Kinetic Model of Matter

Learning Outcomes

Candidates should be able to:

(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

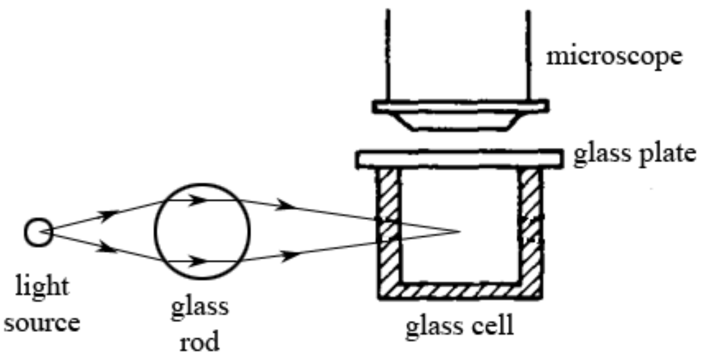
(f) recall and explain the following relationships using the kinetic model (stating of the corresponding gas laws is not required):
- (i) a change in pressure of a fixed mass of gas at constant volume is caused by a change in temperature of the gas
- (ii) a change in volume occupied by a fixed mass of 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

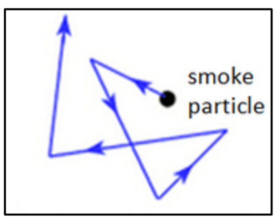
(g) use the relationships in (f) in related situations and to solve problems (a qualitative treatment would suffice)

Relate molecular structure (arrangement, force, motion and distance between particles) and properties of solids, liquids and gases

	Force and arrangement of particles	Properties
Solid	Particles are closely packed Held by strong attractive forces Vibrate about fixed positions	High density Fixed shape and volume Incompressible
Liquid	Particles are slightly farther apart compared to in solids and randomly arranged Free to move over one another Strong attractive forces	High density Fixed volume but no fixed shape Incompressible
Gas	Particles are far apart and randomly arranged Free to move at high speeds Weak forces of attraction between particles	Low density No fixed volume and shape Compressible

Evidence for movement of molecules (Brownian motion)

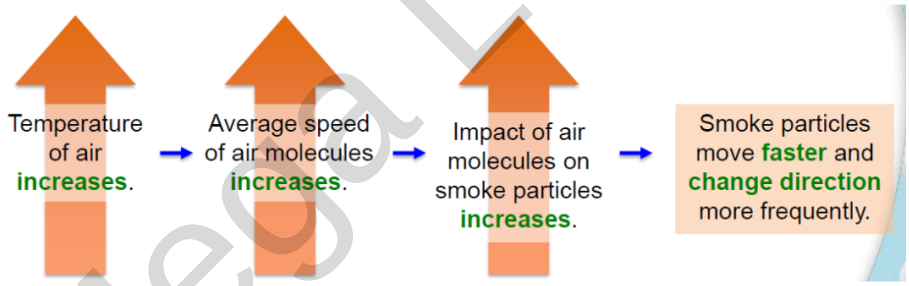




- **Experiment**: observe smoke trapped in the glass cell under a microscope
- **Observations**:
    - smoke particles appear as bright dots because they scatter the light that shines on them
    - smoke particles move in random directions
    - the larger the particles the less agitated the motion
- **Deduction**:
    - The smoke particles moved randomly because they were being bombarded by many air molecules in all directions. The air molecules are too small to be seen
- **Conclusion**:
    - Brownian motion refers to the **random motion** of particles, such as pollen and dust specks, suspended in fluids (e.g. air, water).
    - This random motion is due to the fluid particles moving about randomly and bombarding the suspended particles.

Relationship between motion of molecules and temperature

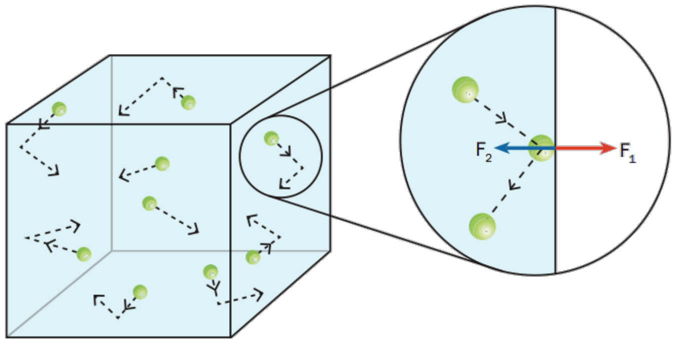
- When a substance is heated, it gains thermal energy.
- The thermal energy gained increases the random kinetic energy of the molecules
- Hence when temperature increases, kinetic energy and speed of molecules increase



Assumptions of the kinetic model of an ideal gas (not tested)

- The gas consists of a very large number of identical molecules
- The volume of the molecules is negligible compared with the total volume occupied by the gas
- The molecules are moving in completely random directions, at a wide variety of speeds
- There are no forces between the molecules
- The total kinetic energy of the molecules remain constant at the same temperature

Pressure of a gas (Recall P = F/A)

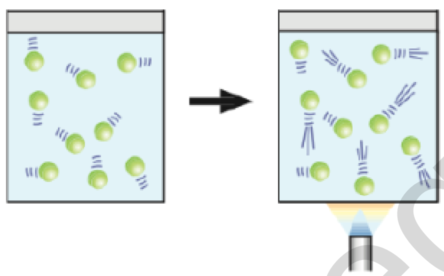


- Moving gas molecules collide with the **inner wall** of the container and exert a force on it.
- The **force exerted per unit area** is the called gas pressure.

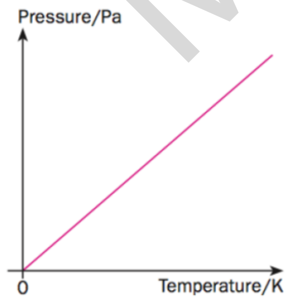
[Note: Each and every collision can result in a different sized force, and it is not realistic to know all the forces that individual molecules exert on the walls. However, because the molecular motions are random and because of the very large number of them, the total force caused by many molecular collisions on any unit area of the container wall will be completely predictable and will (usually) be constant at all places in the container.]

Relationship between Pressure, Volume and Temperature of a gas

1. **Pressure and temperature (keeping volume constant)**

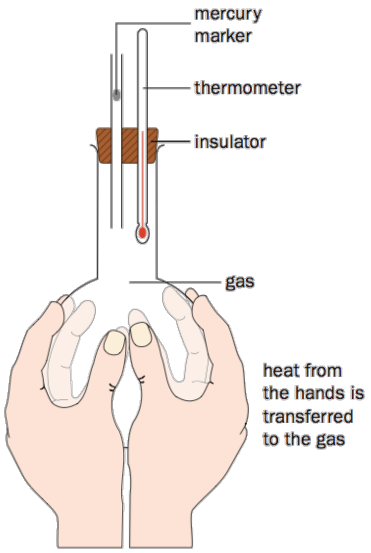


- At a higher temperature, the air molecules have greater speeds (greater average **kinetic energy**).
- The air molecules will then bombard the walls of their container **more forcefully** and **more frequently**.
- This causes an **increase** in gas pressure inside the container.



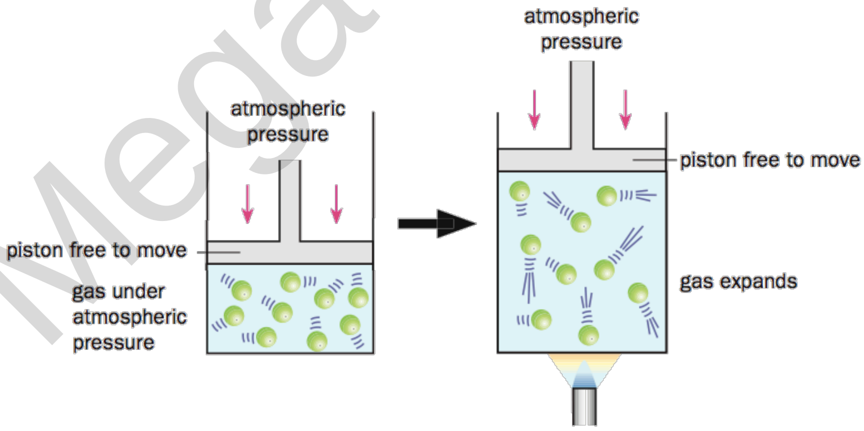
The **pressure *p*** of a **fixed mass** of gas is **directly proportional** to its **temperature *T*** at **constant volume**.

2. Volume and temperature (keeping pressure constant)

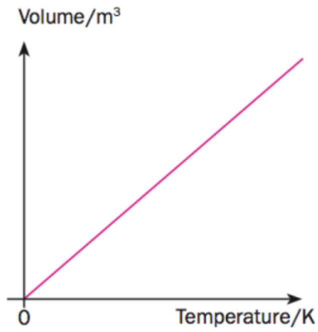


- The glass tube allows the gas in the round-bottomed flask to expand.
- An increase in the gas volume can be observed by the rise of the coloured water droplet.

- When the air is heated, the increased temperature causes the air molecules to move at **higher speeds**.
- The air molecules will then bombard the walls of their container **more forcefully** and **more frequently**. In other words, the gas pressure **increases**.
- **To maintain a constant pressure**, the air **expands** and the air molecules move farther apart. As the air molecules occupy a larger volume, they collide with the walls less frequently, resulting in a decrease in pressure.
- The pressure will stop decreasing when it is **equal to the atmospheric pressure** again.

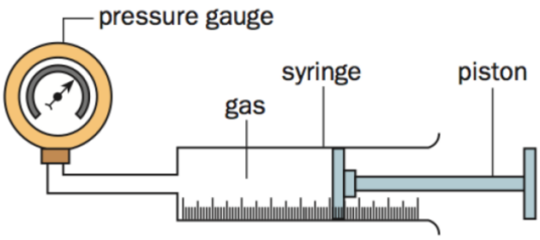


	Before heating	After heating	Explanation and conclusion
Volume	Constant	Increases	
Frequency of collision	Higher	Lower	Molecules move faster and farther apart hence colliding with the walls less frequently
Force of collision	Lower	Higher	Temperature increases so KE increases and force of impact with walls increases
Gas Pressure	Atmospheric pressure	Atmospheric pressure	Remains unchanged

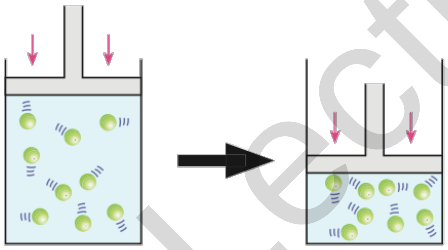


The **volume *V*** of a **fixed mass** of gas is **directly proportional** to its **temperature *T*** at **constant pressure**.

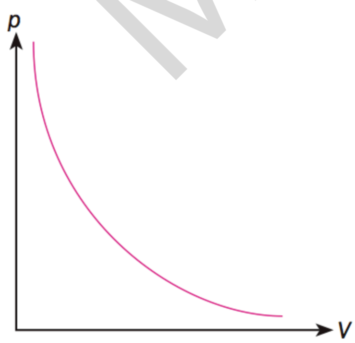
3. Pressure and volume (temperature remains constant)

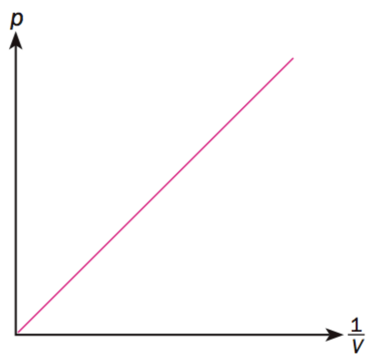


The pressure of the gas inside the syringe is increased by slowly pushing the piston inwards (to compress the gas).



- When the volume of the gas is **decreased**, the number of air molecules per unit volume **increases**.
- The air molecules will therefore bombard the walls of the container **more frequently**.
- This causes an increase in the **average force** exerted on the walls of the container, and hence an increase in the **gas pressure**.





The **pressure *p*** of a **fixed mass** of gas is **inversely proportional** to its **volume *V*** at **constant temperature**.

Question 1

Some gas is trapped in a container. Use the kinetic model of matter to explain and predict the changes in the gas pressure for the following cases. State any assumptions you made to arrive at your answer.

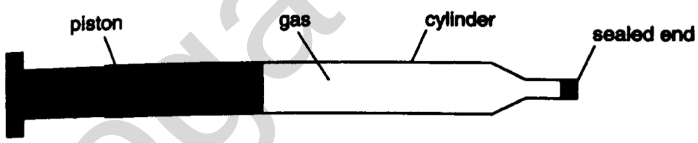
1. The container that holds the gas is rigid (i.e. its volume is constant), and the gas is heated.

2. The container that holds the gas is able to expand freely (i.e. its volume is not constant), and the gas is heated.

3. The container that holds the gas is flexible (i.e. its volume is not constant), and the gas volume is increased.

Question 2

The figure shows a syringe that contains gas at the same pressure as the air outside. The piston moves freely along the piston without any friction. No gas escapes.



As the syringe is heated from 20°C to 100°C, the piston moves outwards. It stops moving when the temperature is steady. State how the value of each of the following quantities compares at 100°C, after the piston stops, with its value at 20°C. For each quantity, you should write *greater*, *the same* or *less*.

The average distance between the gas molecules	
The pressure of the gas after the piston stops	
The average speed of the gas molecules	
The frequency of the collisions between the gas molecules and the piston	