Unit - 7

PROPERTIES OF MATTER

Matter is made up of tiny particles called molecules.

Matter exists in different states. three basic states of matter are solid liquid and gas.

The properties of matter in these states can be described on the basis of the forces and distances between their molecules and energy of the molecules..

The temperature and pressure of a gas depends upon the motion of its molecules.

A change in volume of a fixed mass of a gas at constant temperature is caused by a change in pressure applied to the gas.

This fact is used in many fields of daily life. For example, in using syringe, in pumping air to the tyre through a bicycle pump, in spraying color etc.

Matter can change its state and water is the best example of it.

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- Describe States of matter.
- State kinetic molecular model of matter
- Explain the kinetic model in terms of forces between particles
- Explain the behavior of gases
- Calculate changes in pressure and volume

$$p_1 V_1 = p_2 V_2$$

Fig 7.1 (a)

Fig 7.1 (b)

Fig 7.1 (c)

A balloon kept under sunlight shattered, why? Why a hot coffee or tea in a cup became cold as the time passes? Clothes dry up quickly under sunlight? Honey is thicker than water, why?

Why do water and milk or other liquids boil at different temperatures? Why do water and milk take the shapes of the container in which they are poured? Have you ever think that when you sit at your chair or bed, their foams compresses but their wooden frame do not?

After studying this unit you will be able to find the answers of such questions and other similar questions and develop the clear concepts.

7.1 STATES OF MATTER

There are three states of matter. These states are solid, liquid and gas. All the material objects around us belong to any one of these states. Water is the best example of three states of matter.

- The solid state of water is ice figure. 7.1(a). Ice exists in many forms like, ice cubes, snow, glaciers and icebergs.
- The liquid state is water itself figure. 7.1(b). Water is found in oceans, rivers and underground deposits.
- The gaseous state of water is steam. The "white smoke" that you see in figure. 7.1(c) is, in fact, a small cloud formed by water vapours in air above the cup.

These states have different properties which are listed in the following table.

Table 7.1 Properties of Matter

States of Matter	Shape	Volume	Density	Compressibility
Solid	Fixed	Fixed	High	Incompressible
Liquid	Not fixed	Not fixed	High	Incompressible
Gas	Not fixed	Not fixed	Low	Compressible

Addition or removal of a certain amount of energy can change the state of a matter. The terms for these changes in the state are:

Melting: conversion from solid to liquid.
Boiling: conversion from liquid to gas.
Condensing: conversion from gas to liquid.
Freezing: conversion from liquid to solid.
Evaporation: conversion from liquid to gas.

Evaporation is different from boiling.

Evaporation is a process by which a liquid becomes a gas at temperatures below its boiling point.

For example, drying of wet clothes, drying of wet floor etc. Conversion of matter between three states involves physical changes and not chemical changes.

Why liquids and gases take the shapes of their containers while solids have definite shapes? Why do different substances boil and melt at different temperatures? Why can gases be compressed easily while solids and liquids cannot?

The answers of the above and such other questions can be obtained by considering the arrangements of the particles in these states and how these particles are able to move about. This is explained by the kinetic molecular theory of matter.

Kinetic Molecular Model of Matter

The kinetic molecular model of matter is,

Matter is made up of tiny particles called atoms, or group of atoms called molecules. These molecules are always in continuous random motion.

According to this model particles are in continuous motion. Thus an alternative name for model is 'The particle model of matter'.

The evidence of molecular motion is Brownian motion.

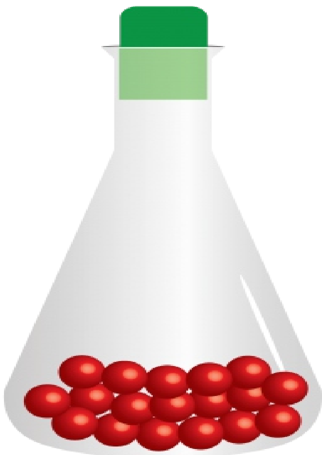
Do You Know!

Water is different from other substances because it is less dense in its solid state (ice), than its liquid state (water).

Weblinks

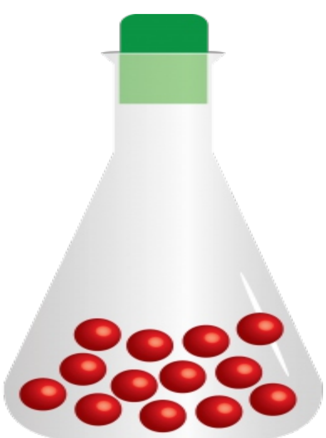
Web link of Brownian motion.

http://www.phyntau.edu



Solid

Fig 7.2 (a)



Liquid

Fig 7.2 (b)

Brownian Motion

The evidence of molecular motion first discovered by the botanist Robert Brown in 1827. He observed the irregular motion of pollen grains suspended in water and deduced that the water molecules were in constant, random motion. This irregular motion caused by water molecules is called "Brownian motion" named after the scientist.

The kinetic molecular theory explains the physical properties of solids, liquids and gases by considering the position and motion of molecules.

The particles in **solids** (Fig7.2a) have following features:

- The molecules are closely packed together and occupy minimum space.
- The molecules usually arranged in a regular pattern called lattice.
- There is a large number of particles per unit volume. That is why solids have the highest densities.

The movement of particles in solids have following features:

- The forces of attraction between particles are very strong.
- The particles are not able to change positions.
- The particles vibrate about fixed positions thus are not entirely stationary.
- This explains why solids have fixed shapes and volumes.

The particles in **liquids** (Fig 7.2b), have following features:

- The molecules are slightly further apart compared to that of solids.
- The molecules occur in clusters.

- There is slightly less number of particles per unit volume compared to solids.
- This why liquids have relatively high densities.

The movement of particles in liquids have following features:

- The forces of attraction between particles are strong.
- The particles are free to move about within the liquid.
- These features explain why liquids have fixed volumes, but take the shape of the container.

The particles in **gases** (Fig 7.2c), have following features:

- The molecules are very far apart.
- The molecules are arranged randomly and are free to move with very high speeds.
- There is small number of particles per unit volume.

The movement of particles in gases has following features:

- The forces of attraction between particles are negligible.
- The particles are able to move freely in random directions at very high speeds.
- The particles occupy any available space.

SELF ASSESSMENT QUESTIONS:

Q1: Explain why the measurement of volume of a given liquid remains same although it is measured by measuring cylinders of different shapes and sizes.

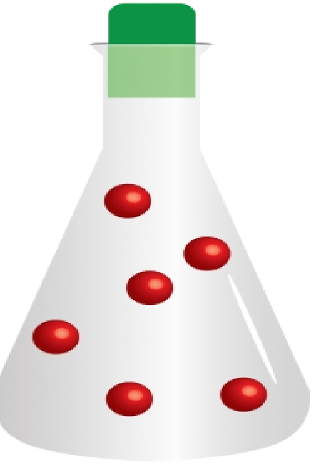
Q2: What is the difference between evaporation and boiling?

Q3: What is the difference between three states of matter? in terms of the spacing between the molecules.

Do You Know!

Human body consists of all three states of matter.

1. Solid in the form of organs.
2. Liquid in the form of blood.
3. Gas in the form of Oxygen and carbondioxide for respiration.



Gas

Fig 7.2 (c)

7.2 FORCES AND KINETIC THEORY

Why some materials are solid and liquid while others are gases at room conditions?

Forces between the molecules are responsible for the different states of matter as well as for the physical properties. According to the Kinetic molecular model molecules of gases have large kinetic energy as a result there are no forces of attraction between them as a result molecules of gases can move freely and go farther apart. This is why gases can occupy any available space and can be compressed easily. Boiling and melting points of gases are also very low because of this reason. The molecules of liquids as compared to that of the gases have less kinetic energy hence intermolecular forces come into play. That is why the molecules of liquids are very close to each other but still free to move. therefore liquids do not have fixed shape but fixed volume. The melting and boiling points of liquids are also high as compared to gases. The molecules of solids have extremely lowest energies therefore experience strong attractive forces and can not move freely but only have small vibrations about mean positions. this gives solid a fixed shape and volume. That is why densities, melting and boiling points of solids are very high.

As a result we are able to convert water into ice, cream into ice cream, natural gas into compressed natural gas 'CNG' etc.

The state of a substance can be changed either by heating or by cooling it. on the other hand when a solid substance (Fig7.3) is heated, the molecules start to vibrate more and more strongly. Eventually, the molecules vibrate more violently and inter molecular forces become weak. As a result 'material becomes a liquid,'if process of heating is continued further, then molecules have sufficient energy to overcome all of the attractive forces as a result 'substance becomes a gas'.

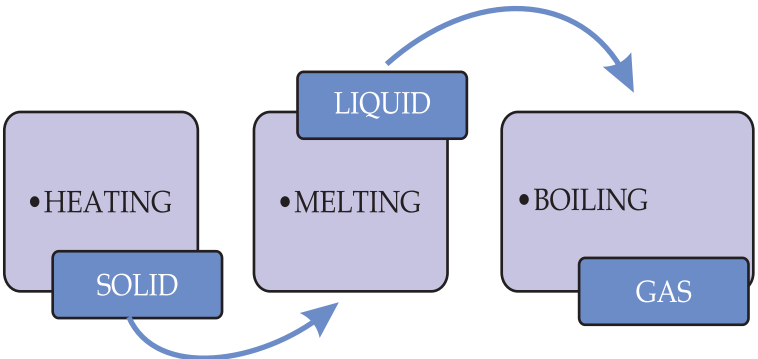


Fig 7.3

When a gas is cooled (Fig 7.4), the molecules move more slowly and collide with one another, may stick together and force of attraction between molecules increases. Keep cooling the gas and eventually all of the molecules stick together to form a liquid. Further cooling will cause all the molecules to stick together to form a solid.

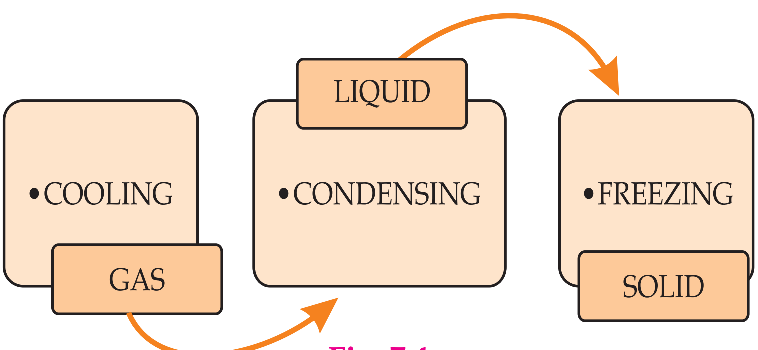


Fig. 7.4

Table 7.2 on the right shows the boiling and melting points of some pure substances:

Helium has lowest boiling and melting points as compared to other substances. It solidifies only when it is cooled and compressed. Mercury is the only metal that is not solid at room temperature.

Table 7.2
Boiling and melting points of some pure substances

Substance	Melting point (°C)	Boiling point (°C)
Helium	-272	-269
Oxygen	-218	-183
Nitrogen	-191	-177
Mercury	-39	257
Water	0	100
Iron	2080	3570
Diamond (Carbon)	4100	5400
Tungsten	3920	6500

Self Assessment Questions:

Q4: Why Tungsten melts at a much higher temperature than iron?

Q5: What is the name of process in which a liquid changes into a solid?

Q6: What is the name of temperature at which a liquid changes into a solid?

7.3 GASES AND THE KINETIC THEORY

Kinetic molecular theory clearly describes the properties and behavior of gases. Hot air balloons (Fig 7.5)are the practical applications of the discussion given below:

Fig 7.5

The behavior of gases

The molecules in the gases have relatively large distance between them. The molecules in the gases move about very quickly. A gas molecule moves in a straight line. It changes its direction only when (i) it collides with another gas molecule or (ii) with the walls of its container. After collision it moves away in a new direction .Since gas molecules collide many times each second. Therefore the motion of molecules is constant and random.

The behavior of a gas can be described completely by its pressure, volume and temperature.

Pressure

We already know that pressure is defined as the force per unit area. All the gases exert pressure on the walls of their container. This pressure is the total force exerted per unit area by the gas molecules during collision. The gas molecules exert pressure only when they collide with the walls. The number of collisions is proportional to the number of molecules. If the number of molecules is doubled then number of collisions will also be doubled (Fig 7.6 a, b, c and d). Hence the pressure is also doubled.

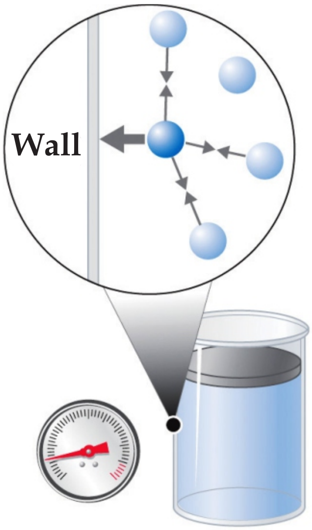


Fig.7.6 (a)

Low pressure

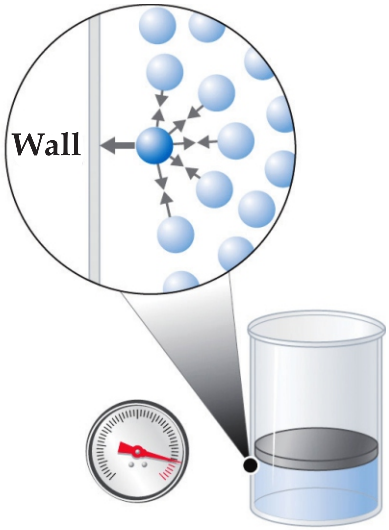


Fig.7.6 (b)

High pressure

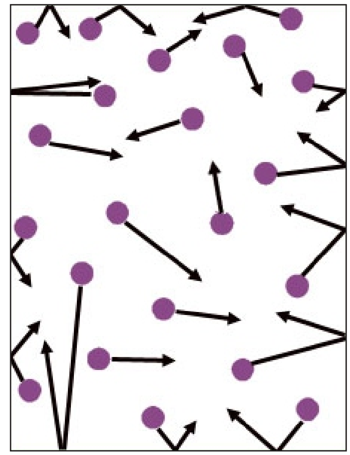


Fig.7.6 (c)

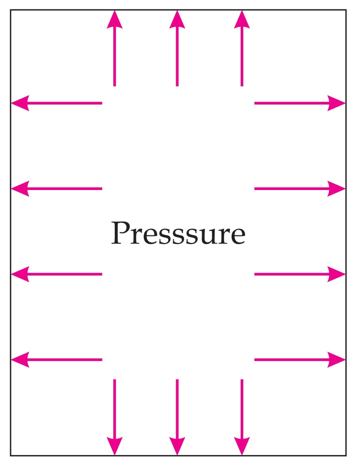


Fig.7.6 (d)

of molecules is doubled then number of collisions will also be doubled (Fig 7.6 a, b, c and d). Hence the pressure is also doubled.

Blowing up a balloon is an example of pressure. If more air is pushed into the balloon it will be inflated more. Because air molecules apply pressure on the rubber walls of balloon hence it gets inflated.

Pressure of a gas can also be increased by compressing it. This is done by reducing the size of the gas container (Fig7.7). The gas molecules have been compressed into a smaller volume so they will collide more frequently with the walls of container and creates more pressure. If the gas is compressed to half its original volume its pressure will be doubled.

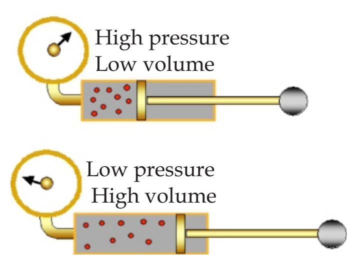


Fig 7.7

Volume

We know that the space occupied by substance is known as volume. The gas has no definite volume because the molecules of the gas are far away from each other and can move freely at high speeds. Therefore gas always takes up the shape and volume of its container.

For example, the smell of a perfume quickly spreads through the room as soon you spray it at your body or clothes. Because, the molecules move freely and randomly at high speeds through out the room. Volume of a gas can also be increased by decreasing its pressure. This could be done by reducing the load on the piston of the gas container. As the gas molecules are in random motion (Fig 7.8) they quickly covers the whole space and the volume increases. If the gas is compressed to half its original volume its pressure will be doubled.

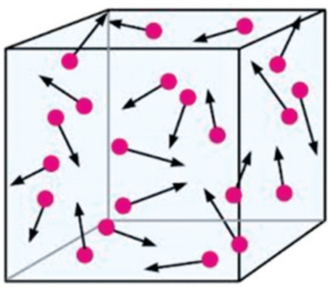
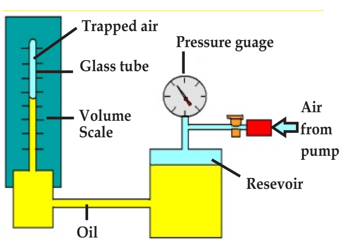


Fig 7.8

Temperature

The temperature of a gas is determined by the average translational kinetic energy of its molecules. If a gas is heated the average translational kinetic energy of its molecules increases and temperature of the gas rises. If a gas is cooled down the average translational kinetic energy of its molecules decreases and temperature of the gas falls.



Boyle's Law

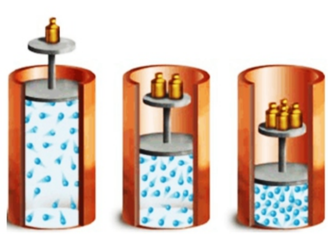


Fig 7.9

Pressure - volume relationship in gases

Robert Boyle, an English physicist and chemist in 1662, studied the relationship between pressure and volume of a gas (Fig 7.9) .

The results of a Boyles experiment are shown below:

$$p \propto \frac{1}{V} \text{ or } V \propto \frac{1}{p}$$

1. If pressure of the gas is double its volume becomes half. If pressure increases by three times then volume becomes one-third and so on.
2. The graph (Fig.7.10) between "p" and "V" between "p" and 1/V" are shown below:
3. The graph between "p" and "V" shows that if pressure increases then volume decreases and vice-versa, i.e.
4. The graph between "p" and "1/V" shows a straight line passing through the origin.
5. At constant temperature the product of pressure and volume is constant. i.e.

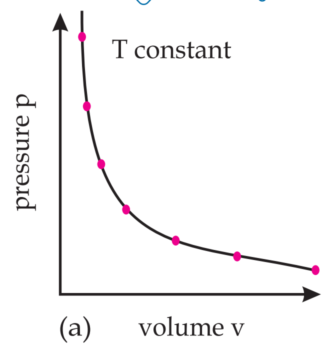
$$pV = \text{constant} \ldots\ldots\ldots\ldots(7.1)$$

6. Using above result, at constant temperature, we can write Initial pressure x initial volume = Final pressure x final volume

$$p_1 V_1 = p_2 V_2 \ldots\ldots\ldots\ldots(7.2)$$

Thus Robert Boyle conclude his law known as 'Boyle's law' which states that;

The volume of a fixed mass of a gas is inversely proportional to its pressure, provided its temperature remains constant .



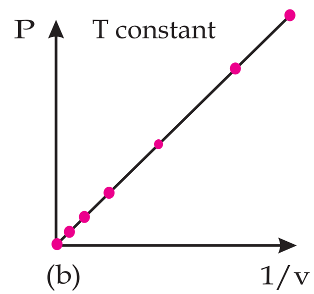


Fig 7.10

Aerosols, such as spray paints, use the Boyle's law in their working mechanism.

Fig 7.11 (a)

Applications of (p-V) relationship of a gas "Boyle's law"

Some applications of pressure-volume (p-V) relationship of a gas i.e. Boyle's law are given below in Fig. 7.11(a, b, c):

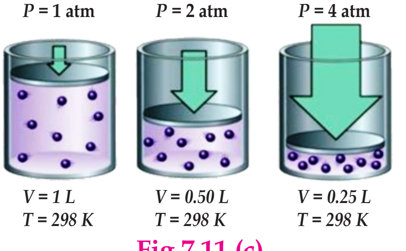


Fig 7.11 (c)
Applications of Boyle's Law

- A bicycle pump is good example of Boyle's law.
- As the volume of the air trapped in the pump is reduced, its pressure goes up, and air is forced into the tyre.

Fig 7.11 (b)

Worked Example 1

A cylinder contains $60cm^3$ of air at a pressure of 140kPa. What will its volume be if the pressure on it is increased to 420 kPa?

Solution

Step 1: Write down the known quantities and quantities to be found.

p_1=140kPa

V_1=$60cm^3$

p_2=420kPa

V_2=?

Step 2: Write down the formula and rearrange if necessary.

$p_1V_1 = p_2V_2$ or

$$V_2 = \frac{p_1 \times V_1}{p_2}$$

Step 3: Put the values and calculate.

$$V_2 = \frac{140kPa \times 60cm^3}{420kPa} = 20cm^3$$

The new volume is 20 cm^3.

Worked Example 2

Air at a pressure of 1.0×10^5 Pa is contained in a cylinder fitted with a piston. The air is now compressed by pushing the piston, so that the same mass of air now occupies one-fifth the original volume without any change in temperature. Calculate the pressure of the air.

Solution

Step 1: Write down known quantities and quantities to be found.

$p_1 = 1.0 \times 10^5$ Pa

$V_1 = V_1\ cm^3$

$V_2 = \frac{1}{5} V_1\ cm^3$

Step 2: Write down the formula and re arrange if necessary.

$p_1 V_1 = p_2 V_2$ or

$$p_2 = \frac{p_1 \times V_1}{(1/5)V_1}$$

Step 3: Put the values in formula and calculate.

$$p_2 = \frac{1.0 \times 10^5\ Pa \times V_1\ cm^3}{(1/5)V_1\ cm^3} = 5.0 \times 10^5 Pa$$

So, the final pressure is now 5.0×10^5Pa.

Self Assessment Questions:

Q7: Draw diagrams of the molecules in a gas to explain the effect of pressure change on its volume.

Q8: What is the meant by the subscripts 1 and 2 in the equation, $p_1V_1 = p_2V_2$?

Q9: What is the effect of temperature on average translational kinetic energy of molecules?

Do You Know!

An important feature of the equation $p_1V_1 = p_2 V_2$ is that it does not matter what units we use for p and V, as long as we use the same units for both values of p (for example Pa, kPa or atmosphere etc), and the same units for both values of V (for example m^3, dm^3 or cm^3 etc)

Do You Know!

when gas is compressed, volume decreases and the pressure increases.

SUMMARY

- Matter exists in three states: solid, liquid and gas.
- The state of a matter can be changed by adding or removing a certain amount of energy .
- The kinetic molecular theory is based upon the arrangement and movement of molecules in a substance.
- The kinetic molecular theory suggests that the molecules in a substance are always in continuous random motion.
- When molecules close to each other, the attractive forces between them become strong .
- The change in force between molecules causes change of state.
- Boyle's law describes the pressure - volume relationship of a gas.
- The pressure and volume of a gas are inversely proportional to each other.'
- Mathematically "$p_1V_1 = p_2V_2$".

CONCEPT MAP

Matter

- States of matter
  - Solid
  - Liquid
  - Gas
- Properties
- Molecular motion
  - Brownian Motion

Properties

Solid

- Fixed shape
- Fixed Volume
- High Density
- Incompressible
- Minimum Kinetic Energy
- Cannot be poured

Liquid

- No fixed shape
- Fixed Volume
- High Density
- Not easy to compress
- Medium Kinetic energy
- Can be poured

Gas

- No fixed shape
- No fixed Volume
- Low Density
- Easy to compress $\frac{1}{v}$
- Maximum Kinetic energy
- Can be poured

behaviour of a gas

Boyle's Law

Pressure and volume of a gas are inversely proportional to each other

$p \propto \frac{1}{v}$ or

pV = constant or

$p_1V_1 = p_2V_2$

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. An object with particles close together and vibrating describes a__________.

   a) Gas b) Liquid
   c) Solid d) All three

2. A burning candle is an example of __________ state of matter.

   a) Gas b) Liquid
   c) Solid d) All three

3. During which process a gas becomes a liquid ______.

   a) Melting b) Freezing
   c) Condensing d) Boiling

4. A solid can ______________________.

   a) have a fixed shape
   b) be easily compressed
   c) take a shape of container
   d) have freely moving molecules

5. According to kinetic molecular theory, the pressure exerted by a gas is caused by the __________.

   a) bombardment of the gas molecules on the walls of the container.
   b) collision between gas molecules.
   c) large distances between gas molecules.
   d) random motion of the gas molecules.

6. If a gas is heated in a sealed cylinder, then________ increases.

   a) pressure inside the container
   b) average kinetic energy of the particles
   c) temperature of the gas
   d) All of them

7. A gas in a container of fixed volume is heated. What happens to the molecules of the gas?
   a) They collide less frequently.
   b) They expand.
   c) They move faster.
   d) They move further apart.
8. In a liquid, some energetic molecules break free from the surface even when the liquid is too cold for bubbles to form. What is the name of this process?
   a) boiling b) condensation
   c) convection d) evaporation
9. What happens to the molecules of a gas when the gas changes into a liquid?
   a) They move closer and lose energy.
   b) They move closer and gain energy.
   c) They move apart and lose energy.
   d) They move apart and gain energy
10. A substance has a melting point of –17 °C and a boiling point of 117 °C. In which state does the substance exist at –10 °C and at 110 °C?

	at -10^{0}C	at 110^{0}C
a	Solid	liquid
b	solid	gas
c	liquid	liquid
d	liquid	gas

Section (B) Structured Questions

Kinetic molecular model of matter

1. a) "The particles are free to move within the material, has a fixed volume but takes up the shape of its container", which state of matter is being described here?
   b) Write a similar description of the particles that make up a solid.
   c) Write down any two properties of a solid.
2. a) Why the kinetic model of matter is called kinetic?
   b) In which state of matter the molecules are widely separated?
   c) In which state of matter the molecules are most closely packed?
   d) In which state of matter molecules can move freely at high speed?
3. a) By using kinetic molecular theory explain why we can walk through air, swim through water but can not walk through a solid wall.
   b) In which state of matter do the molecules have minimum kinetic energy?
   c) Which state of matter is highly incompressible?

Forces and Kinetic Theory

4. A sample of a gas is in a sealed test tube is cooled. Describe what happens to:
   a) The size of the molecules.
   b) The speed at which molecules move.
   c) The number of the molecules.
   d) The pressure inside the tube.
   e) The state of the gas.

5. An inflated car tyre is considered to have a constant volume, regardless of any changes in temperature or pressure. Use the kinetic molecular theory of gases to answer the following:
   a) How does air in the tyre exert a pressure on the walls of the tyre?
   b) Why is the pressure the same at all points on the inside wall of the tyre?
   c) More air is pumped into the tyre while the temperature is kept constant until there are twice as many molecules as before. Explain why you would expect the pressure to be doubled.
6. Describe the following:
   a) What happens to the motion of the molecules of a gas when it cools down?
   b) What happens to the motion of a liquid when it cools down?

Gases and Kinetic theory

7. The pressure on $9cm^3$ of oxygen gas is doubled at a fixed temperature. What will its volume become?
8. A container holds $30m^3$ of air at a pressure of 150000Pa. If the volume changed to $10m^3$ by decreasing load on the piston. What will the pressure of the gas become? Assume that its temperature remains constant.
9. Air at atmospheric pressure of 760 mm of Hg is trapped inside a container available with a moveable piston. When the piston is pulled out slowly so that the volume is increased from $100dm^3$ to $150dm^3$, the temperature remaining constant. What will be the pressure of the air becomes?