Topic 8: **Answers**
Kinetic Particle Theory

SYLLABUS RELEVANCE & TEXTBOOK CHAPTERS		
O-LEVEL PURE (5072)	✓	Chapter 1
O-LEVEL SCIENCE (5116)	✓	Chapter 1
N-LEVEL SCIENCE (5155)	✓	Chapter 1

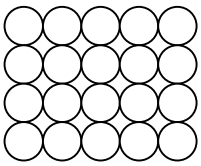
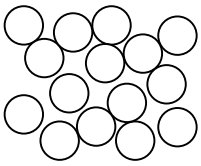
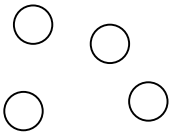
Lesson Package & Accompanying Slides Designed by Alex Lee (2007)
Last Modified by Alex Lee (2011)

1. Kinetic Particle Theory – An Overview

As early as 400 BC, the Greeks were interested in finding out what were the basic building blocks of matter – i.e., what was the smallest indivisible unit that made up all matter. Back then, we had no idea what an atom, a molecule or an ion was; all we knew was that all matter were made up of small things, which we will loosely refer to as 'particles'.

The **kinetic particle theory** proposes that all matter is made up of small particles,

and that these particles are in constant random motion.

	Solids	Liquids	Gases
			
Arrangement	Particles have a **regular arrangement.** Property: fixed shape	Particles have an **irregular arrangement.** Property: no fixed shape	Particles have an **irregular arrangement.** Property: no fixed shape
Concentration	Particles **closely packed**. Particles cannot come closer to each other. Property: cannot be compressed	Particles **loosely packed**. Particles cannot come closer to each other. Property: cannot be compressed	Particles are **spread far apart**. Particles have space to come closer to each other. Property: can be compressed
Attractive Forces	Particles have **very strong attractive forces** between them. Property: fixed volume	Particles have **some attractive forces** between them, not as strong as solids. Property: fixed volume	Particles have **negligible attractive forces** between them. Property: no fixed volume
Movement	Hence particles vibrate and rotate at **fixed positions**. Property: does not diffuse much	Hence particles vibrate, rotate and **move freely, keeping contact with each other**. Property: diffuses slowly	Hence particles vibrate, rotate and **move with no restriction, at high speeds.** Property: diffuses rapidly

2. **Describing Structure & Physical Properties**

We have to pay attention to the difference between the terms 'structure' and 'physical properties'. When we describe structure, we are looking for details such as arrangement, movement and forces of attraction between particles. However, when we describe physical properties, we are looking for observations, such as shape and ability to be compressed.

(a) Describe the **structure** of a gas in terms of the kinetic particle theory.

Particles are spread far apart, with negligible forces of attraction between them, and moving randomly at high speeds.

(b) Compare and contrast between the **structure** of a solid and a liquid.

Solid particles are closely packed in a regular arrangement, whereas liquid particles are loosely packed with no regular arrangement. Solid particles have a stronger attraction between them than liquids. Solid particles vibrate in fixed positions, whereas liquid particles are free to move within the volume of the liquid.

(c) Describe the **physical properties** of a solid.

Solids have fixed shape and volumes, and may not be compressed.

(d) Compare and contrast between the **physical properties** of a liquid and a gas.

Both liquids and gases have no fixed shape, and takes on the shape of their containers. However, liquids have a fixed volume and may not be compressed, while a gas does not have a fixed volume and may be compressed.

3. **What Are These 'Particles'?**

Suggest what the discrete 'particles' are in the following structures:

(a) a block of copper metal — copper ions and delocalised electrons

(b) a crystal of sodium chloride — sodium ions and chloride ions

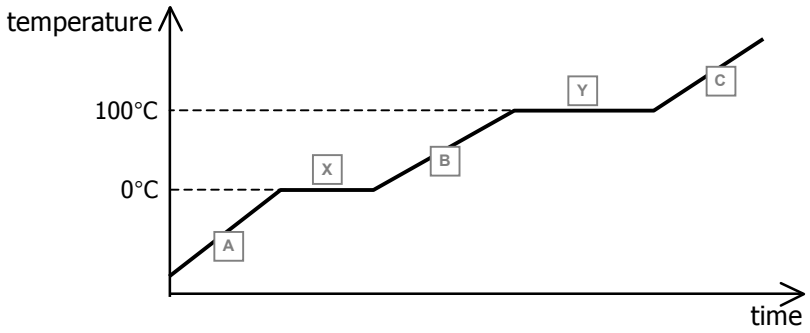
(c) a cube of pure ice — water molecules

(d) a solution of copper(II) sulfate — copper ions, sulfate ions and water molecules

(e) a grain of sand — silicon atoms and oxygen atoms

4. **Changes Of State – An Illustration**

The temperature-time graph below shows the heating curve of an unknown solid substance which is placed on an electric heater for some time.



(a) In what physical state is the substance at A, B, C, X & Y?

A: solid **B:** liquid **C:** gas

X: both solid and liquid **Y:** both liquid and gas

(b) Name the processes which are occurring at X and Y.

X: melting **Y:** boiling

(c) What are the melting, freezing, boiling and condensation points of the unknown substance?

Melting Point: 0 °C *Boiling Point:* 100 °C

Freezing Point: 0 °C *Condensation Point:* 100 °C

(d) Suggest the identity of the unknown solid.

Pure ice

(e) Describe how melting and boiling points can be used to determine

(i) the identity of a particular substance.

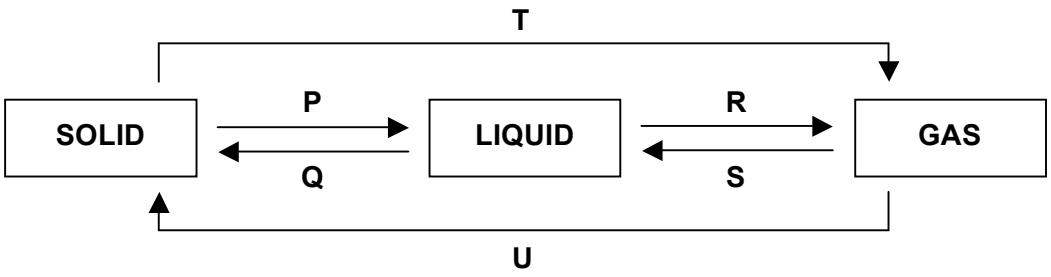
All substances have fixed melting and boiling points (at standard atmospheric pressure), and so we can use this information to identify the substance.

(ii) the purity of a particular substance.

A pure substance will melt or boil at an exact point, whereas impure substances melt or boil over a range of temperatures.

5. **Types of Changes of State**

The diagram below shows the conversions between various states of matter.



(a) Name the processes **P**, **Q**, **R**, **S**, **T** and **U** in the diagram above.

P: melting **R:** boiling **T:** sublimation

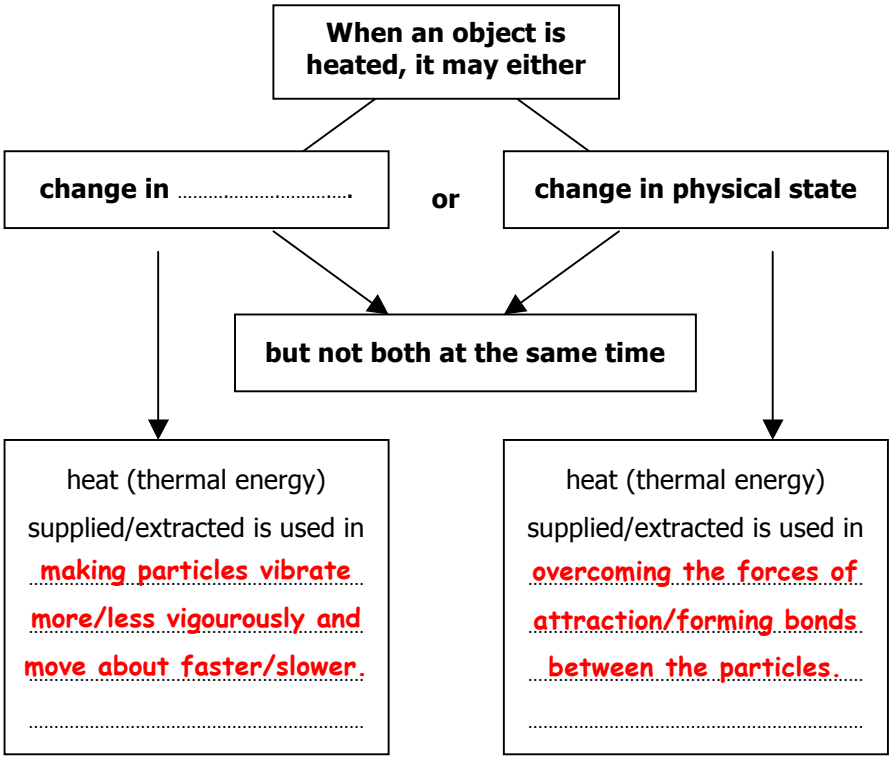
Q: freezing **S:** condensation **U:** condensation

(b) Name three substances which can undergo process **T**.

Ammonium chloride, iodine, carbon dioxide (dry ice)

6. **What Happens To The Energy? – A Summary**

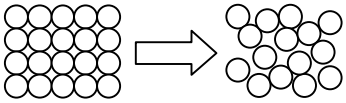
Complete the diagram below, which shows the difference between a change in state and a change in temperature.



7. **Describing Changes Of State**

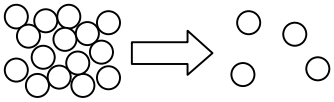
Fill in the blanks in the diagram below to describe the microscopic changes that occur during melting, boiling, freezing and condensing.

melting



"During melting, solid particles gain energy and vibrate more vigourously. Eventually, they gain enough energy to weaken the attractive forces between the particles and break from their fixed positions. They are now able to move freely within the liquid."

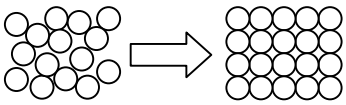
boiling



"During boiling, liquid particles gain energy and move about more quickly. Eventually, they gain enough energy to overcome the attractive forces holding the liquid particles together. They leave the liquid and are now able to move rapidly with no constraints."

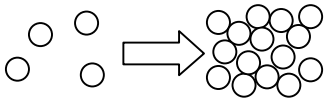
Changes Of State

freezing



"During freezing, liquid particles lose energy and move about less quickly. Eventually, they lack enough energy to move freely within the liquid and begin to vibrate in fixed positions. Stronger forces of attraction are

condensing

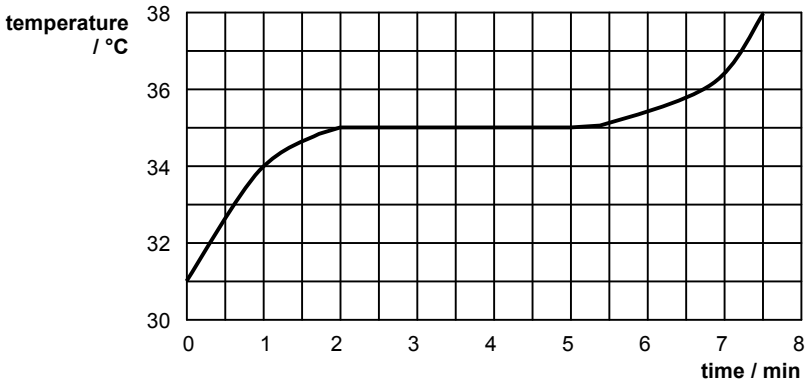


"During condensing, gas particles lose energy and move about less quickly. Eventually, they lack enough energy to move freely with no constraint and begin to move closer to each other. Stronger forces of attraction are

formed between the particles.”	formed between the particles.”

8. **Review Question**

An unknown liquid substance **Q** was heated steadily under a constant flame. The temperature of the substance was plotted against time, as shown.



(a) What is the boiling point of unknown substance **Q**?

35 °C

(b) At what physical state is the substance at

(i) t = 1 min? liquid

(ii) t = 4 min? both liquid and gaseous

(iii) t = 7 min? gaseous

(c) Is the substance gaining any heat energy at t = 4 min? Explain your answer.

Yes. The heat energy gained from the flame is used to overcome the attractive forces between the liquid particles, instead of being used to increase temperature.

(d) Describe the microscopic changes that occur between t = 0 min and t = 2 min.

The liquid particles gain heat energy and begin to vibrate, rotate and move about more quickly.

(e) Describe the microscopic changes that occur between t = 2 min and t = 5 min.

The liquid particles gain energy and move about more quickly, eventually gaining enough energy to overcome the attractive forces holding them together. They leave the liquid to become a gas, and move at high speeds with no constraints.

9. **Diffusion – Evidence for the Kinetic Particle Theory**

If you leave an open bottle of perfume at one end of a room, after some time you would be able to smell the perfume at the opposite corner of the room. This is because the small particles of perfume are able to travel throughout the air and spread out evenly, in a phenomenon which we call diffusion.

Diffusion is often used as evidence of the kinetic particle theory, because it proves that matter exists as small particles and not merely as a giant block. At the same time, it also proves that these small particles are constantly moving, hence its ability to occupy any available space.

Diffusion is defined as the random movement of particles from a region of higher concentration to a region of lower concentration.

Diffusion can occur **in both gases and liquids**, and under special circumstances, even solids. For example, the smell of perfume can diffuse through the air (gaseous diffusion), or a drop of paint in a glass of water can diffuse throughout the water (liquid diffusion). Complete the table below with two factors which affect the rate of diffusion.

Factor	Relationship
temperature	the higher the temperature, the faster the rate of diffusion
molecular mass (M_r)	the larger the molecular mass, the slow the rate of diffusion

10. **Calculating Relative Molecular Mass (M_r)**

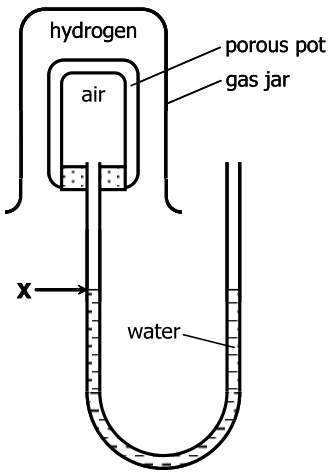
Eight gases are listed below. Complete the table and indicate which of the gases diffuse the fastest and the slowest by placing a tick (✓) in the appropriate box.

Gas	Formula	Relative Molecular Mass (M_r)	Diffuse Fastest	Diffuse Slowest
Ammonia	NH_3	14 + 3 (1) = 17		
Carbon Dioxide	CO_2	12 + 2 (16) = 44		
Chlorine	Cl_2	2 (35.5) = 71		✓
Hydrogen Chloride	HCl	1 + 35.5 = 36.5		
Hydrogen	H_2	2 (1) = 2	✓	
Methane	CH_4	12 + 4 (1) = 16		
Nitrogen	N_2	2 (14) = 28		
Sulfur Dioxide	SO_2	32 + 2 (16) = 64		
Water Vapour	H_2O	2 (1) + 16 = 18		

11. **Diffusion – Some Questions**

(a) A tube, containing some water, is connected to a porous pot as shown. A jar of hydrogen is inverted over the porous pot. The porous pot initially contains air, which is a mixture largely consisting of nitrogen.

Suggest, with reasons, what changes you would observe to the water level at **X**.

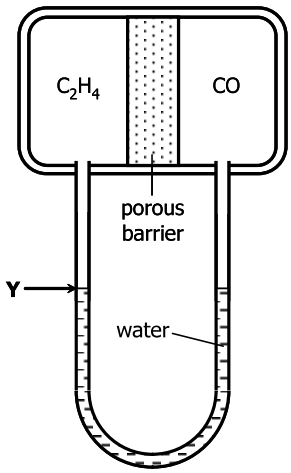


Hydrogen, having a lower M_r than nitrogen, will diffuse into the porous pot faster than nitrogen can diffuse out of it, leading to an initial drop in level X.

However, after some time, hydrogen would have completely diffused, leaving nitrogen to continue diffusing out of the pot, leading to an eventual rise in level X.

(b) A container, separated into two by a porous barrier, is filled with ethene gas (C_2H_4) and carbon monoxide (CO) on each side. A tube containing water is connected to both sides of the container as shown below.

Suggest, with reasons, what changes you would observe to the water level at **Y**. Also, name another gas that could be used to replace carbon monoxide and still obtain the same result.



Ethene and carbon monoxide both have the same molecular mass of 28. Hence the rate in which the two gases diffuse across the porous barrier are the same, leading to no change in the water level at Y.

Another gas that can be used is nitrogen, as it also has a molecular mass of 28.

Self-Designed Summary

Supplementary Questions

1. A substance changes from the state in which its particles are in contact but still able to move freely to the state in which its particles are widely spaced and able to more freely. This process is
   A freezing. **B** diffusion. **C** evaporation. **D** condensation.

2. The particles in a liquid can be described as
   A closer than those particles in a solid.
   B being in continuous random motion.
   C vibrating about fixed positions.
   D stationary in an ordered arrangement.

3. Dust particles in the air can be seen through the beams of sunlight entering through the window into a room. The random manner in which the dust particles move is due to
   A moving air currents.
   B diffusion o dust particles in the air.
   C energy absorbed from the sun.
   D collision of the dust particles by the moving air particles.

4. The particles in a gas is best described as
   A rising upwards.
   B moving randomly in all directions.
   C expanding infixed directions.
   D vibrating about fixed positions.

5. 'Matter is made up of particles'. Which of the following is evidence for this statement?
   A Gases are usually lighter than liquids.
   B If a bottle of perfume is opened, the smell spreads quickly.
   C Water always fills the space available to it.
   D Metal expands when heated.

6. A few drops of liquid bromine is placed at the bottom of a gas jar. Brown fumes of bromine slowly spread through the whole gas jar. This happens because
   A bromine molecules move faster than those in air.
   B bromine molecules and those in air are always moving around.
   C bromine molecules are smaller than those in air.
   D bromine is less dense than air.

7. The process where particles can escape from the surface of a liquid at temperature below its boiling point is called
   A evaporation. **B** boiling. **C** dissociation. **D** condensation.

8. Water slowly collecting on a cool surface is due to
   A melting. **B** condensation. **C** evaporation. **D** sublimation.

9. A liquid metal at room temperature and pressure is
   A copper. **B** silver. **C** bromine. **D** mercury.

10. The freezing point is defined as the temperature at which
    A is always at 0 °C.
    B a gas becomes a solid.
    C a liquid has completely frozen.
    D a liquid first becomes a solid.

11. The change taking place in I_2 (s) $\longrightarrow$ I_2 (g) is
    A sublimation. **B** evaporation. **C** condensation. **D** melting.

12. A test tube containing a liquid **X** is placed in a beaker of boiling water. The liquid **X** starts to boil immediately. From this, it can be deduced that the boiling point of **X** is

A above 100 °C.
B exactly 100 °C.
C less than 0 °C.
D between room temperature and 100 °C.

13. Three substances are described below:
    - *Substance 1 is brittle at room temperature.*
    - *Substance 2 melts at -50 °C and boils at 50 °C.*
    - *Substance 3 has a high melting point of 300 °C.*

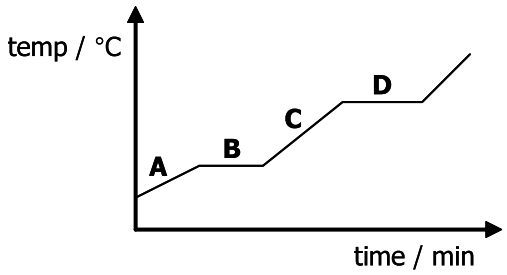
    Which of the following statements are true?

A Substance 1 is liquid at room temperature.
B Substance 2 is solid at -30 °C.
C Both substances 1 and 3 are solid at room temperature.
D Both substances 2 and 3 are solid at room temperature.

14. Bromine melts at -2 °C and boils at 59 °C. At which temperature is bromine a liquid?

A -3 °C **B** -1 °C **C** 60 °C **D** 100 °C

15. In the below heating curve, which region **A**, **B**, **C** or **D** has both solid and liquid co-existing?



Supplementary Questions (Answers)

Multiple-Choice Questions

1	C	2	B	3	D	4	B	5	B	6	B	7	A	8	B
9	D	10	D	11	A	12	D	13	C	14	B	15	B		

Lecture Slides

Kinetic Particle Theory

Anglo-Chinese School (Barker Road)

CHEMISTRY
Prepared by Alex Lee

Chapter Overview

In This Chapter, We Will Learn …

1. Structure of Solids, Liquids and Gases
2. Properties of Solids, Liquids and Gases
3. Changes in State & Latent Heat
4. Changes in Temperature
5. Diffusion *(for Pure Chemistry Only)*

What is the kinetic particle theory?

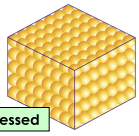
movement | small discrete pieces

"The kinetic particle theory states that all matter is made up of **discrete particles**, and these particles are in **constant random motion**."

We will thus look at how this theory applies to the three states of matter – **solids**, **liquids** & **gases**.

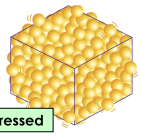
Describing Matter - Solids

- Particles in **regular arrangement.** — fixed shape
- Particles closely **packed**. Particles cannot come closer to each other. — cannot be compressed
- Particles have **strong attractive forces** between them. — fixed volume
- Hence particles vibrate and rotate at **fixed positions**. — does not diffuse much



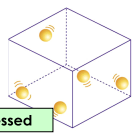
Describing Matter - Liquids

- Particles in **irregular arrangement**. — no fixed shape
- Particles loosely **packed**. Particles cannot come closer to each other. — cannot be compressed
- Particles have **some attractive forces** between them, not as strong as those in solids. — fixed volume
- Hence **particles vibrate, rotate and move freely, keeping contact with each other**. — diffuses slowly



Describing Matter - Gases

- Particles in **irregular arrangement**. — no fixed shape
- Particles **spread far apart**. Have space to come closer to each other. — may be compressed
- Particles have **negligible attractive forces** between them. — no fixed volume
- Hence **particles vibrate, rotate and move with no restriction (high speeds)**. — diffuses rapidly



Describing Structure

- When describing structure, sure to mention:
  - ② proximity (close or far apart?)
  - ① arrangement (regular or irregular?)
  - ③ forces of attraction
  - ④ movement

- For example, when describing a solid:

"In a solid, particles are packed closely together in an orderly arrangement. The particles are held together by strong forces of attraction, and vibrate and rotate in fixed positions."

Describing Properties

- When describing physical properties, sure to mention:
  - ① whether it has a fixed volume
  - ② ability to be compressed
  - ③ whether it has a fixed shape
  - ④ ability to take the shape of its container

- For example, when describing a gas:

"Gases do not have a fixed volume, and are able to be compressed. They also do not have a fixed shape, and are able to take the shape of its container."

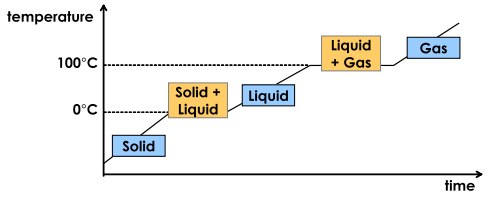
Just What Are These 'Particles'?

- Concept of the kinetic particle theory existed before the time where atoms or molecules were discovered! 'Particles' can refer to many things, including: atoms, molecules, ions, electrons.

- What 'particles' make up the following solids?
  - a block of copper metal → copper ions + delocalised electrons
  - crystal of sodium chloride → sodium ions and chloride ions
  - cube of pure ice → water molecules
  - a solution of copper(II) sulfate → copper(II) ions, sulfate ions and water molecules
  - a grain of sand → silicon and oxygen atoms

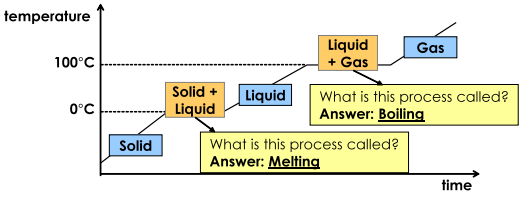
A Heating Curve

- Below shows the graph of an unknown substance being heated at a **constant rate**.



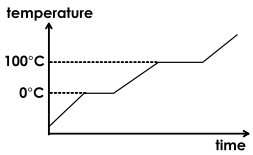
A Heating Curve

- During a change in state, is there a change in
  (i) thermal energy? ***YES – heat is absorbed/evolved***
  (ii) temperature? ***NO – temperature is constant***



A Heating Curve

- Observe the heating curve of the graph below:



Determine:

Melting Point	= 0 °C
Boiling Point	= 100 °C
Freezing Point	= 0 °C
Condensation Point	= 100 °C

- **Q.** Suggest what this unknown solid may be.

A. Pure Ice ← We can identify chemicals by their melting and boiling points!

Melting & Boiling Points

- The temperature at which a substances melts is the same temperature at which it freezes!

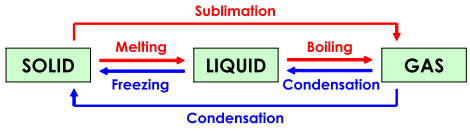
Melting Point temperature at which a **solid** changes to **liquid**	same temperature	**Freezing Point** temperature at which a **liquid** changes to **solid**
Boiling Point temperature at which a **liquid** changes to **gas**	same temperature	**Condensation Point** temperature at which a **gas** changes to **liquid**

Melting & Boiling Points

Given the melting and boiling points of a substance, what information can we deduce?

- **Identity of substance –** all substances have fixed melting and boiling points (at standard atmospheric pressure), so we can use this information to identify the substance. This value does not change.
- **Purity of a substance –** a pure substance will melt or boil at an exact point, while an impure substance will melt or boil over a range of temperatures. For example, bee wax (mixture) melts over 62°C to 64°C.

Changes of State



- Most substances go through a liquid phase, but some substances are able to move directly from a solid phase to a gaseous phase, i.e. undergo sublimation.
- *Examples:*
  dry ice (carbon dioxide), ammonium chloride, iodine

Energy Changes - Heating Curve

When thermal energy is supplied to or withdrawn from an object, it may either

change in temperature or **change in physical state**

but not both at the same time

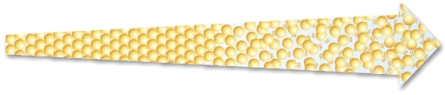
thermal energy supplied (withdrawn) is used in **making particles vibrate more** (less) vigorously, and move about faster (slower).

thermal energy supplied (withdrawn) is used in **overcoming the forces of attraction** (forming bonds) between the particles.

Describing Changes of State

MELTING

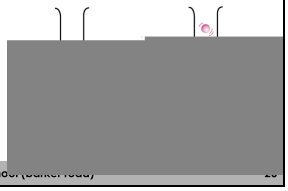
During melting, solid particles gain energy and **vibrate more vigorously**. Eventually, they gain enough energy to **weaken the attractive forces** between the particles and **break from their regular arrangements**. They are now able to **move freely within the liquid**.



Describing Changes of State

BOILING

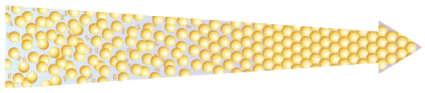
During boiling, liquid particles gain energy and **move about more quickly**. Eventually, they gain enough energy to **weaken the attractive forces** holding the liquid particles together. They leave the liquid and are now able to **move freely with no constraints**.



Describing Changes of State

FREEZING

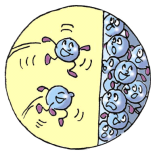
During freezing, liquid particles lose energy and **move about less quickly**. Eventually, they lack enough energy to **move freely within the liquid** and begin to **vibrate in fixed positions**. Stronger **forces of attraction** are formed between the particles.



Describing Changes of State

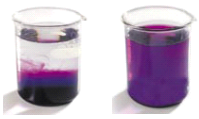
CONDENSING

During condensing, gas particles lose energy and **move about less quickly**. Eventually, they lack enough energy to **move freely with no constraint** and begin to **move closer to each other**. Stronger **forces of attraction** are formed between the particles.



Diffusion

- Defined as the movement of particles from a region of higher concentration to a region of lower concentration.
- Occurs mainly in **liquids** and **gases**, as the particles are free to move / not held in fixed positions.



Diffusion

- The rate of diffusion is affected by two factors:
  - mass of the particle — **the smaller the mass, the faster the particle can diffuse!**
  - temperature — **the higher the temperature, the faster the particle can diffuse!**
- The mass of the particle ('relative molecular mass') can be calculated using the periodic table.

e.g. mass of carbon dioxide gas (CO_2)
= mass of 1 carbon atom and 2 oxygen atoms
= 1 × (12) + 2 × (16) = ***44***