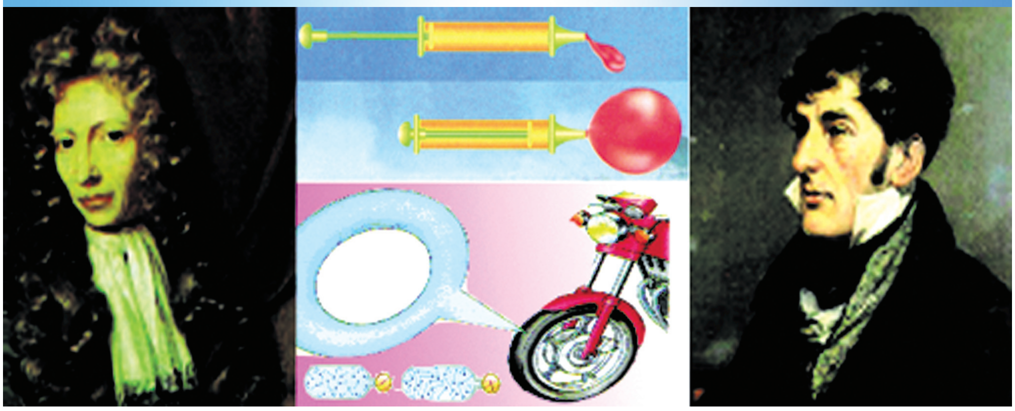
Chemistry

1. Factors affecting the behavioural patterns of gases



At the end of this chapter, you will be competent to:

- Investigate the arrangement of particles in solids, liquids and gases
- Investigate the effect of temperature, pressure, volume and quantity of matter on the behaviour of gases
- Analyse the pattern of variation of volume of a constant mass of gas with changing pressure at constant temperature
- Analyse the pattern of variation of volume of a constant mass of gas with changing temperature at constant pressure

1.1 Factors affecting the behaviour of gases

Matter is anything that occupies space and has a mass. Matter exists in three physical states, solid, liquid and gas. By now, you know that all matter is composed of particles.

Solids have a fixed shape as well as a fixed volume. But water or any other liquid when poured into a container takes the shape of the part of container which is below the liquid level. Liquids do not have a fixed shape but have a fixed volume Liquids flow easily.

Activity 1.1

Under the guidance of your teacher, add concentrated nitric acid to copper turnings, and collect the nitrogen dioxide gas evolved, into three vessels of different shapes (test tube, reagent bottle, round bottomed flask). Close the vessels and observe.

When the gas is collected into different vessels, it occupies all the space inside the vessel. Also, it takes the shape of the container. This proves that the gases have neither a fixed shape nor a fixed volume.

Arrangement of particles in solids, liquids and gases

Based on the observable changes of solids, liquids and gases, a picture can be made with regard to the behaviour of particles in these three states. The attractive forces among the particles are strongest in a solid, so the particles are close together and arranged in a fixed pattern. But in liquids, these attractive forces are weaker than in a solid. Therefore, the particles are not as close as in a solid, but much more closer than in a gas. Thus they are loosely packed and have a freedom of moving.

In gases, particles are neither closely packed nor orderly arranged. The attractive forces among the particles are very weak. So they can move freely and randomly with different speeds.

When compared to liquids and solids, the interparticle distances among gaseous particles are very high. Therefore unlike solids and liquids gases can be compressed easily.

When a gas is enclosed in a container, the moving particles of gases (molecules) collide with the wall of the container. These collisions exert pressure on the wall of the container in every direction.

Fig 1.1

As the rate of striking of molecules on the wall of the container is increased, the pressure exerted by the gas too increases. When the rate of collision of molecules is decreased the pressure also decreases.

The behaviour of a gas is affected by temperature, pressure, volume and the amount of substance. This section investigates how the behaviour of a gas changes when the above factors are changed. Here, the relationship between two factors are considered at a time keeping others constant.

Variation of temperature (T) versus pressure of a fixed amount of a gas of constant volume

Activity 1.2

Set up the apparatus as shown in the Fig 1.2, and heat the test tube with a Bunsen burner keeping the stopper away from the body. The stopper will be thrown out of the test tube due to the increase of pressure inside the test tube. This shows that the pressure of a gas increases when the temperature is increased.

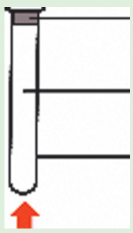
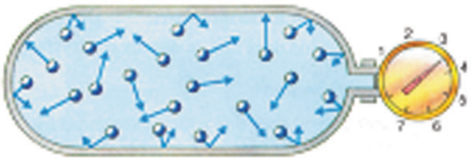


Fig 1.2

As the temperature of a gas is increased, the speed of the gas molecules too is increased. Therefore, the number of collisions of gas molecules per unit time per unit area is also increased. As a result the pressure increases.


Low temperature - low pressure


High temperature - high pressure

Fig 1.3

Variation of volume with temperature of a fixed amount of a gas at constant pressure

Activity 1.3

Take two identical bottles and two similar balloons. Set up the apparatus as shown in the Figure 1.4. Keep one bottle in hot water and the other in cold water. Observe what happens.

Volume of the balloon fixed to the bottle in hot water increases.

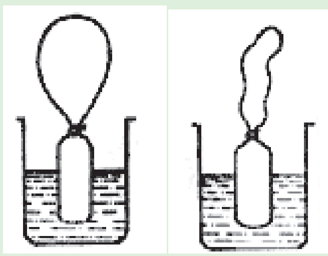


Figure 1.4

This shows that volume increases as the temperature increases.

The variation of volume with presure of a fixed amount of a gas at constant temperature

Close the hole at one end of a bicycle pump with a finger and push the piston in. You will sense increasing pressure (Fig 1.5).

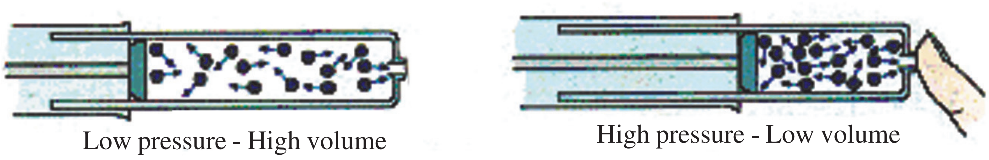


Figure 1.5

When the volume of a fixed amount of a gas at a constant temperature is decreased, its pressure increses. When the volume is increased the pressure decreases.

The relationship between amount of a gas and the pressure, under constant temperature and volume

Activity 1.4

Pump air into a deflated tube with a suitable pump and observe what happens to the hardness.

Figure 1.6

It is clear that hardness of the tube is increased due to the increase of pressure inside the tube.

Pressure of a gas is due to the collision of moving molecules upon the walls of the container. Larger number of molecules, increases the number of collisions, thus exerting a higher pressure.

Activity 1.5

Blow a small amount of air into a ballon; touch it and observe the hardness. Blow more air into it and touch. How do you feel?

You may observe that the hardness of the ballon is increased due to increase of pressure.

Hence, the pressure of a gas at constant volume and temperature increases with the amount of the gas.

The relationship between the amount of a gas and the volume under constant pressure and temperature

Activity 1.6

Blow air into a balloon with an air pump as shown in the Figure 1.7. The volume of the air inside the pump gradually decreases and the volume of air inside the balloon gets increased. Hence it can be understood that when the amount of air inside the baloon increases, its volume also increases.

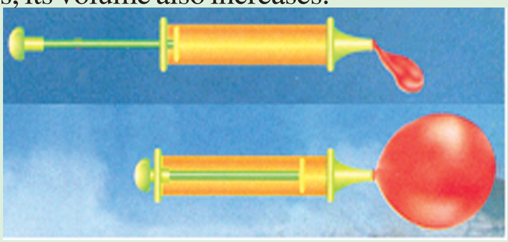


Figure 1.7

From the foregoing activities, it is clear that the factors like temperature (T), pressure (P), volume (V) and amount of substance (n) affect the behaviour of a gas.

1.2 Behavioural patterns of gases

We know that the temperature, pressure, volume and the amount of the substance affect the behaviour of gases. Now let us investigate the quantitative relationships among these factors.

The relationship between the pressure and the volume of a fixed amount of a gas at constant temperature

Take a narrow glass tube about 100 cm in length closed at one end.

Introduce a column of mercury into it as shown in Fig.1.8 (a). Keep this tube horizontally on a table and measure the length (1) of the air column trapped in the tube.

As the tube is uniform, the volume of air trapped in the tube is proportional to the length of the tube. As the tube is kept horizontal the pressure of air in the tube is equal to the atmospheric pressure.

Now turn the closed end of the tube downwards, keep it vertical, and measure the length of the air column. Now the pressure on the air column is equal to the surm of the atmospheric pressure and the pressure of the mercury column.

Then, turn the open end of the tube downwards and measure the length of the air column. Here the pressure exerted on the air column is equal to the value obtained by subtracting the pressure of the mercury column from the atmospheric pressure.

Find out the volume of the fixed amount of air at different pressures and draw a graph.

The graph will be as in Fig. 1.9.

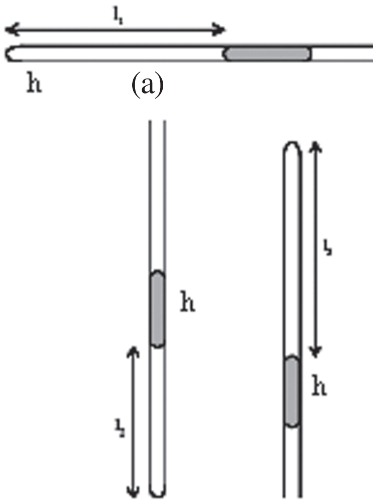


Figure 1.8

Figure 1.9

It is seen that when the pressure increases, volume decreases.

If we plot pressure against the reciprocal of the volume, ($\frac{1}{V}$), the result will be a straight line passing through the origin (Fig 1.10).

From this we know that the volume of a given fixed amount of gas is inversely proportional to the pressure to which it is subjected if the temperature is constant.

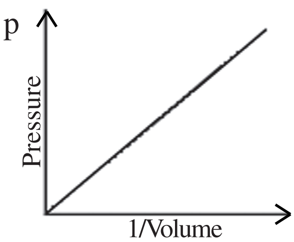


Figure 1.10

In other words, if the pressure is doubled, the volume is halved and if the pressure is increased four times the volume is reduced to one-fourth.

This relationship was first discovered by the scientist named Robert Boyle in 1661 and hence is known as **Boyle's law.**

According to Boyle's law: $p \propto \frac{1}{V}$

$$\therefore P = k \times \frac{1}{V}$$

$$\therefore PV = k$$

Boyle's law states that, under constant temperature, the product of the pressure(P) and volume(V) of a fixed amount of a gas is a constant.

Worked example:

The volume of a fixed amount of a gas is 600 cm^3 at a pressure of 76 cm Hg. What will be the volume, if the pressure is increased to 152 cm Hg, keeping the temperature constant?

Figure 1.11 Robert Boyle

$PV = k$

$P_1V_1 = k$

$P_2V_2 = k$

$\boxed{P_1V_1 = P_2V_2}$

$76\ cmHg \times 600\ cm^3 = 152\ cm\ Hg \times V_2$

$V_2 = \frac{76 \times 600}{152}\ cm^3$

$= 300\ cm^3$

Relationship between volume and temperature of a fixed amount of a gas at constant pressure

Activity 1.7

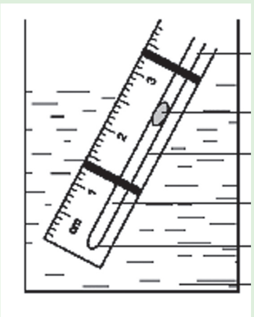


Figure 1.12

Take a narrow tube closed at one end. Introduce a drop of sulphuric acid or mercury into it and keep it in a beaker which contains water as shown in Figure 1.12. Place a thermometer in the beaker. Heat the beaker and measure the length of the air column at different temperatures. Here the pressure of the gas is a constant. It is equal to the sum of the atmospheric pressure and the pressure due to the weight of the mercury or acid column.

From this experiment, we see that there is a relationship between the volume of the gas and its temperature.

This relationship was first discovered by the French scientist Charles in 1787. It is called Charles' law.

Fgure 1.13 Charles

Charles' law states that the volume (V) **of a fixed mass of gas is directly proportional to the temperature expressed in Kelvin (T), when the pressure of the gas is constant.**

$V \ \alpha \ T$

Therefore, V/T = constant

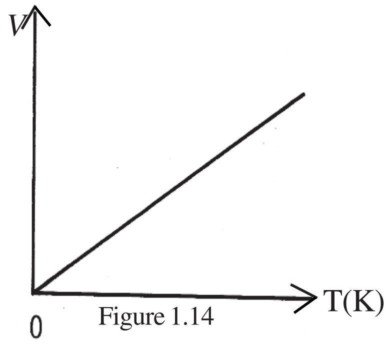


Figure 1.14

$$\frac{V}{T} = k$$

$$V = kT$$

If the volume of a fixed amount of a gas under constant pressure is V_1 at temperature T_1 and V_2 at temperature T_2,

$$\frac{V_1}{T_1} = k$$

$$\frac{V_2}{T_2} = k$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Worked example:

Volume of a fixed amount of a gas is 600 cm^3 at 300 K. If the pressure is kept constant what will be the volume of the gas at 400 K ?

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{600cm^3}{300K} = \frac{V_2}{400K}$$

$$V_2 = \frac{400 \times 600}{300} cm^3 = 800\ cm^3$$

Exercise

1. i) State one common property for solids and liquids and explain the reason for it.

   ii) State two special properties of gases which are not found in solids and liquids.

   iii) The smell of a perfume dabbet on on cotton wool spreads quickly throughout a room. Explain.

   iv) Diffusion rates of gases are higher than those of liquids. Explain why this is so.

2. i) What are the factors affecting the behaviour of gases?

ii) State how the number of molecules affect the volume, the pressure and the temperature of a gas.

iii) Describe how the pressure of a gas affects its volume.

3. i) When an air bubble rises up in water it becomes larger gradually. Explain why.

ii) The volume of air in a bicycle pump at a pressure of 1×10^5 Pa is 60 cm^3? What will be the volume of air in the pump at a pressure of 1.5×10^5 Pa if the temperature does not change.

iii) Give an activity to show that the pressure increases with the increase in temperature.