

# 2

## Kinetic Particle Theory

### Study Station >>

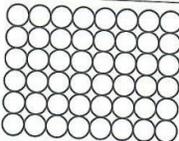
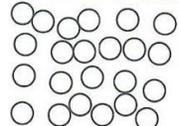
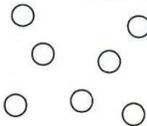
#### A How Are Solids, Liquids and Gases Different?

##### Learning Outcomes

- Outline the kinetic particle theory of matter.
- Describe the solid, liquid and gaseous states of matter and explain their interconversion.

##### Kinetic Particle Theory

1. The **kinetic particle theory** states that all matter is made up of tiny particles, which move randomly all the time.
2. Matter can exist in the physical states of **solid, liquid and gas**.

State of Matter	solid	liquid	gas
Representation of Particles			
Arrangement of Particles	very closely packed and arranged in an orderly manner	closely packed but arranged in a disorderly manner	very far apart and arranged in a disorderly manner
Forces of Attraction Between Particles	very strong	less strong than the forces of attraction between the particles in a solid	very weak
Motion of Particles	vibrate or rotate about fixed positions	move freely throughout the liquid	move rapidly and freely in any direction
Kinetic Energy of Particles	very low	low but higher than the kinetic energy of the particles in a solid	high
Shape	definite	not definite	not definite
Volume	definite	definite	not definite
Compressibility	cannot be compressed	cannot be compressed	can be compressed

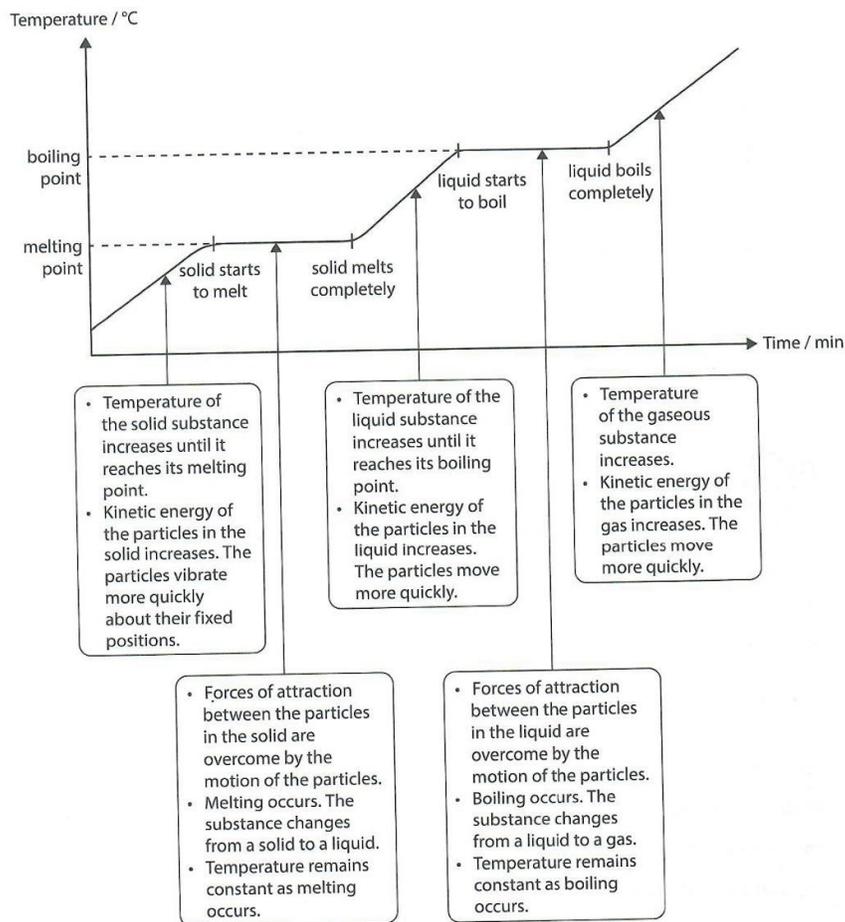
##### Common Misconception

- ✗ Particles in a solid do not move at all.
- ✓ Particles in a solid do not move from one place to another, but they vibrate or rotate about their fixed positions.

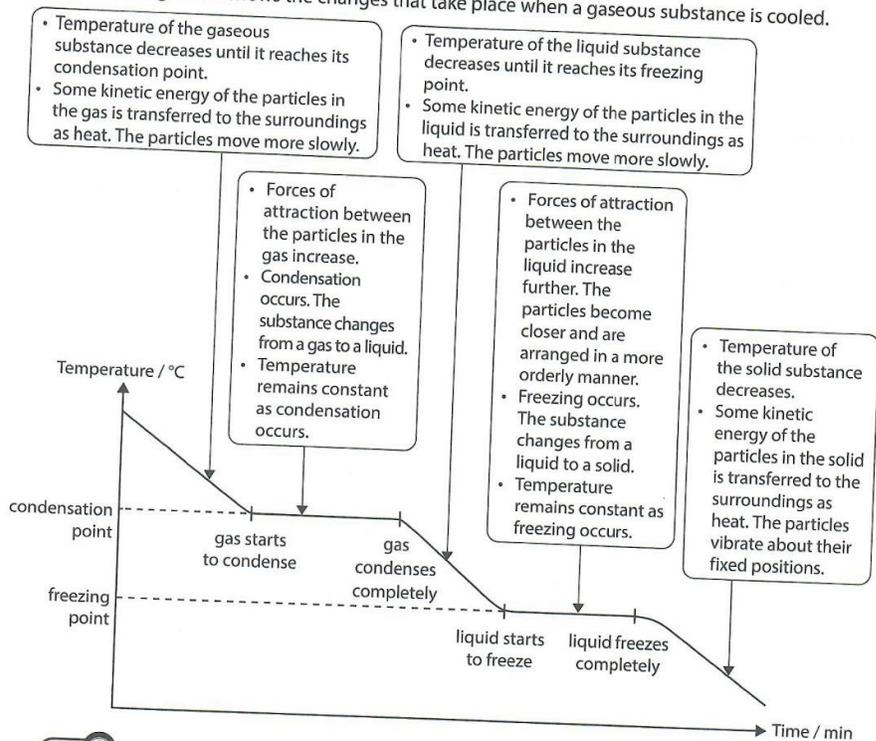
3. The strength of **attractive forces** between particles in a substance depends on the distance between the particles.
4. The average kinetic energy of the particles in a substance depends on temperature.

### Changes in States of Matter

1. Matter can change its state when it is heated or cooled.
2. Changes in the state of matter occur at specific temperatures called **transition temperatures**.
3. Examples of transition temperatures are melting and boiling points.
4. The **heating curve** shows the changes that take place when a solid substance is heated.



5. The **cooling curve** shows the changes that take place when a gaseous substance is cooled.



Condensation is the reverse of boiling, while freezing is the reverse of melting. Thus, a cooling curve is the mirror image of a heating curve and vice versa.

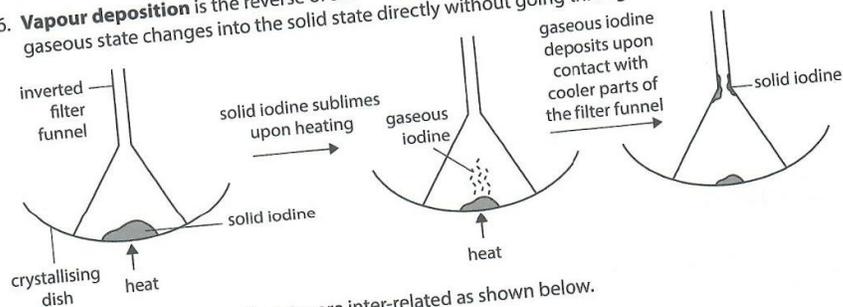
6. A pure substance boils and condenses at the same temperature. Thus, the boiling point of a substance is also its condensation point.
7. Similarly, a pure substance melts into a liquid and freezes into a solid at the same temperature. Thus, the melting point of a substance is also its freezing point.
8. The melting and boiling points of some substances, as well as their physical states at different temperatures, are shown below.

Substance	oxygen	ethanol	iron
Melting Point / °C	-219	-114	1535
Boiling Point / °C	-183	78	2750
Physical State at -196 °C	liquid	solid	solid
Physical State at 25 °C	gas	liquid	solid
Physical State at 100 °C	gas	gas	solid

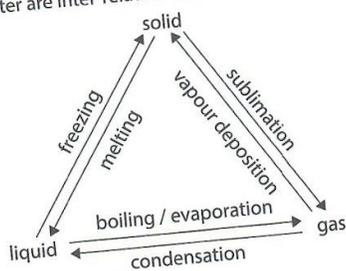
9. **Evaporation** occurs when some particles at the surface of a liquid substance have enough energy to overcome the attractive forces between the particles and escape into the air as a gas.
10. The differences between boiling and evaporation are shown below.

Boiling	Evaporation
<ul style="list-style-type: none"> <li>• It occurs at the boiling point of a substance only.</li> <li>• It occurs throughout a substance in the liquid state.</li> <li>• The temperature of the substance remains constant until all of the substance has changed to the gaseous state.</li> </ul>	<ul style="list-style-type: none"> <li>• It occurs at temperatures below the boiling point of a substance.</li> <li>• It occurs only at the surface of a substance in the liquid state.</li> <li>• The temperature of the substance decreases.</li> </ul>

11. Liquids that evaporate easily are said to be **volatile**. Such liquids usually have low boiling points.
12. Examples of volatile liquids are ethanol (boiling point of 78 °C) and propanone (boiling point of 56 °C).
13. **Sublimation** is the process in which a substance in the solid state changes into the gaseous state directly without going through the liquid state.
14. The change in state from solid to gaseous takes place when the particles at the surface of the solid possess sufficient energy to break away from the solid and escape as a gas.
15. Examples of substances that undergo sublimation are iodine, dry ice (solid carbon dioxide), ammonium chloride and naphthalene.
16. **Vapour deposition** is the reverse of sublimation. It is the process in which a substance in the gaseous state changes into the solid state directly without going through the liquid state.



17. The changes in states of matter are inter-related as shown below.



**Worked Example 2.1**

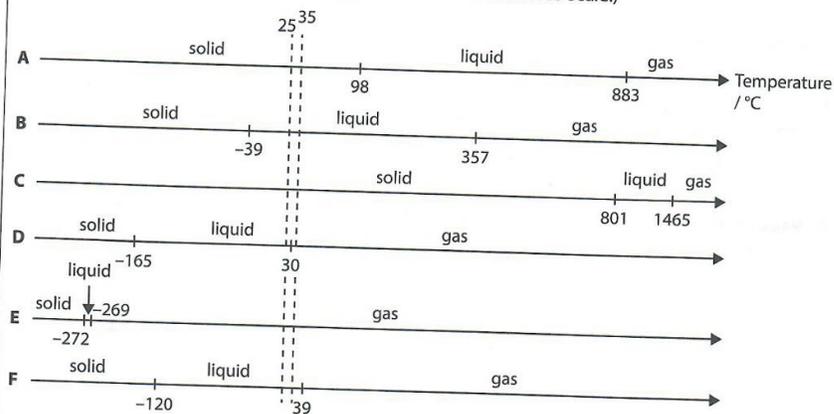
The melting and boiling points of six substances, **A**, **B**, **C**, **D**, **E** and **F**, are shown below.

Substance	A	B	C	D	E	F
Melting Point / °C	98	-39	801	-165	-272	-120
Boiling Point / °C	883	357	1465	30	-269	39

- Classify substances **A** to **F** according to their physical states at 25 °C.
- Which substance(s) exist(s) as a gas at 35 °C?
- Which substance(s) exist(s) as a liquid in the smallest temperature range?

 **Strategy**

Use a number line to visualise the temperature range at which each substance exists as a solid, a liquid and a gas. (Note: The number lines below are not drawn to scale.)


 **Solution**

- Solid state: **A** and **C**
  - Liquid state: **B**, **D** and **F**
  - Gaseous state: **E**
- D** and **E**
- E**

**Worked Example 2.2**

Explain the following phenomena based on the kinetic particle theory.

- (a) A piece of dry ice disappears when left in the open at room temperature.
- (b) Perspiration helps to cool the body on a hot day.

 **Strategy**

- (a) Take note that when dry ice (solid carbon dioxide) disappears at room temperature, it shows that the solid has changed into a gas directly without going through the liquid state.
- (b) Take note that when water from the sweat on the skin evaporates, heat from the body is transferred to the surroundings.

 **Solution**

- (a) The particles on the surface of the solid dry ice possess sufficient energy at room temperature to overcome the forces of attraction between them. Hence, dry ice sublimates and changes into a gas.
- (b) A small amount of the water particles located near the surface of sweat droplets possesses sufficient kinetic energy to overcome the forces of attraction between them. As water particles with greater kinetic energy escape, heat from the body is transferred to the surroundings. Thus, the temperature of the body drops and the body cools down.

**Worked Example 2.3**

Water droplets are seen on the underside of the metal cover of a pot containing some hot soup after some time. Which of the following processes are involved in this phenomenon?

- 1 Boiling
- 2 Condensation
- 3 Evaporation
- 4 Vapour deposition

- A 1 and 3 only
- B 1 and 4 only
- C 2 and 3 only
- D 2 and 4 only

 **Solution**

C

**Explanation**

Water evaporates from the surface of the hot soup in the pot. The water vapour then condenses into water droplets upon touching the cooler metal cover of the pot.

 **Link** Discover Chemistry (3rd Edition) Textbook — Sections 2.1 to 2.4

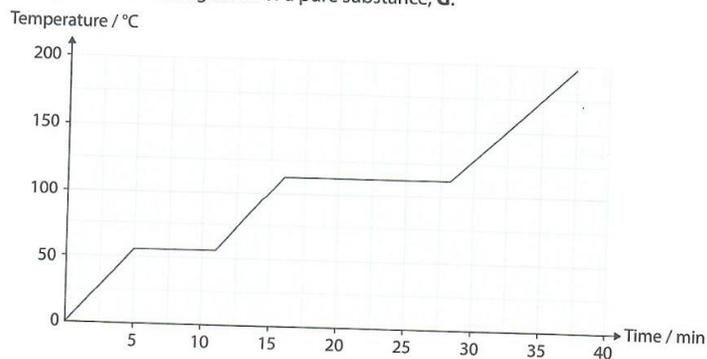
**Checkpoint 2.1**

1. Table 2.1 shows the melting and boiling points of six substances, **A**, **B**, **C**, **D**, **E** and **F**.

**Table 2.1**

Substance	Melting Point / °C	Boiling Point / °C	Physical State	
			at 25 °C	at 250 °C
<b>A</b>	1085	2562		
<b>B</b>	80	218		
<b>C</b>	-159	28		
<b>D</b>	44	280		
<b>E</b>	420	907		
<b>F</b>	-182	-161		

- Complete Table 2.1 and state the physical states of the six substances at 25 °C and 250 °C.
  - Which substance is a volatile liquid?
  - Which substance remains in the liquid state over the greatest temperature range?
  - Which **two** substances are most likely metals? Explain your answer.
2. Figure 2.1 shows the heating curve of a pure substance, **G**.


**Figure 2.1**

- Based on Figure 2.1, determine the melting point and boiling point of substance **G**.
- Use the graph to state the physical state(s) of substance **G** at
  - 5 min,
  - 12 min,
  - 20 min.
- Draw the arrangement of the particles of substance **G** at 100 °C.
- Explain why the temperature of substance **G** remains constant between 20 min and 25 min.
- Suggest why the changes in state of substance **G** take different amounts of time to occur.

3. Particle mass, or the mass of particles in a substance, is a factor that affects the rate of evaporation.
- Explain the phenomenon of evaporation.
  - A student claimed that, at the same temperature, the rate of evaporation decreases with the particle mass of a liquid. Suggest why his claim is **correct**.
  - Another student claimed that water evaporates more slowly than ethanol at the same temperature, even though its particle mass of 18 is smaller than the particle mass of ethanol, which is 46. Suggest why her claim is **correct**.
  - Based on your answer in (c), suggest a physical property that can compare the rates of evaporation of different liquids more accurately.

 **Test Station** ▶▶

1. The boiling points of some substances are shown in Table 2.2.

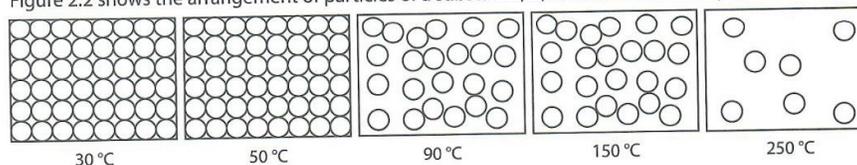
**Table 2.2**

Substance	argon	helium	krypton	neon	xenon
Boiling Point / °C	-186	-269	-152	-246	-107

The temperature of a liquid mixture of the five substances was slowly increased from  $-271\text{ }^{\circ}\text{C}$  to  $-133\text{ }^{\circ}\text{C}$ .

Which of the five substances would be in the liquid state at  $-133\text{ }^{\circ}\text{C}$ ?

- Argon and krypton
  - Argon, helium, neon and krypton
  - Helium, neon and krypton
  - Xenon
2. Figure 2.2 shows the arrangement of particles of a substance, Z, at five different temperatures.



**Figure 2.2**

Which of the following statements about substance Z is **true**?

- It changes from the gaseous state to the liquid state at  $90\text{ }^{\circ}\text{C}$ .
- It melts at  $30\text{ }^{\circ}\text{C}$ .
- Its particles have more kinetic energy at  $250\text{ }^{\circ}\text{C}$  than at  $50\text{ }^{\circ}\text{C}$ .
- Its particles have the same amount of kinetic energy at  $50\text{ }^{\circ}\text{C}$  and at  $150\text{ }^{\circ}\text{C}$ .

3. Figure 2.3 shows the arrangement of particles of a compound, E, at two different temperatures.

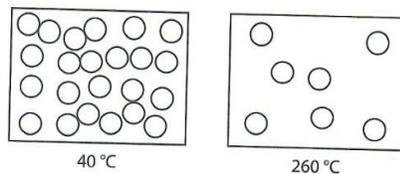


Figure 2.3

Which of the following could be the melting and boiling points of compound E?

	Melting Point / °C	Boiling Point / °C
A	27	103
B	33	277
C	42	154
D	46	262

4. Figure 2.4 shows the arrangement of the particles of mercury at four different temperatures.

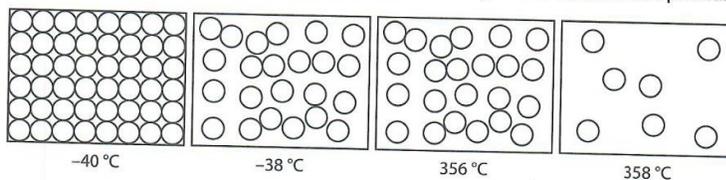


Figure 2.4

- (a) Predict the melting point and boiling point of mercury. [2]  
 (b) Figure 2.5 shows a liquid-in-glass thermometer which contains liquid mercury.

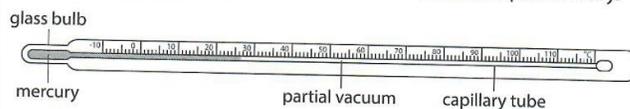


Figure 2.5

- (i) Using the kinetic particle theory, explain why mercury expands when heated. [2]  
 (ii) The upper temperature range of a mercury thermometer may be extended by introducing an unreactive gas such as nitrogen into the capillary tube of the thermometer to replace the partial vacuum. This increases the boiling point of mercury.

Suggest why the boiling point of mercury is increased when nitrogen gas is introduced into the capillary tube of the mercury thermometer. [2]

5. Carbon dioxide is a colourless gas at normal temperature and pressure.
- At normal atmospheric pressure, the gas changes directly to a solid at temperatures below  $-78.5\text{ }^{\circ}\text{C}$ , and the solid changes directly to a gas above  $-78.5\text{ }^{\circ}\text{C}$ . Carbon dioxide in the solid state is commonly called dry ice.
- (a) (i) State the name of the process in which dry ice changes into carbon dioxide gas directly. [1]
- (ii) Using the kinetic particle theory, describe how dry ice changes into carbon dioxide gas directly. [1]
- Under sufficiently high pressure, such as the pressure inside fire extinguishers, carbon dioxide gas can be changed to the liquid state at below  $31.1\text{ }^{\circ}\text{C}$ . This allows for storage, such as in fire extinguishers. When liquid carbon dioxide is further cooled to  $-56.6\text{ }^{\circ}\text{C}$  under high pressure, dry ice is formed.
- (b) (i) Based on the properties of a liquid and a gas, explain why storing liquid carbon dioxide in fire extinguishers is preferred. [2]
- (ii) Explain, using the kinetic particle theory, why carbon dioxide gas at room temperature can be liquefied by applying high pressure. [2]
- (c) On the same axes, sketch and label a cooling curve for carbon dioxide gas from  $100\text{ }^{\circ}\text{C}$  to  $-150\text{ }^{\circ}\text{C}$  under
- (i) normal atmospheric pressure, [1]
- (ii) high pressure. [1]
6. The human body usually cools down by releasing water and salts in the form of sweat droplets through the pores on the skin.
- (a) Suggest how evaporation helps to cool the body. [1]
- (b) The rate at which sweat evaporates depends on humidity, which refers to the amount of water present in the air. Sweat evaporates more quickly on dry days and more slowly on humid days.
- (i) Suggest why sweat evaporates more slowly on humid days. [1]
- (ii) Based on your answer in (b)(i), explain why wind can also affect the rate at which sweat evaporates. [2]
- (c) Suggest why one would feel hotter in Singapore than in the Sahara Desert in Africa at the same temperature. [2]
- (d) To help athletes and labourers keep cool under extremely hot and humid conditions, scientists have developed special clothing fabric that contains tiny pores. Suggest how the tiny pores in such fabric help athletes and labourers to keep cool. [1]