Kinetic Particle Theory

Matter consists of tiny particles. How the particles behave determines their physical state — solid, liquid or gas. The kinetic particle theory outlines how these particles move and rearrange themselves in each state (Figure 2.2).

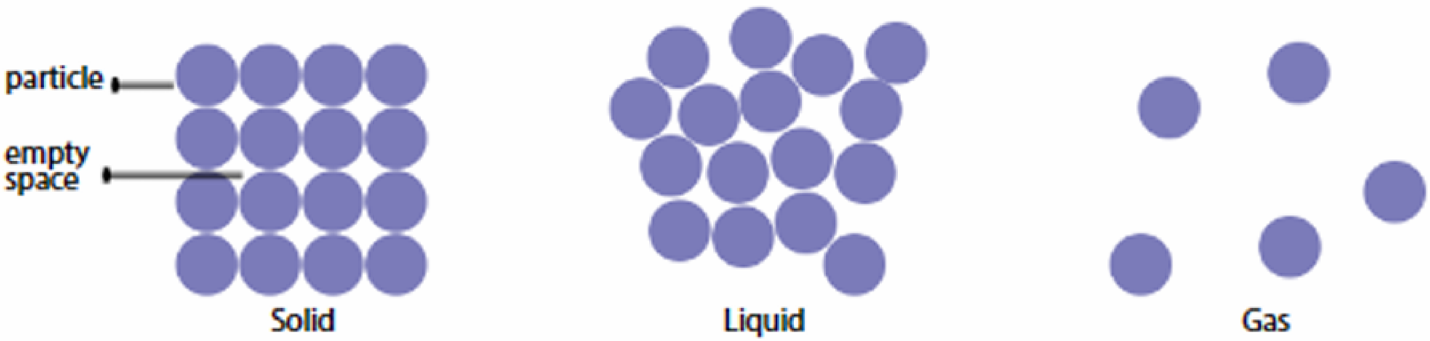


Figure 2.2 Arrangement of particles in a solid, liquid and gas

The **kinetic particle theory** states that all matter is made up of tiny particles and these particles are in constant random motion. particles have-store Kinetic Energy

The theory not only accounts for changes of state, but also other physical changes like temperature changes and expansion or contraction within a state of matter. Potential Energy

- Elastic Collission (Kinetic Energy is sustained)
- Inelastic Collission (-II- -II- is not conserved)

So when we provide heat to a substance, the particles receive this type of energy and they convert it into kinetic, thus starting to vibrate and rotate even more, which leads to an increase in temperature.

An increase in Temperature will eventually lead to a change of "phase" (phase is the state of matter - solid - liquid - gas)

Solids, Liquids and Gases

Since the **kinetic** particle theory considers the movement of particles, we have to consider the forces experienced by the particles and the energy changes that occur. Adding or removing energy from the particles affects the forces experienced by them, which in turn determines their physical **state**.

Particles in a solid have strong forces of attraction

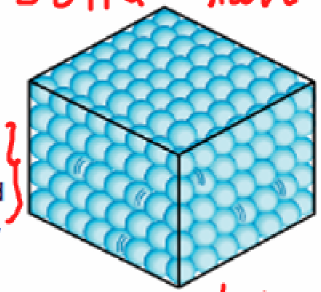


Figure 2.3
Arrangement of particles in a solid

Solids

As shown in Figure 2.3, particles of a solid are very closely packed in an orderly manner. Thus, they vibrate or rotate only about their fixed positions and have very low kinetic energy. The particles experience strong attractive forces, so a lot of energy is needed to break up the regular arrangement. Hence, a solid has a definite volume and shape.

definite volume but not definite shape

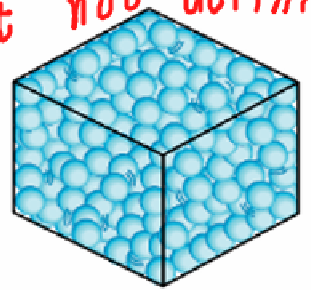


Figure 2.4
Arrangement of particles in a liquid

Liquids

As shown in Figure 2.4, the particle spacing in liquids is larger than in solids, so the attractive forces are less strong. Their arrangement is disorderly, unlike that found in solids. The particles can slide past one another freely. Thus, a liquid has a definite volume but no definite shape. Liquids take on the shape of their container.

Very low attractive forces.

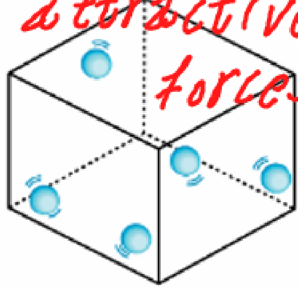


Figure 2.5
Arrangement of particles in a gas

Gases

Finally, in gases, the particle spacing is so large that the attractive forces between them are very weak. The particles are found very far apart in a disorderly manner. The particles can move quickly and randomly, in any direction. Hence, a gas has no definite volume nor shape (Figure 2.5). A gas takes on the volume and shape of its container.

Table 2.1 summarises the differences between particles in solids, liquids and gases.

Word Alert

kinetic: has to do with movement
state: how a substance behaves at a certain temperature or pressure

Disciplinary Idea

The three physical states of matter (i.e. solid, liquid and gas) could be differentiated based on the arrangement and movement of the particles.

Link

Physics

The kinetic particle model of matter describes the behaviour of sub-microscopic particles in the three states of matter and their interconversion, including the energy changes involved.

Table 2.1 summarises the differences between particles in solids, liquids and gases.

Table 2.1 Summary of the differences between particles in solids, liquids and gases.

State of Matter	Solid	Liquid	Gas
Particle Arrangement	very closely packed in an orderly manner	closely packed in a disorderly manner	very far apart in a disorderly manner
Attractive Forces Between Particles	very strong	less strong	very weak
Kinetic Energy of Particles	very low	low	high
Particle Movement	vibrate and rotate about fixed positions	slide past one another freely throughout the liquid	move quickly and randomly in any direction
Shape	definite	indefinite	indefinite
Volume	definite	definite	indefinite
Compressibility	no	no	yes

Changes of State

Have you watched how solid wax melts into a liquid when candle is lit (Figure 2.6)? Most candles consist of a mixture of hydrocarbons which you will learn about later in Chapter 19. One such substance is icosane ($C_{20}H_{42}$). Using the kinetic particle theory, we can describe what happens to the particles of isocane as it changes from a solid to a liquid.

Figure 2.6 Candle wax contains icosane.

Lavoisier Principle

Disciplinary Idea

Energy is neither created nor destroyed, but changed from one form to another. During heating or cooling (without changes in state), the temperature of the substance changes as thermal energy is converted to kinetic energy of the particles and vice versa.

When a substance is heated, thermal energy is transferred to the substance. Some of the energy is converted to kinetic energy of the particles. The increased kinetic energy of the particles results in an increase in temperature of the substance.

Conversely, when a substance is cooled, thermal energy is transferred from the substance to its surroundings. The kinetic energy of the particles in the substance is reduced, which results in a drop in temperature of the substance.

phase

At certain temperatures, heating or cooling a substance results in changes of state instead of changes in temperature. These temperatures are the freezing, melting and boiling points of the substance, also known as **transition temperatures**.

= Temperatures where we a change of state

Converting Between Solid and Liquid

When icosane melts, it changes from the solid state to the liquid state. Let us look at the **heating curve** in Figure 2.7 to study how the movement and arrangement of particles change when solid icosane is heated to become a liquid.

converted to kinetic energy of the particles and vice versa.

When icosane melts, it changes from the solid state to the liquid state. Let us look at the **heating curve** in Figure 2.7 to study how the movement and arrangement of particles change when solid icosane is heated to become a liquid.

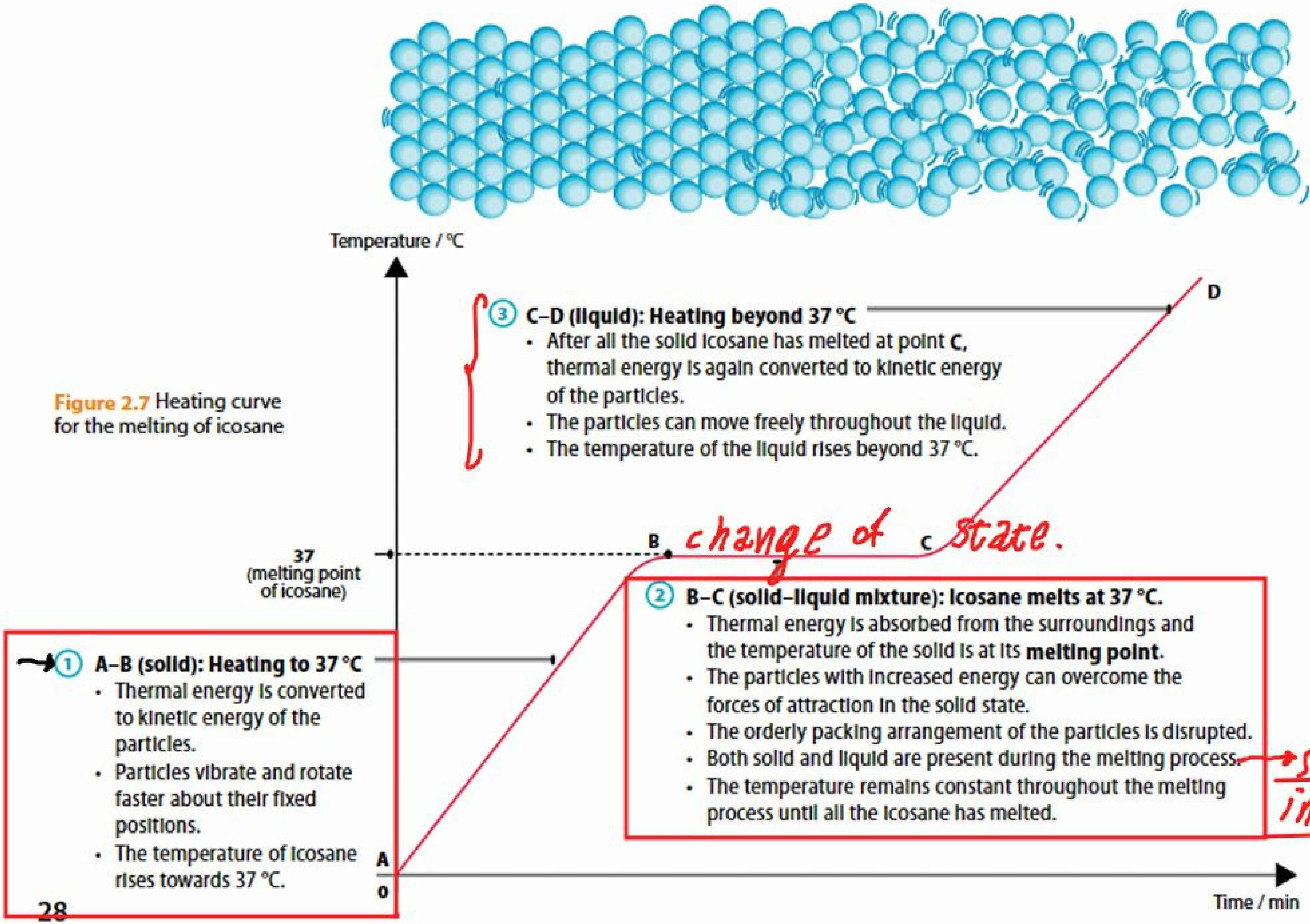


Figure 2.7 Heating curve for the melting of icosane

① $P \cdot V = n \cdot R \cdot T$ state equation →

$P \cdot V = \frac{N}{N_A} R \cdot T$

$\frac{R}{N_A} = K$ (boltzman)

The opposite of melting is **freezing**, so the steps for melting are reversed. The **cooling curve** in Figure 2.8 shows the changes as icosane freezes.

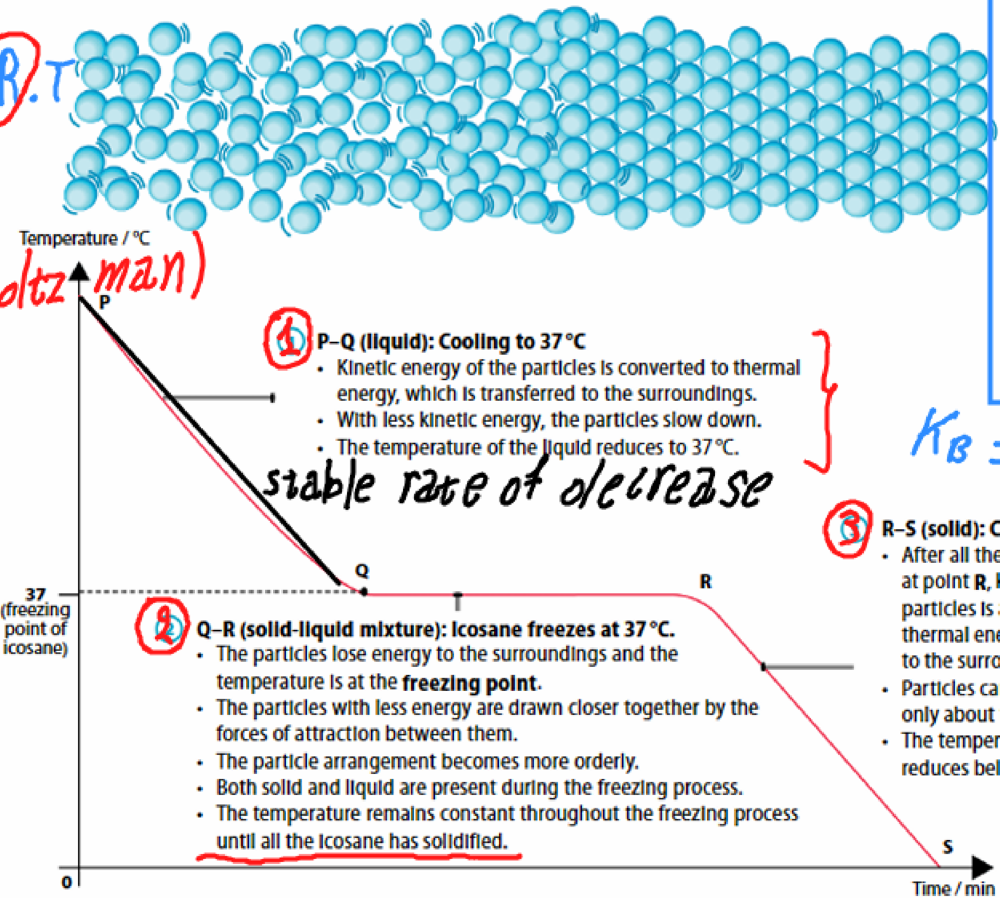


Figure 2.8 Cooling curve for the freezing of icosane

SOS

Disciplinary Idea

Temperature is a measure of the average kinetic energy of the particles in a substance.
During changes of state, the temperature remains constant as the average kinetic energy of the particles does not change. Instead, thermal energy is converted to chemical potential energy and vice versa.

$K_B = \frac{3}{2} K \cdot T_B$ (K is called boltzman constant)

Expansion and Contraction of Solids

Ice has less density than water

When railway tracks are built, small gaps are left between segments of the track (Figure 2.9). The gaps cater for the expansion of the tracks on a hot day. This prevents the tracks from expanding sideways, causing trains to derail.

When a solid is heated at temperatures below its melting point, the particles cannot spread out freely as they are strongly attracted to each other. Instead, the particles vibrate more quickly about their positions, but with a slightly wider spacing than before. The solid has undergone **expansion**.

When a solid is cooled, thermal energy is transferred from the particles to the surroundings. The particles possess less kinetic energy, so they vibrate slower and come closer than before. The solid has undergone contraction.

Volume shrinks

Figure 2.9 Gaps in railway tracks allow the tracks to expand on a hot day without buckling.

Helpful Note SOS

Water behaves differently from most substances when freezing. Typically, particles in solids are more closely packed than in liquids. However, the particles are more closely packed in water than in ice. This is why ice is less dense than water and floats on it.

Helpful Note

Evaporation occurs more quickly at higher temperatures, but it can occur at *any temperature* on the *surface* of the liquid. Boiling is the conversion from liquid to vapour *throughout* the liquid, at the *boiling point* of the substance.

You can have evaporation at different boiling points.

Converting Between Liquid and Gas

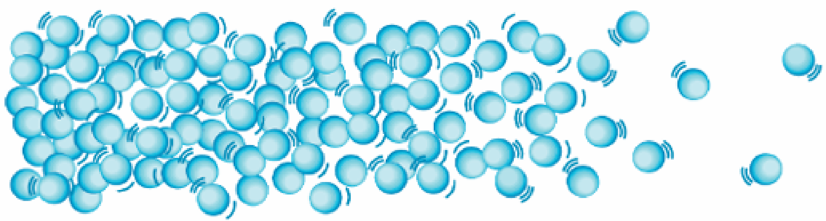
When a liquid is heated, the particles gain thermal energy. The thermal energy is converted to kinetic energy and the particles slide more quickly past each other. At the surface of the liquid in contact with air, some particles have enough energy to overcome the attractive forces to "escape" from the liquid as a vapour. This is known as **evaporation**.

When the temperature of the liquid is high enough, bubbles of gas are formed within the liquid as the liquid changes into a gas (Figure 2.10). This is known as **boiling**. At the **boiling point**, thermal energy transferred to the liquid results in the substance converting from liquid to gas. The temperature remains constant until all of the substance is in the gaseous state (Figure 2.11).

Figure 2.10 Water boils at 100 °C.

How does a pressure cooker keep water in liquid form above 100 C ?

By providing pressure to the system, the forces of attraction are not overcome, therefore the liquid water cannot be transformed into a gas and cannot escape



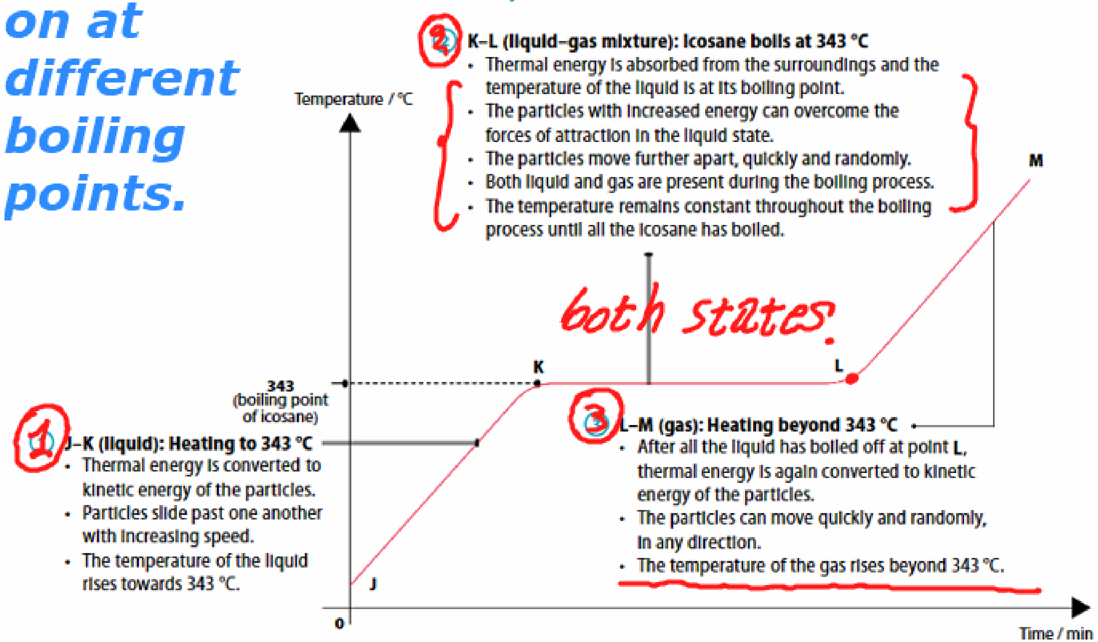
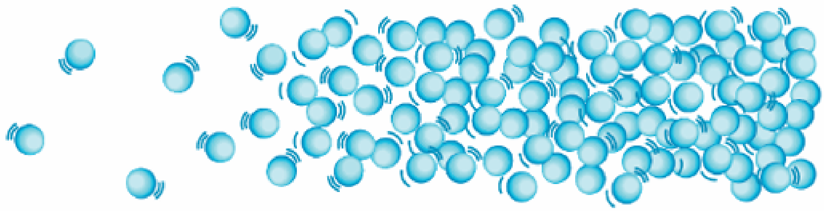


Figure 2.11 Heating curve for the boiling of icosane

Conversely, when a gas is cooled, kinetic energy of the particles is converted to thermal energy and transferred to the surroundings. The volume of gas decreases as the spacing between particles reduces as it cools. The gas continues to contract until the particles come close enough to form a liquid. This process is called **condensation**, shown in the cooling curve in Figure 2.12.



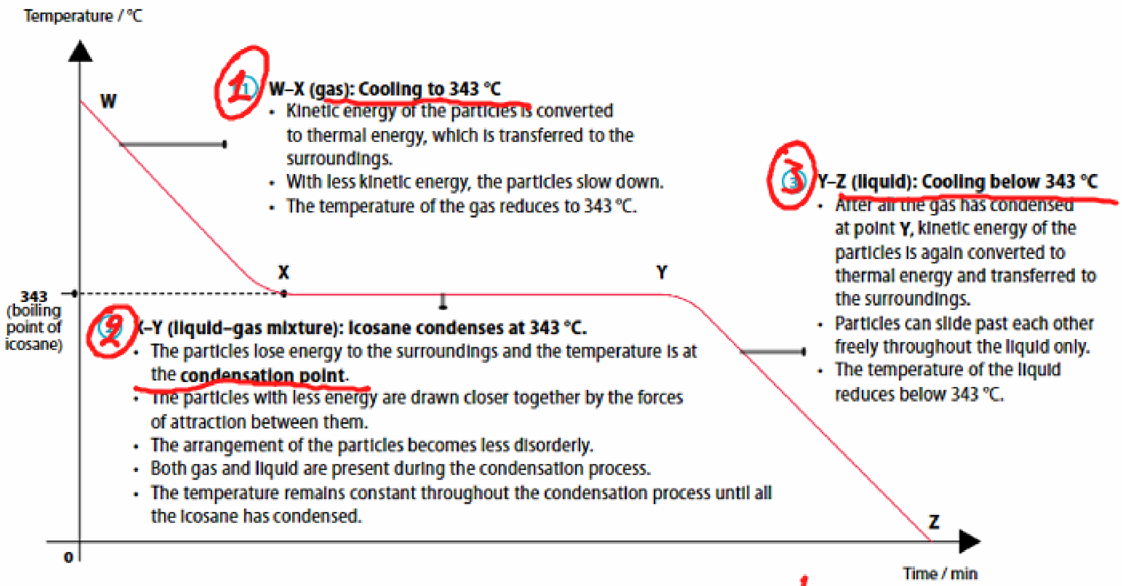


Figure 2.12 Cooling curve for the condensation of icosane

Liquefying Gases

Gaseous oxygen shrinks almost 900 times in volume as it cools and condenses into the liquid state. This is even more than the 700-fold contraction when liquid nitrogen is made, as seen on page 25. By transporting oxygen in the liquid state to hospitals, the number of storage tanks needed and hence the number of truck deliveries would be reduced. Valves on the tanks control the evaporation of the stored liquid oxygen and supply the gas to patients as required.

valves control the pressure of the tanks.

Converting Between Solid and Gas

Under certain conditions of temperature and pressure, some substances can change directly from a solid to a gas through **sublimation**. Thermal energy from the surroundings is transferred to the solid, resulting in the substance converting from a solid to a gas. The temperature remains constant until all the substance is in the gaseous state.

Figure 2.13 Dry ice is used to keep food cool.

Dry ice is carbon dioxide in the solid state. It is commonly used to keep frozen foods cool during transport (Figure 2.13). It provides the same function as an ice pack made from frozen water, but without the liquid mess. At room temperature and pressure, solid carbon dioxide sublimes directly into a gas.

The opposite of sublimation is **vapour deposition**. The particles in the gas are cooled until they slow down and arrange themselves directly into the solid state. For example, when iodine vapour comes into contact with a cold glass surface, iodine crystals are formed (Figure 2.14).

As observed in Let's Investigate 2A, spoon **A** is cooler than the surrounding air, so gaseous water vapour undergoes condensation to form liquid droplets on the underside of the spoon. Dry ice sublimes at temperatures higher than –78 °C. Since spoon **B** is in contact with the dry ice, its temperature should be between 0 °C and –78 °C. When in contact with the cold spoon, water vapour from the surroundings transfers thermal energy to the spoon. As seen in Figure 2.15, the vapour undergoes deposition to form solid ice crystals on the underside of spoon **B**.

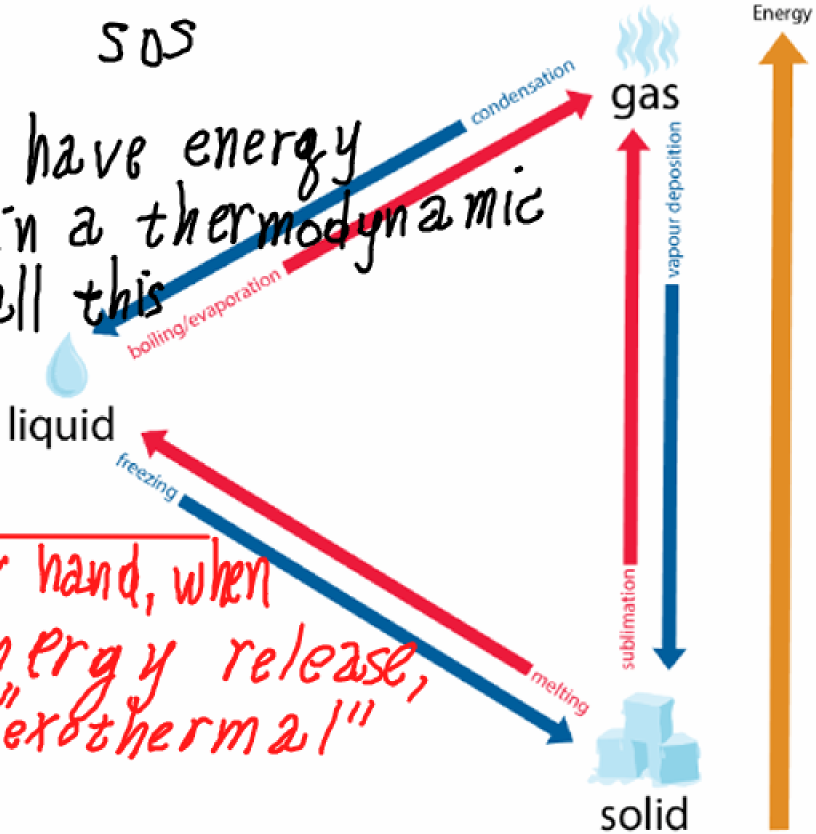
Figure 2.15 Ice crystals forming on a cold spoon

Figure 2.16 shows the interconversion between the solid, liquid and gaseous states of matter.

SOS

- When we have energy absorption in a thermodynamic level, we call this "endothermal" reaction.

- On the other hand, when we have energy release, we call it "exothermal" reaction.



Helpful Note

The absorption of energy from the environment is often confused with its release into the surroundings. The red lines in Figure 2.16 indicate the *absorption* of energy from the surroundings. The blue lines indicate the *release* of energy to the surroundings.

Figure 2.16 Interconversion between the three states of matter

Have you ever followed the smell of freshly baked pastries to find a bakery before even seeing it (Figure 2.17)? If your answer is yes, then you have experienced the movement of particles.

Figure 2.17 Trays of freshly baked buns

When you smell something in the air, it is because the particles in the air which contain the fragrance or odour have dissolved into the moist lining of your nose. As you approach the source of the smell particles, the smell gets stronger.

For sharks, "smelling" underwater is no different, except that the particles are already dissolved in the seawater, so the particle movement is in liquid instead of air (Figure 2.18).

The dissolved particles of sugar will move from regions with more particles of sugar to regions with fewer particles of sugar. This is known as diffusion.

Diffusion is the net movement of particles from a region of higher concentration to a region of lower concentration.

For sharks, blood in seawater undergoes a similar diffusion process to ink in water, as seen in Figure 2.20. Additionally, sharks are very sensitive to blood. They can detect very few particles of blood in a large volume of water.

Figure 2.20 Ink diffusing in water

Link

Biology

Diffusion is important to help our bodies regulate the exchange of substances like oxygen and nutrients for survival. Osmosis is a special case of diffusion that describes the movement of water across a partially permeable membrane.