Chapter 9 – Kinetic Model of Matter

Subject content

Content
- States of matter
- Brownian motion
- Kinetic model

Learning outcomes
(a) compare the properties of solids, liquids and gases
(b) describe qualitatively the molecular structure of solids, liquids and gases, relating their properties to the forces and distances between molecules and to the motion of the molecules
(c) infer from a Brownian motion experiment the evidence for the movement of molecules
(d) describe the relationship between the motion of molecules and temperature
(e) explain the pressure of a gas in terms of the motion of its molecules
(f) recall and explain the following relationships using the kinetic model (stating of the corresponding gas laws is not required):
  (i) a change in pressure of a fixed mass of gas at constant volume is caused by a change in temperature of the gas
  (ii) a change in volume occupied by a fixed mass of gas at constant pressure is caused by a change in temperature of the gas
  (iii) a change in pressure of a fixed mass of gas at constant temperature is caused by a change in volume of the gas
(g) use the relationships in (f) in related situations and to solve problems (a qualitative treatment would suffice)

Definitions

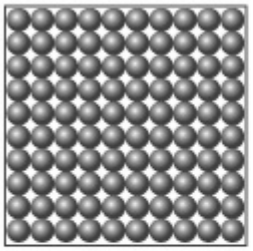
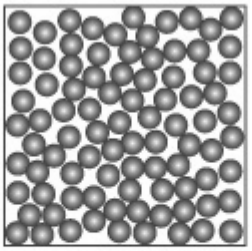
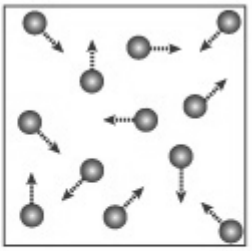
Term	Definition	SI unit
Kinetic model of matter	Matter is being made up of particles in continuous random motion	

Formulae

Ideal gas pressure			
$P = R(\frac{nT}{V})$ where P = pressure (Pa) n = number of moles (mol) T = temperature (K) V = volume (L) R = gas constant			
Avogadro's Law	Gay Lussac's Law	Charles's Law	Boyle's Law
$\boldsymbol{P \propto n}$	$\boldsymbol{P \propto T}$	$\boldsymbol{V \propto T}$	$\boldsymbol{P \propto \frac{1}{V}}$

9.1 Kinetic Model of Matter

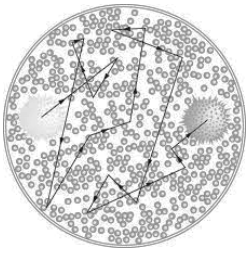
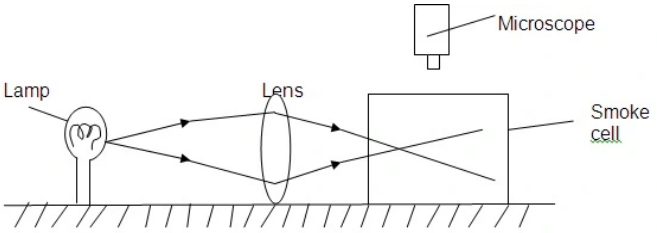
Molecular structure of solids & liquids & gases:

Characteristics	**Solids**	**Liquids**	**Gases**
Arrangement of particles	regular pattern	not in regular pattern (randomly)	not in regular pattern (randomly)
Distance between particles	close together	still close together but separation is slightly larger	far apart
Attractive force between particles	very strong	strong	negligible
Motion of particles	limited to vibrations about fixed position	slide past each other randomly and freely	independent random motion, spread to fill space available
Molecular structure			

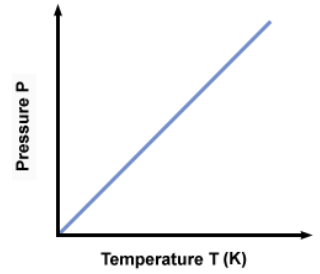
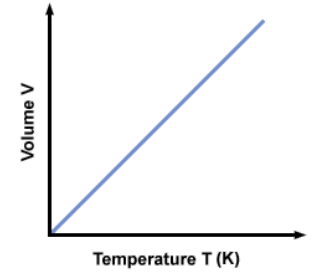
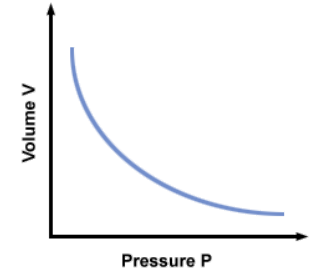
Brownian motion

Brownian motion

- Particles in liquids and gases (collectively called fluids) move randomly
  - Large particles move in random / haphazard zigzag manner
  - Unevenly bombarded by light air molecules
    (moving continuously + randomly at high speeds)
- Experiments:

Pollen grains in water	Smoke particles illuminated
	

9.2 Gas Laws

Gas law	Explanation	Graph
Gay Lussac's Law $P \propto T$ When volume of fixed mass of gas remains constant, change of gas pressure is directly proportional to change in temperature	Temperature increases: ● Average kinetic energy of particles gain kinetic energy → greater speed ● More forceful + frequent collisions with walls of container ● Average force per unit area exerted by particles increase → greater pressure	
Charles's Law $V \propto T$ When pressure of a fixed mass of gas remains constant, change of gas volume is directly proportional to change in temperature	Temperature increases: ● Average kinetic energy of particles gain kinetic energy → greater speed ● More frequent collisions with walls of container ● Average force per unit area exerted by particles increase → greater pressure inside container ● Trapped gas expand → average spacing between particles and walls increase ● Less frequent + more forceful collisions with walls of container ● Gas pressure inside container decrease = atm pressure outside	
Boyle's Law $P \propto \frac{1}{V}$ When temperature of fixed mass of gas remains constant, change of gas pressure is inversely proportional to change in volume	Volume decreases: ● Number of particles per unit volume increases (average spacing between particles & walls decrease) ● More frequent collisions with walls of container ● Average force per unit area exerted by particles increase → greater pressure	

Typical questions

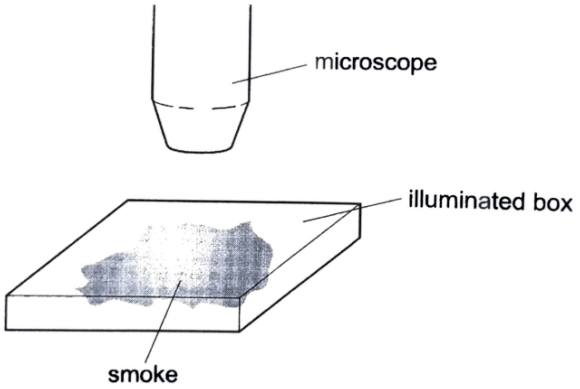
Multiple choice questions

1 Oxygen can be supplied to a fish tank by bubbling air into the water.
What happens to the pressure and the volume of air bubbles while they are rising?

(2011 P1 Q15)

	pressure	volume
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

2 The diagram shows a small glass box containing some air and smoke. A microscope is used to observe the smoke.



What is seen through the microscope? (2012 P1 Q18)

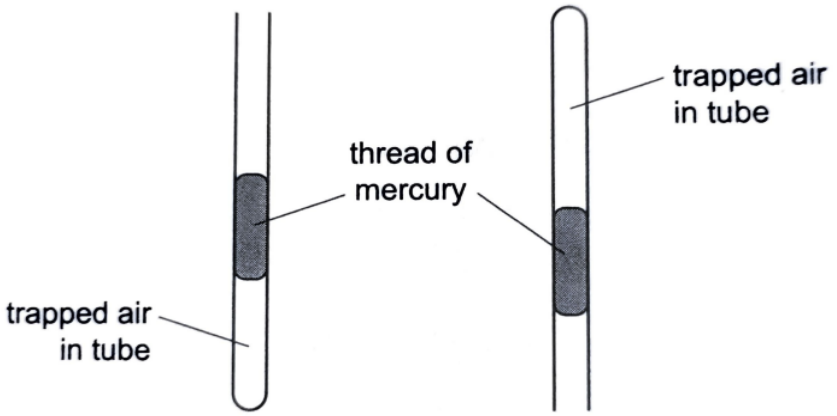
A random movement of air molecules
B random movement of smoke particles
C regular movement of air molecules
D regular movement of smoke particles

3 Sunlight falls on a tyre of a parked car. The tyre has constant volume.
What effect does this have on the pressure, temperature and mass of the air inside the tyre?

(2013 P1 Q19)

	pressure	temperature	mass
A	increases	increases	increases
B	increases	increases	no effect
C	increases	no effect	no effect
D	no effect	increases	increases

4 A thin tube contains a thread of mercury which traps air at the end of the tube. The other end of the tube is open to the atmosphere.



When the tube is turned upside down, the volume of the trapped air increases.
Which statement explains this? (2014 P1 Q14)

A The air gets hotter when the tube is turned upside down.
B The atmosphere pushes less when it acts upwards on the mercury.
C The pressure of the trapped air is reduced.
D The trapped air molecules hit the mercury harder when travelling downwards.

5 Air in a closed container contains smoke, illuminated by bright light. When viewed through a microscope, bright specks of light are seen moving at random.
Which statement is correct? (2015 P1 Q14)

A The random motion of the specks is faster in a vacuum.
B The specks move faster when the air is at a higher temperature.
C The specks seen are molecules of air in rapid random motion.
D When the light is turned off, the specks slow down and stop moving.

6 Smoke particles in the air are illuminated by a beam of light and viewed through a microscope. The smoke particles undergo jerky random motion.
What causes this motion? (2016 P1 Q15)

A atomic vibrations within the smoke particles
B collisions between the smoke particles
C impacts of fast-moving air molecules
D the energy of the beam of light

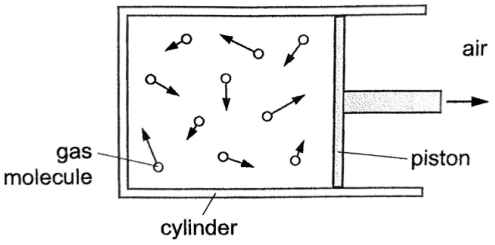
7 The pressure of a gas in container P is increased by heating the gas at constant volume.
The pressure of a gas in container Q is increased by reducing the volume of the gas at constant temperature.
Which row describes the effect on the collisions of the gas molecules with the walls of each container? (2016 P1 Q16)

	collisions in container P	collisions in container Q
A	harder and more frequent	harder
B	harder and more frequent	more frequent
C	harder and less frequent	harder
D	harder and less frequent	more frequent

8 Which row explains why a liquid has a fixed volume but does **not** have a fixed shape?
(2016 P1 Q17)

	force between molecules in the liquid	movement of molecules in the liquid
A	large	move throughout the liquid
B	large	vibrate at fixed positions
C	small	move throughout the liquid
D	small	vibrate at fixed positions

9 Gas inside a cylinder is heated slowly to a higher temperature and the piston moves outwards.



As the volume increases, the pressure of the gas remains constant.
What happens to the speed of the gas molecules and their rate of collision with the piston?
(2017 P1 Q15)

	speed of molecules	rate of collision
A	increases	decreases
B	increases	increases
C	increases	stays constant
D	stays constant	increases

10 What happens to the molecules of mercury when it freezes? (2017 P1 Q17)

A They attract each other more strongly.
B They expand.
C They get smaller.
D They stop moving.

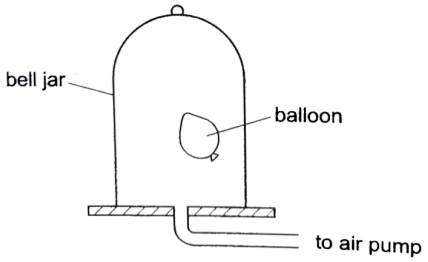
11 A fixed mass of gas is kept at constant temperature.
When the volume of the gas decreases, the pressure increases.
Why is this? (2018 P1 Q18)

A The molecules are closer together and they collide more frequently.
B The molecules are closer together and they move faster.
C The molecules move more quickly and they collide more frequently.
D The molecules move more quickly and they hit each other harder.

12 Brownian motion can be observed by the behaviour of smoke particles in a smoke cell.
What is this evidence for? (2019 P1 Q16)

A Air is a poor conductor.
B Air molecules are moving.
C Air molecules have more mass than smoke particles.
D Convection occurs in air.

13 A partially inflated balloon is placed inside a bell jar. The bell jar is connected to an air pump.



The air pump is switched on and air is pumped into the bell jar. The pressure in the bell jar is increased.
What happens to the pressure and to the volume of the gas inside the balloon?
(2019 P1 Q17)

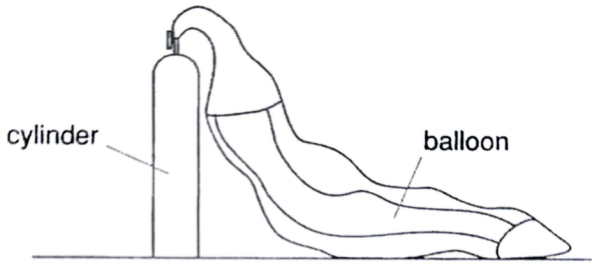
	pressure	volume
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

14 Stars form in space from huge clouds of hydrogen atoms that attract each other because of the force of gravity.
As the atoms attract, the cloud gets smaller and the atoms move faster.
What effect will this have on the temperature and the pressure in the cloud?

	pressure	volume
A	decreases	decreases
B	increases	increases
C	increases	no change
D	no change	increases

Structured questions

1 The figure below shows a weather balloon. The balloon is shown partly filled with a gas from a cylinder.



The balloon contains no gas initially. When it is connected to the cylinder, gas enters the balloon. The pressure in the cylinder decreases. Explain why the molecules inside the cylinder

(a) exert a large pressure initially;

- The number of gas molecules per unit volume in the cubic cylinder is high before it is connected to the balloon.
- Gas molecules collide with the container wall more frequently, exerting a force on the wall.
- The average force exerted per unit area is also high. Hence, a large pressure is exerted.

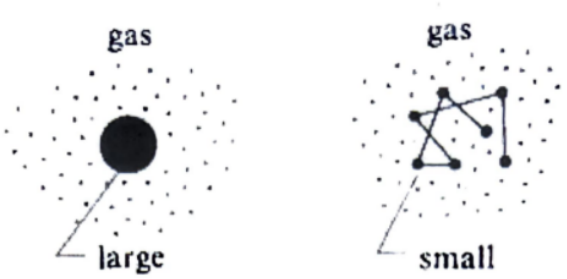
(b) exert a smaller pressure in the cylinder when the balloon is filled.

- There are less molecules per unit volume in the cylinder when the balloon is being filled.
- Gas molecules collide with the container wall less frequently.
- The average force exerted per unit area is lesser. Hence, a smaller pressure is exerted in the cylinder.

2 A balloon is filled with helium gas. The balloon is released and it floats up into the air. As the balloon rises higher, it is observed that the size of the balloon increases. Assume that there is no change in temperature, explain the change in pressure using the kinetic theory of matter.

As the balloon rises into the air, the pressure in the surrounding decreases and this causes the balloon to expand. When the balloon expands, the number of helium molecules per unit volume decreases, the helium molecules will collide less frequently with the wall of the balloon. The average force per unit area exerted will be lesser. Pressure inside the balloon decreases to be at equilibrium with the environment.

3 A large particle suspended in a gas as shown in the left figure below does not move, but a very small particle as shown in the right figure below moves in an irregular way.



(a) What is this phenomenon?

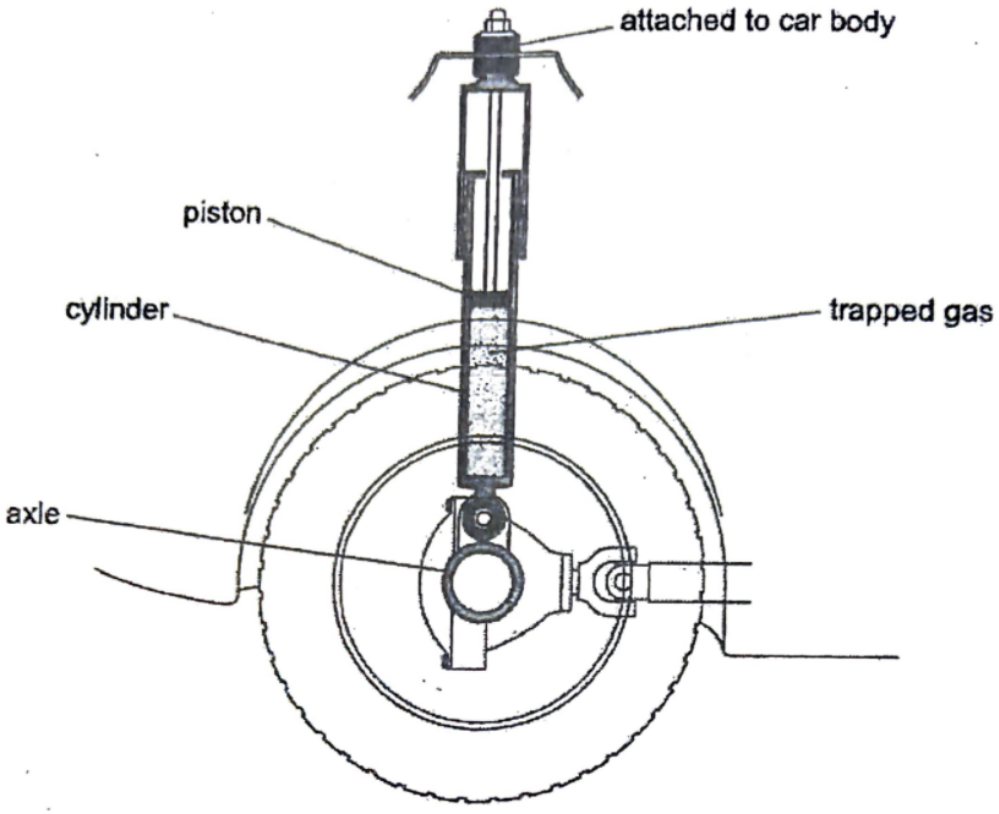
Brownian motion

(b) Explain why this happens.

- Small particles bombarded by air molecules move randomly in all directions. Large number of bombardments on different sides of the big particle cancel out the effects of the impacts.
- Furthermore, the mass of the big particle is larger, hence the average force exerted by the air molecules may not be large enough to displace it.

4 A car has a gas-filled shock absorber for each of its four wheels. The figure below shows one of these shock absorbers.

The axles are attached to the cylinder. The body of the car is supported by the four pistons, which can move up and down inside the cylinders. Each piston has a cross-sectional area of 35 cm^2.



(a) Explain in detail, how the gas molecules trapped inside the cylinder by the piston exert a pressure on the cylinder.

The gas molecules are in continuous random motion and they collide with the cylinder walls, exerting a force on the wall. As there are many such collisions taking place at the same time, the average force per unit area exerted by these gas molecules give rise to pressure.

(b) The temperature of the trapped gas remains constant. Explain why the pressure of the gas increases as the piston is moved further into the cylinder.

P-T:

At constant temperature, the volume of gas decreases, hence there are more gas molecules per unit volume (OR spacing between molecules and walls is reduced). This would result in an increase in frequency of collisions between the molecules and the walls, thus increasing the average force per unit area exerted on the walls, leading to greater gas pressure.

(c) At the end of a long journey, the temperature of the trapped gas in the shock absorbers has increased substantially.

(i) State what happens to the molecules of the trapped gas due to the temperature increase.

Speed of molecules increase

OR

Kinetic energy of molecules increase

(ii) State and explain the effect of the increased temperature of the gas on the height of the car body above the road surface.

V-T:

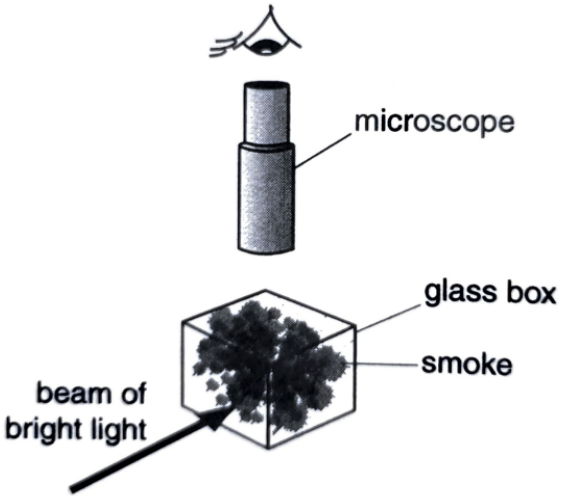
As temperature increases, the gas molecules move faster, colliding with the piston and walls more frequently and thus exert a greater average force. This leads to an increase in the pressure of the gas initially, leading to expansion of the gas and the movement of the piston upwards.

5 The kinetic energy of the gas is related to its thermal energy. When the container is heated, the kinetic energy of the gas will increase. Describe and explain the effect on the pressure of the gas when the container is heated, given that the volume of the container remains constant.

P-T:

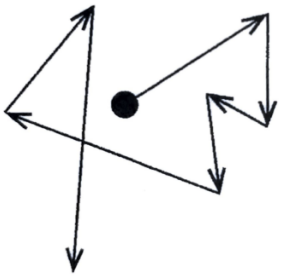
- At constant volume, as temperature increases, the gas molecules have greater kinetic energy.
- They move at greater speeds and collide with the walls of the container more frequently.
- The average force per unit area exerted by the gas molecules on walls of the container increases.
- This leads to an increase of the pressure of the gas when the container of fixed volume is heated.

6 An experiment to show the Brownian motion of smoke particles in air is illustrated in the figure below.



The smoke particles move randomly. The motion is caused by air molecules colliding with the smoke particles. (2014 P2A Q4)

(a) In the space below, draw the movement of a smoke particle seen through the microscope. [1]



(Zig zag motion of the smoke particle)

(b) State two reasons why collisions between air molecules and smoke particles cause the smoke particles to move randomly. [2]

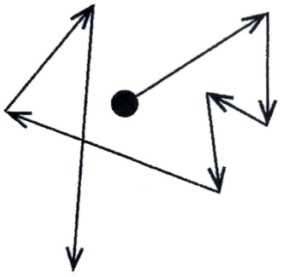
- The air molecules are in constant random motion.
- The air molecules bombard the smoke particles from all directions.

(c) When the temperature of the air inside the glass box increases, the molecules move faster. Explain why this increases the pressure of the air. [2]

P-T:

- When the molecules move faster at higher temperature, they collide with the walls of the container / box more frequently and forcefully.
- As a result the average force acting on the walls of the container / box per unit area increases, thus increasing the pressure.

7 In a Brownian motion experiment, particles of smoke are introduced into a container of air. A microscope is used to view the smoke particles. The air molecules in the container cannot be seen using the microscope, but they collide with the smoke particles.
The figure below shows the path of a smoke particle. (2018 P2A Q4)



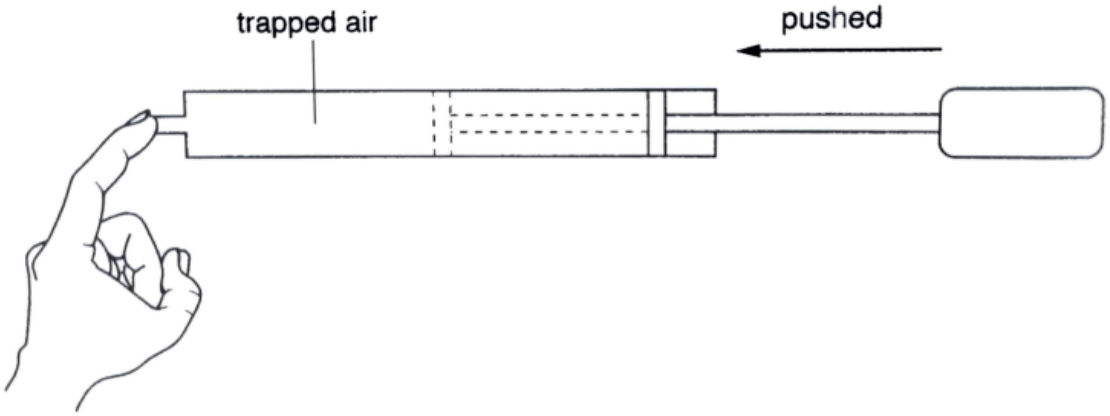
(a) State what can be concluded about the movement of the air molecules from the path shown in the figure above. [1]

The movement of the air molecules is constant and random.

(b) The mass of an air molecule is very small. The pressure created by the air molecules as they collide against the sides of the container is large. Explain how the air molecules create a large pressure. [3]

- Air molecules move about freely and randomly in the container at high speeds.
- When they collide with the sides of the container, they exert a force on the container.
- Due to the large number of air molecules colliding with the sides of the container at a high rate, a large force is exerted on the sides of the container, which when averaged by the area of the container, creates a large pressure.

8 A student pushed inwards the piston of a bicycle pump with his finger blocking the other end, as shown in the figure below.



The temperature of the trapped air remains constant.
The volume of the trapped air decreases and its pressure increases. (2019 P2A Q4)

(a) Using ideas about molecules, explain why the pressure increases. [2]

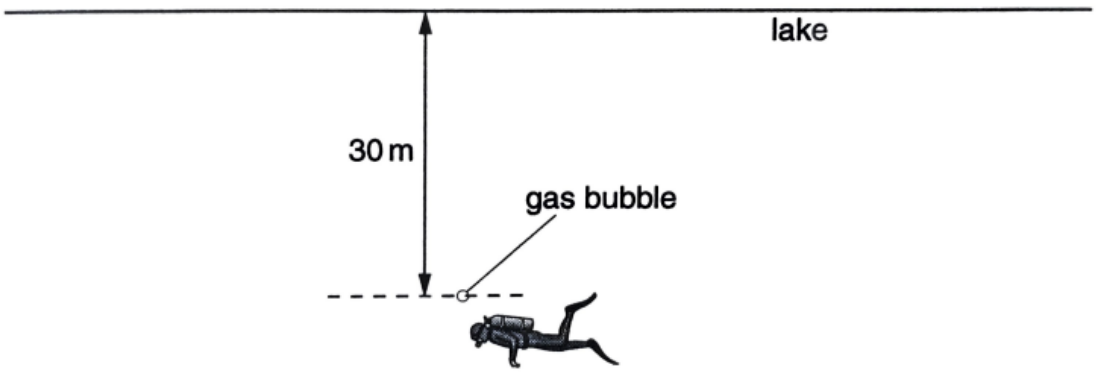
P-V:

- As the volume decreases, the density of the trapped air increases.
- This increases the rate of collision between the air molecules and the walls of the piston, as there are more molecules per unit volume now.
- As such, a greater force is exerted on the walls of the piston per unit area, which gives a larger pressure.

(b) He repeats the experiment with the bicycle pump filled with water instead of air. He applies the same force and the volume of water does not change. Using ideas about molecules, explain why the volume of water does not change. [2]

- Water molecules are closely packed with no long range order.
- As a result, when a force is applied on water, the molecules are unable to move any closer to one another, and thus there is no change in its volume.

9 A bubble of gas rises from a diver to the surface of a lake, as shown in the figure below.

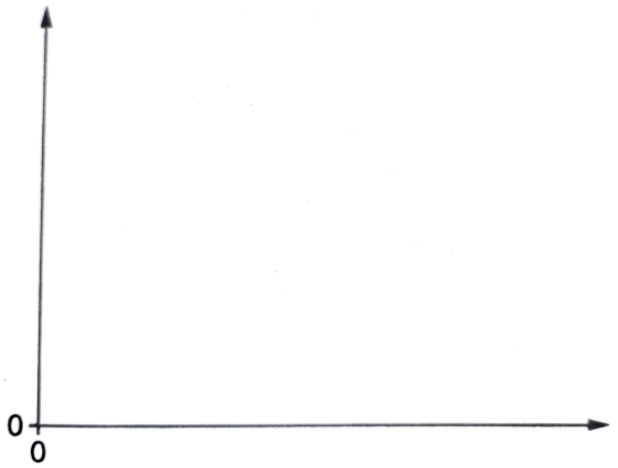


The bubble is 30 m below the surface of the lake.
As the bubble rises, the temperature remains constant. (2013 P2B Q12b OR)

(a) State the relationship between the pressure of the gas in the bubble and the volume of the bubble. [1]

Pressure of the gas in the bubble is inversely proportional to the volume of the bubble.

(b) On the figure below, sketch a graph to show the relationship between the pressure of the gas in the bubble and the volume of the bubble. [1]



(Note: Pressure is inversely proportional to volume. Therefore when the volume increases, the pressure decreases, provided the temperature remains constant.)

(c) Using ideas about molecules, explain

(i) how the gas inside the bubble creates a pressure; [2]

- The gas molecules inside the bubble are moving about randomly, and constantly at high speeds.
- When the molecules collide with the surface (air-water boundary) of the bubble, they exert a force on the surface.
- The numerous collisions of the molecules average over the surface area of the bubble creates a pressure.

(ii) why the pressure changes as the volume of the bubble increases. [1]

P-V:

- As the volume of the bubble increases, the gas molecules are spread over a bigger volume.
- This means that in the same volume, there are now lesser gas molecules,
- which results in fewer collisions with the surface of the bubble,
- thus the pressure decreases.