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Richard Harwood , Ian Lodge , Mike Wooster
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Chapter 1

States of matter

Changing physical state

KEY WORDS

boiling: the process of change from liquid to gas at the boiling point of the substance; a condition under which gas bubbles are able to form within a liquid – gas molecules escape from the body of the liquid, not just from its surface

freezing point: the temperature at which a liquid turns into solid – it has the same value as the melting point; a pure substance has a sharp freezing point

melting point: the temperature at which a solid turns into a liquid – it has the same value as the freezing point; a pure substance has a sharp melting point

Exercise 1.1

IN THIS EXERCISE YOU WILL:

- develop your understanding of the distinguishing properties of solids, liquids and gases
- show how the properties of each state of matter are linked to the organisation of the particles present
- use data on melting and boiling points to determine the physical state of a substance at a given temperature.

Focus

1 There are three states of matter, which have different basic physical properties. For all physical states, complete the sentences by adding two properties they show.

A solid has a fixed .... and ....

A liquid has a fixed .... but its .... changes to that of the container in which it is placed.

A gas has no fixed .... or .... A gas completely fills the container that it is in.

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2 Complete Figure 1.1 to show how the particles of a substance are arranged in the three states of matter.

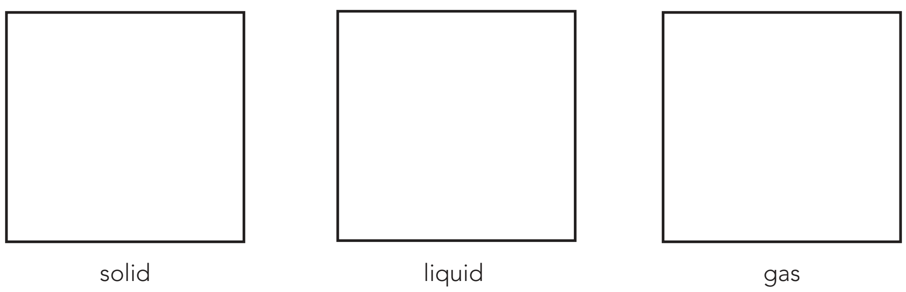

Figure 1.1: The three states of matter.

Practice

Question 2 illustrates the differences in structure and organisation of the particles in the three states. The differences can also be expressed in words. Table 1.1 describes the arrangement of the particles in four different substances A, B, C and D.

Substance	Distance between particles	Arrangement of particles	Movement of particles
A	Very far apart	Randomly arranged	Moving about with high speed
B	Very close together	Regularly ordered	Vibrating about fixed positions
C	Very far apart	Regularly ordered	Vibrating about fixed positions
D	Close together	Irregularly arranged	Moving about

Table 1.1: The arrangement and movement of particles in substances A, B, C and D.

3 Which of substances A, B, C and D is:

a a solid ....

b unlikely to be a real substance ....

c a gas ....

d a liquid ....

TIP

In a liquid, the particles are still close together. However, the particles are not regularly arranged and can move around and move past each other.

4 Changing the temperature can result in a substance changing its physical state. What are the changes of state A, B, C and D in Figure 1.2? (Note that sublimation is not required knowledge.)

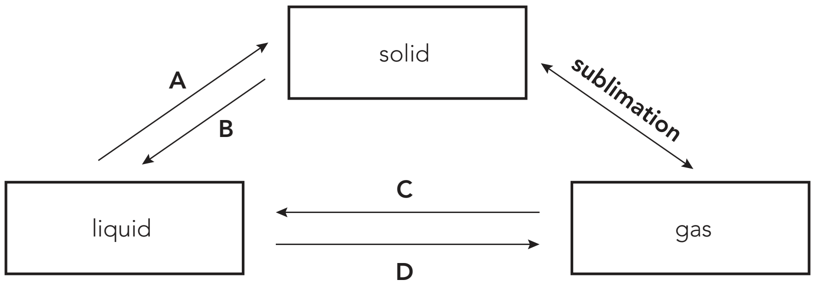

Figure 1.2: Changes of physical state.

A ……………………..

B ……………………..

C ……………………..

D ……………………..

Challenge

5 Use the data provided in Table 1.2 to answer the questions about the physical state of the substances listed when at a room temperature of 25 °C and at atmospheric pressure.

Substance	Melting point / °C	Boiling point / °C
Sodium	98	883
Radon	−71	−62
Ethanol	−117	78
Cobalt	1492	2900
Nitrogen	−210	−196
Propane	−188	−42
Ethanoic acid	16	118

Table 1.2: Melting points and boiling points of various substances.

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a Which substance is a liquid over the smallest range of temperatures?

....

b Which two substances are gaseous at −50 °C?

.... and ....

c Which substance has the lowest freezing point?

....

d Which substance is liquid at 2500 °C?

....

e A sample of ethanoic acid was found to boil at 121 °C at atmospheric pressure. Use the information provided in Table 1.2 to comment on this result.

....

....

TIP

Be careful when dealing with temperatures below 0 °C, and remember that −100 °C is a higher temperature than −150 °C.

Plotting a cooling curve

KEY WORDS

evaporation: a process occurring at the surface of a liquid, involving the change of state from a liquid into a vapour at a temperature below the boiling point

kinetic (particle) theory: a theory which accounts for the bulk properties of the different states of matter in terms of the movement of particles (atoms or molecules) – the theory explains what happens during changes in physical state

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Exercise 1.2

IN THIS EXERCISE YOU WILL:

- use data from an experiment to plot a cooling curve for a substance
- develop your understanding of the changes in organisation and movement of particles that take place as a substance changes state
- look at the changes in movement of particles in evaporation and boiling, and consider some unusual changes of state
- link the different changes of state to the kinetic (particle) theory of matter and explain the changes taking place.

Focus

A student carried out the following data-logging experiment as part of a project on changes of state. An organic crystalline solid was melted by placing it in a tube in a boiling water-bath. A temperature sensor was placed in the liquid.

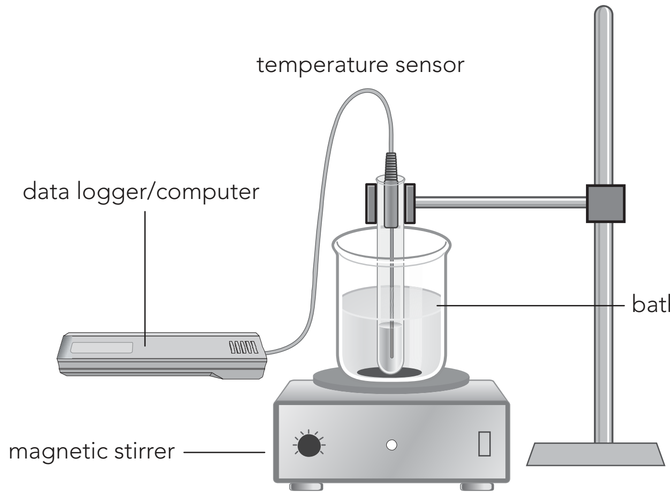

Figure 1.3: Using a temperature sensor to plot a cooling curve.

The student followed the temperature change as the liquid was allowed to cool. The data shown in Table 1.3 are taken from the computer record of the temperature change as the liquid cooled to room temperature.

Time / minutes	0	0.5	1.0	1.5	2.0	2.2	2.4	2.6	2.8	3.0	3.5	4.0	4.5	5.0
Temperature / °C	96.1	89.2	85.2	82.0	80.9	80.7	80.6	80.6	80.5	80.3	78.4	74.2	64.6	47.0

Table 1.3: Results for cooling curve experiment.

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6 On the grid provided, plot a graph of the temperature change that took place in this experiment.

7 The student decided to carry out the experiment using a compound that has a melting point greater than 100 °C. What change would she need to make to carry out the experiment?

8 What change is taking place over the third minute of the experiment?

Practice

9 Why does the temperature remain almost constant over this period of time (the third minute of the experiment)? When giving your answer, think about how the organisation of the molecules of the substance is changing.

(continued)

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....

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....

....

10 Another student carried out a similar experiment to demonstrate the cooling curve for paraffin wax.

a In the space provided, sketch the shape of the graph you would expect the student to produce.

b Explain why you have chosen the shape for the curve you drew in **a**.

....

....

TIP

Pure substances have definite, precise melting points and boiling points. When a substance contains impurities, the melting and boiling points change and become less precise (spread over a range of temperatures).

Challenge

11 Experiments that allow a student to plot a cooling curve can be reversed, and a heating curve can be plotted instead. Figure 1.4 shows the heating curve for a pure substance. The temperature rises with time as the substance is heated.

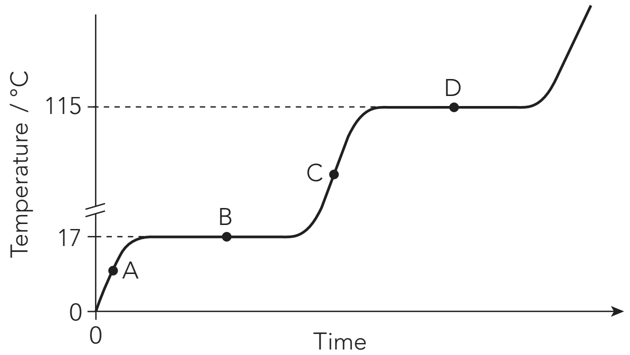

Figure 1.4: A heating curve for a pure substance.

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a What physical state(s) is the substance in at points A, B, C and D?

A ....

B ....

C ....

D ....

b What is the melting point of the substance?

....

c What is the boiling point of the substance?

....

d How does the temperature change while the substance is changing state?

....

e The substance is not water. How do you know this from the graph?

....

12 Dry ice is the name given to the solid form of carbon dioxide. Dry ice is used in commercial refrigeration and to create spectacular and misty stage effects. The surface of dry ice at atmospheric pressure is different from that of ordinary water ice as there is no liquid film on it.

a If you gently shake a fire extinguisher filled with carbon dioxide (Figure 1.5), you will feel the presence of liquid within the extinguisher. What conditions within the extinguisher mean that the carbon dioxide is liquid?

....

....

Figure 1.5: A carbon dioxide fire extinguisher.

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b Frost is ice crystals that form on surfaces when conditions are very cold. Using the words provided, complete the following paragraph about a particular type of frost known as hoar frost.

colder crystals humid ice liquid surrounding white

Hoar frost is a powdery .... frost caused when solid ....

forms from .... air. The solid surface on which it is formed must be

.... than the .... air. Water vapour is deposited on a surface

as fine ice .... without going through the .... phase.

c For most substances, the change from a solid to a gas involves a liquid phase. The final stage of this, from liquid to gas, takes place by evaporation and/or boiling. Use the ideas of kinetic (particle) theory to explain the difference between these two processes.

Evaporation:

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Boiling:

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SELF-ASSESSMENT

Use the checklist below to give yourself a mark for the graph you drew in question **6**.

For each point, award yourself:

2 marks if you did it really well

1 mark if you made a good attempt at it and partly succeeded

0 marks if you did not try to do it, or did not succeed

Then ask your teacher to mark you on the skills as well.

Checklist	Marks awarded	
	You	Your teacher
Have you drawn the axes with a ruler, using most of the width and height of the grid?		
Have you used a good scale for the *x*-axis and the *y*-axis, which goes up in easily managed units (1 minute, 2 minutes, etc.)? (Note that the axes do not necessarily need to start at the origin (0,0).)		
Have you labelled the axes correctly? Have you given the correct units for the scales on both axes?		
Have you plotted each point precisely and correctly?		
Have you used a small neat cross or encircled dot for each point?		
Have you drawn a single, clear best-fit line through each set of points?		
Have you ignored any anomalous (unexpected) results when drawing the line through each set of points?		
Total (out of 14):		

Your total score will reflect how clear and well-presented your graph is. You should be able to deduce reliable information from your graph.

Look at where you scored yourself two marks and where you gave yourself less than that. What did you do well, and what aspects will you focus on next time? Having thought about your assessment, talk it through with your teacher to gain further advice on areas that would help you improve your presentation of graphical data.