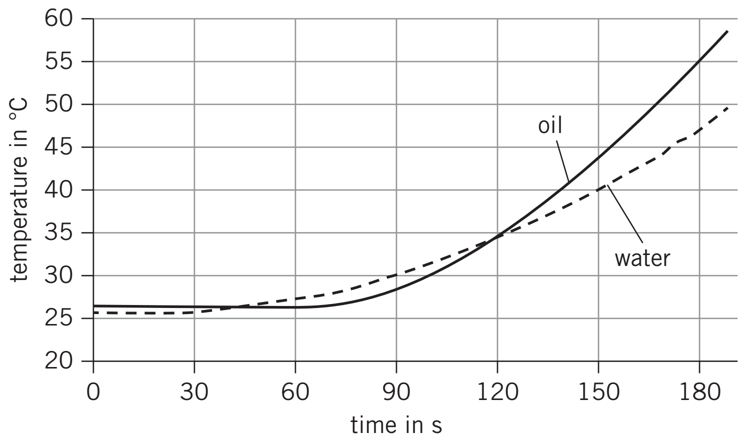
11 A teacher shows data from an experiment involving heating oil and water (**Figure 5**).

The teacher wants to compare the liquids in terms of their specific heat capacity.

Figure 5



11.1 The teacher does not allow the students to conduct an experiment involving heating oil with a Bunsen burner. Suggest why. **[1 mark]**

11.2 Explain why the heater used to heat the liquids needs to have the same power. **[1 mark]**

11.3 Compare the relationships between temperature and time for the liquids. **[3 marks]**

11.4 Use the differences between the graphs to compare the specific heat capacity of oil and water.

State any assumptions that you have made. **[4 marks]**

Exam Tip

Look at the differences in the lines on the graph.

12 A student sees a demonstration involving gallium.

Gallium has a melting point of 29.8 °C.

A small piece of gallium melts in the palm of the demonstrator's hand.

12.1 Calculate the energy needed to raise gallium to its melting point.

Room temperature = 20 °C.

The specific heat capacity of solid gallium is 371 J/kg °C. **[3 marks]**

12.2 The demonstrator uses a second piece of gallium.

It has three times the mass of the first piece of gallium.

Calculate how much energy would need to be transferred to the second piece to raise it to its melting point. **[2 marks]**

12.3 Aluminium has a greater specific heat capacity than gallium.

Describe what you would notice about the temperature rise of 5 g of aluminium if you transferred the same amount of energy as calculated in **12.1**.

Explain your answer. **[2 marks]**

Exam Tip

You don't need to know the temperature of the demonstrator's hand, you only need to work out the temperature change.

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13 One way to heat milk is to pass steam through it.

13.1 Suggest how a jet of steam heats a cup of milk. **[2 marks]**

13.2 The mass of milk in a cup is 242 g. The specific heat capacity of milk is 3.93 kJ/kg °C. Show that the energy required to heat the milk from 20 °C to 70 °C is about 48 kJ. Use an equation from the *Physics Equations Sheet*. **[4 marks]**

13.3 The specific latent heat of vaporisation of water is 2260 kJ/kg. Calculate the mass of steam that would need to condense into water to produce the energy calculated in **13.2** **[4 marks]**

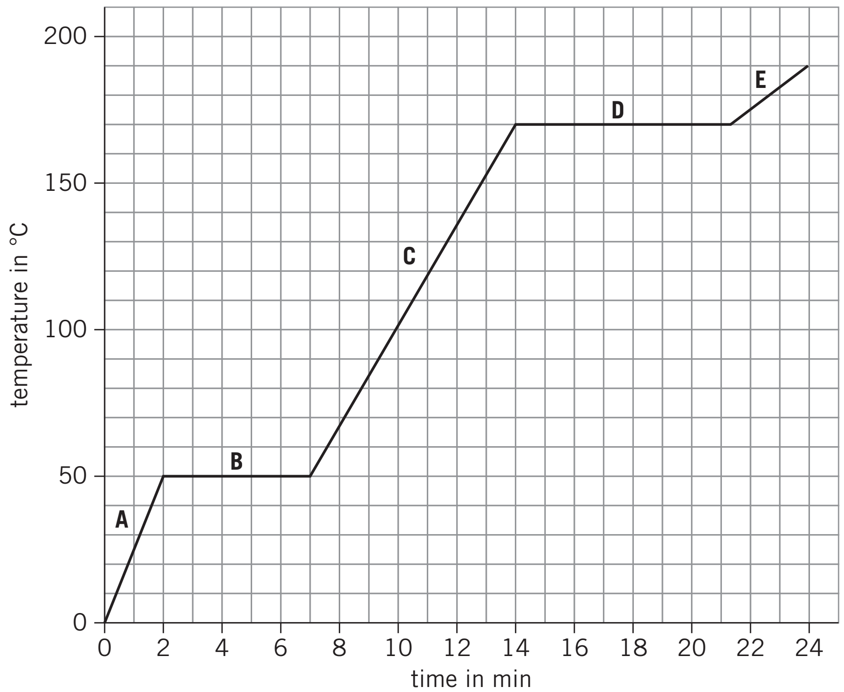
13.4 Write down one assumption that you made when doing the calculation. **[1 mark]**

Exam Tip

Look out for non-standard units!

14 A substance is heated. **Figure 6** shows how the temperature of the substance changes with time. The straight-line sections of the graph are labelled **A, B, C, D,** and **E**.

Figure 6



14.1 Write the letters of all the sections of the graph that show a change of state.

Explain why you have chosen these sections. **[4 marks]**

14.2 Did the substance start out as a solid or a liquid?

Explain your answer. **[2 marks]**

14.3 Write down the section of the graph where the vibration of the particles is increasing. **[1 mark]**

14.4 Write down the **two** sections of the graph where the kinetic energy of the particles is increasing. **[2 marks]**

Exam Tip

Question **14.1** is worth four marks – it gives you a clue to what the examiner is looking for and helps structure your answer:

- 1st mark, give letter showing change of state
- 2nd mark, explain why you chose that letter
- 3rd mark, give letter showing second change of state
- 4th mark, explain why you have chosen this letter