1 THE GASEOUS STATE

Have you seen the picture?

* What could be the reason for the balloons rising upward?

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* In which state does the matter inside the balloon exist?

You have studied that the different physical states of matter are interchangeable.

Aren't you already familiar with the melting of ice and the change of water into steam?

* Here, what is the change in the energy of molecules?

What were the ideas that you gathered in the lower classes about the distance between molecules and intermolecular attraction in the solid, liquid and gaseous states of matter ?

Suppose we take some water in a vessel and cover it with a glass plate. If it is kept for some time like this, we see droplets of water on the bottom of the glass plate. What is the reason for this?

The water vapour formed due to evaporation, condensed on the surface of the glass plate to form water droplets, didn't it?

The energy of the molecules moving continuously in a liquid may not be the same. The molecules collide against one another resulting in an exchange of energy.

* What happens to those molecules which acquire energy enough to overcome intermolecular attraction?

Does evaporation take place only at a particular temperature? Or is it possible at any temperature? Consider this in relation to instances in our day-to-day life.

- Drying of washed clothes in the summer and winter seasons.
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Try a simple experiment.

Fill one quarter of a beaker with water. Insert a thermometer into the water and note the initial reading of the thermometer.

Observe the change in temperature as the beaker is heated.

Record the thermometer readings at regular intervals.

* How does the temperature of water change with time?

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* And since the water started boiling?

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* What peculiarity did you observe in the temperature of water from when the boiling of water started till it ended?

The energy supplied at this stage is completely utilized for breaking the forces of intermolecular attraction, thus facilitating the process of evaporation.

What changes occur to the molecules when a liquid changes to gas?

- Energy : ....
- Distance between molecules : ....
- Speed : ....
- Force of attraction : ....

When 1 mL (1 cm^3) of water is completely converted to steam at normal atmospheric pressure, its volume changes approximately to 1700 mL. That is, the same number of molecules which occupy a volume of 1cm^3 in the liquid state require 1700 times this volume in the gaseous state.

Now can't you explain this on the basis of the difference in the arrangement of molecules in the gaseous and liquid states?

Volume of gas

Volume of a substance is the space it requires to occupy.

Thus the volume of a gas will be the volume of its container.

The volume of ½ L of a liquid will not change however big its container is. But suppose the gas in a balloon of volume 1 L is released into an empty vessel of volume 5 L. Now what will the volume of the gas be?

And what happens if this gas is transferred to a 10 L vessel?

Haven't you realized that a liquid has a definite volume while the volume of a gas will be the volume of its container?

Molecular motion

Fig. 1.1

Didn't you notice a solid, a liquid and a gas kept in three closed vessels? If we remove the lids of all the three vessels, which substance will immediately spread outward? What will be the reason for this?

Light an incense stick in a corner of a closed room. Does its fragrance and smoke spread to other parts of the room? What can be the reason?

Haven't you understood that gases can diffuse more efficiently than solids and liquids?

* Can you give other examples for the rapid diffusion of gases?

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* Can you explain the diffusion of gases relating it to the molecular motion in gases?

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* Is diffusion as much possible in the other two states? Why?

Let us do a simple experiment to demonstrate the characteristic difference between the three states of matter.

Equal quantities of chalk powder, water and air are filled separately in three syringes. After closing the nozzle with the finger, press the piston and observe.

* Our observation.

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* In which physical state was matter compressed by applying force?

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* What may be the reason for this? Explain on the basis of the arrangement of molecules in the gaseous state.

Pressure of gas

A gas taken in a closed vessel is shown in Fig. 1.2.

Do all the molecules move in a particular direction?

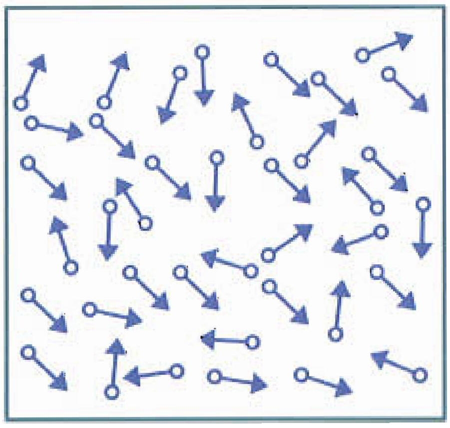

Fig. 1.2

Consider an imaginary plane inside the container.

Wouldn't there be a force on the plane owing to the collision of molecules moving continuously in a random way?

Pressure is the force exerted on unit area of a plane.

Will there be a difference in the force experienced when the plane is kept vertical or inclined?

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* What is the reason?

★ What happens to the pressure when the number of molecules in unit volume of the gas increases? Why?

The common unit used for expressing pressure is atmosphere (atm). 1 atm is the atmospheric pressure at sea level at room temperature.

Fig.1.3 shows a gas kept in a cylinder closed with a movable piston.

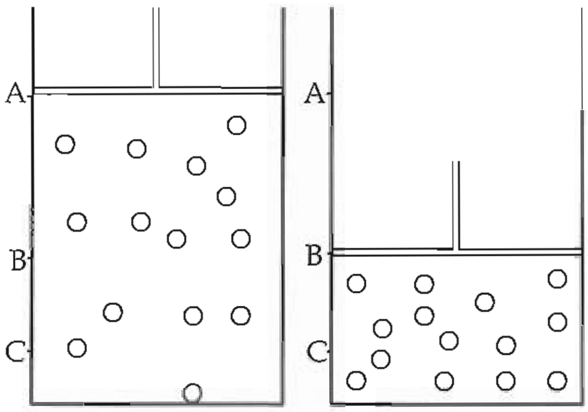

Fig. 1.3

★ What changes may take place when the piston in Fig.1.3 is moved from position A to positions B and C?

★ Will the molecules come closer and become similar to those in the liquid state when the gas is compressed by applying pressure?

★ Is high pressure a prime factor for converting a gas into a liquid?

★ Apart from this, what changes should be brought about in the energy of the molecules? How can it be made possible?

From this we understand that a gas can be liquefied by applying high pressure and lowering the temperature.

Have you noticed some situations where we use liquefied gases?

Cite some examples

- Liquid ammonia
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Volume of gases and pressure

Let us do an experiment.

A balloon partially filled with air is tied well and kept inside an air tight jar as shown in Fig. 1.4. Blow air strongly into the jar.

Fig. 1.4

★ What is the observation?

★ What happens when air is sucked out from the jar?

Now imagine a gas kept in a closed cylinder (Fig. 1.5)

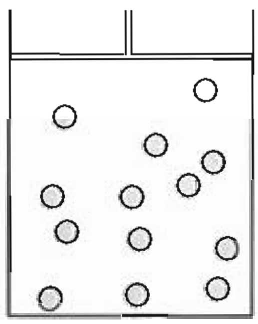

Fig. 1.5

What happens when this gas is completely transferred to a cylinder as shown in Fig. 1.6?

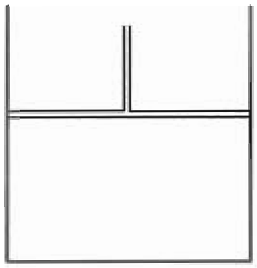

Fig. 1.6

Complete the figure without changing the total number of particles.

When the gas was transferred at constant temperature from the first vessel to the second, which among pressure, volume and mass underwent a change?

pressure	changes / does not change
volume	changes / does not change
mass	changes / does not change

(✓ the correct one)

- ⁎ What change occurred to pressure when volume was decreased?
- ⁎ Let's try an activity which increases the pressure.

Fill a syringe with air and close its nozzle with your finger. Now apply pressure on the piston.

- ⁎ What change occurred to volume when the pressure was increased?

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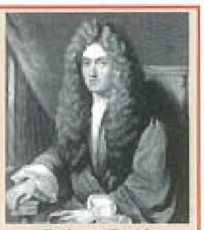
Through some experiments, Robert Boyle established the relationship between pressure and volume of gases in 1662.

The volume of a fixed mass of gas is inversely proportional to its pressure at constant temperature. This is known as Boyle's law.



Robert Boyle

Let us express this law mathematically as

$$V \alpha \frac{1}{P}$$

$$V = \text{constant} \times \frac{1}{P}$$

$$PV = \text{constant}.$$

The volumes and the corresponding pressures of 10 g of hydrogen filled in different cylinders at 0 ^{0}C are given in Table 1.1.

Try to complete the table

Pressure	Volume	Pressure × volume
P_1=1 atm	V_1=112 L	P_1V_1 = 112 L atm
P_2=2 atm	V_2=.... L	P_2V_2 = 112 L atm
P_3=4 atm	V_3 = ... L	P_3V_3 = 112 L atm

Table 1.1

Can you formulate an equation connecting P_1, V_1 and P_2, V_2?

- -

Now examine the values of V and $\frac{1}{V}$ when the same 10 g of hydrogen is taken at 30 ^{0}C but different pressures.

P (atm)	V (L)	$\frac{1}{V}$	PV
1	124.3	0.008	124.3
2	62.15	0.016	124.3
3	41.43	0.024	124.3
4	31.07	0.03	124.3
5	24.86	0.04	124.3

Table 1.2

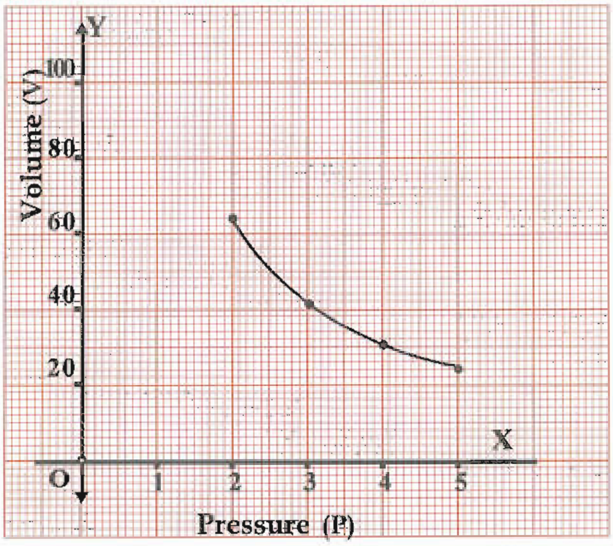
Is the value of PV the same as that obtained earlier?

- -

Mustn't we take care not to change the temperature to get the same constant value for PV? Haven't you understood the significance of the condition of 'constant temperature' used in the statement of Boyle's Law?

If we take the same 10 g of hydrogen at 100 ^{0}C, will the value of PV remain the same?

- -



See the graph drawn using the values of P and V in Table 1.2.

Note down the change in volume (V) when pressure (P) increases.

Now draw a graph using the values of P and $\frac{1}{V}$.

What is the relationship between P and $\frac{1}{V}$?

Doesn't it agree with the relationship $P \alpha \frac{1}{V}$?

On the basis of Boyle's Law, can you explain the following?

* When the balloons used for observing climate changes rise higher up from sea level, their volume increases.

- -

* A fixed mass of oxygen occupies 4 cm^3 at 1 atm pressure. If the pressure is doubled what will be the new volume occupied by the gas? Assume that there is no change in temperature.

Volume of gases and temperature

Let us do an experiment.

Dip an inverted small bottle into the water taken in a beaker and clamp it as shown in Fig. 1.7. Heat the beaker.

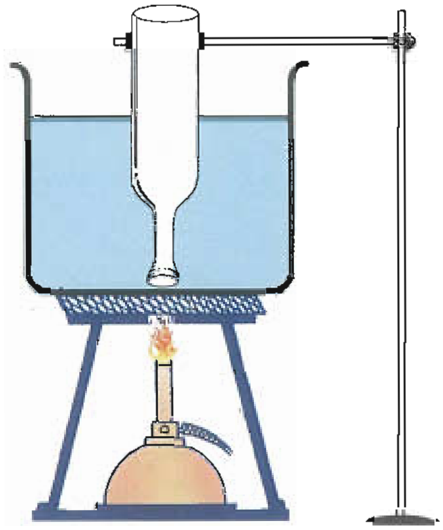


Fig. 1.7

* What did you observe?

- -

From this it is clear that the volume of the gas increases as temperature increases.

Let us try another experiment by keeping the mass of the gas constant.

Arrange the apparatus as shown in Fig. 1.8.

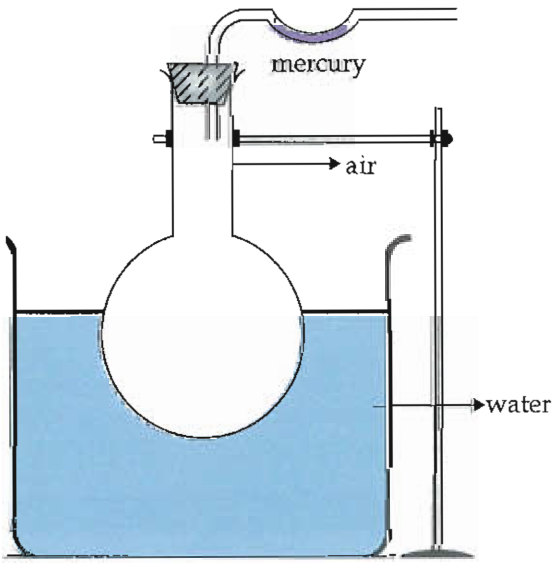


Fig. 1.8

★ Note down what you observe while water in the beaker is being heated.

★ What is the conclusion that can be drawn from this about the change in volume with temperature?

The scientist Jacques Alexandre Charles conducted a detailed study on the change in the volume of a gas brought about by a change in temperature. From his experiments Charles found out that at constant pressure, the volume of a fixed mass of gas was directly proportional to the temperature obtained by adding 273 to the temperature in Celsius. i.e., $V \alpha (t\,^0C + 273)$.

From the previous experiment we have understood that the volume of a fixed mass of gas increases with temperature.

See the graph drawn with volume against temperature based on the values obtained during the experiments.

★ What is the volume at 100 ^{0}C?

★ What are the volumes at 200 ^{0}C and 300 ^{0}C?

★ What happens if the graph is extended backward?

What is the volume at -100 ^{0}C?

And at -200^{0}C? ....

What is the volume at -273 ^{0}C?

★ Is a volume less than this possible?

Therefore, -273 ^{0}C is the lowest temperature attainable by a gas.

Assuming this lowest temperature as zero (absolute zero), Lord Kelvin introduced a new scale of temperature. This is called Kelvin scale and the symbol used is K.

Convert each temperature in the graph from degree Celsius to Kelvin scale:

-273 ^{0}C = 0 K

-250 ^{0}C = ... K

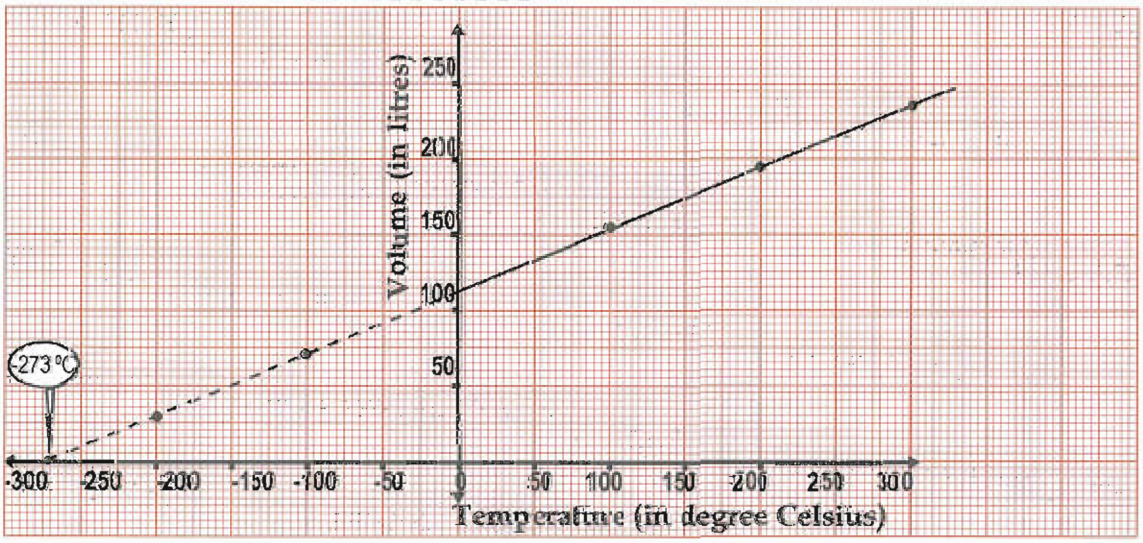
0 ^{0}C = ... K

10 ^{0}C = ... K

100 ^{0}C = ... K

200 ^{0}C = ... K

300 ^{0}C = ... K



Now you have realized that the temperature in Kelvin scale can be obtained by adding 273 to the temperature in degree Celsius?

i.e. $T\,K = t\,^0C + 273$.

Examine the change in volume according to the change in temperature in Kelvin scale.

It can be said that the volume of a gas is directly proportional to its temperature in Kelvin scale.

At constant pressure the volume of a fixed mass of gas is directly proportional to its temperature in Kelvin scale. This is known as Charles' law.

Jacques Alexandre Charles

According to Charles' law,

$V \alpha (t\,^0C + 273)$ (mass, pressure constant)

or

$V \alpha T$ where $T = (t\,^0C + 273)$ the temperature in Kelvin scale.

$V = \text{constant} \times T$

$$\frac{V}{T} = \text{constant}$$

Let the volume of a fixed mass of gas be V_1 at temperature T_1. Keeping the pressure constant if temperature is changed to T_2, the volume becomes V_2. Then according to Charles' law,

$$\frac{V_1}{T_1} = \text{constant}$$

$$\frac{V_2}{T_2} = \text{constant}$$

Therefore it can be written as

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

- The volume of a certain mass of helium is 500 mL at 400 K. If we have to change the volume of this gas to 240 cm^3,

a) what change should be brought about in its temperature?

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b) calculate the new temperature. (Hint: pressure is constant)

- A gas occupies 25 cm^3 at 1 atm pressure and 300 K temperature. What will be the volume occupied by the gas if temperature is increased to 77 ^0C at constant pressure?

Combined gas equation

We have become familiar with the gas laws connecting volume, pressure and temperature of gases.

According to Boyle's law,

$V \alpha \frac{1}{P}$ .... (1) *(mass and temperature constant)*

According to Charles' law,

$V \alpha T$........ (2) *(mass and pressure constant)*

By combining these two laws we get

$$V \alpha \frac{1}{P} \times T$$

$$V = \text{constant} \times \frac{1}{P} \times T$$

$$\therefore \frac{PV}{T} = \text{constant.}$$

If the pressure, volume and temperature of a fixed mass of gas are changed from P_1, V_1 and T_1 to P_2, V_2 and T_2 respectively,

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

This equation is known as **combined gas equation.**

- 320 mL of nitrogen is kept in a cylinder at 273 K under a pressure of 1 atm. What will be the new volume of nitrogen if temperature changes to 27 ^{0}C and pressure changes to 0.5 atm?

Avogadro's law

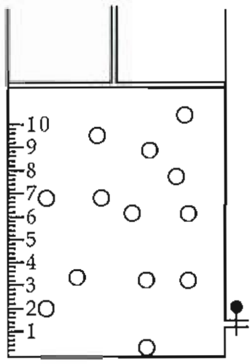

Fig. 1.9

- Did you notice the gas at room temperature and 1 atm pressure filled inside a cylinder fitted with a movable piston?

Suppose the volume of this gas is to be increased. What are the methods that can be used?

- Decrease the pressure
-

★ What is to be done to increase the volume of a gas without changing pressure and temperature?

★ What change will occur in the number of molecules if more gas is introduced in the cylinder?

★ What change occurs in the volume of the gas when the number of molecules increases without a change in pressure and temperature?

★ And what happens if the number of molecules is decreased?

At constant temperature and pressure, let the volume of a gas be V and the number of molecules be n. Then V can be related to n as V α n

This relationship between the volume and number of molecules of a gas was found out by the scientist Avogadro through a series of experiments.

Avogadro

At constant pressure and temperature the volume of a gas is directly proportional to the number of molecules.

This is known as Avogadro's law.

★ What will be the change in volume if the number of molecules is doubled without changing pressure and temperature?

Volume of a molecule

As the molecules in gases are far apart, the volume of a molecule is negligibly small when compared to the volume occupied by the gas. Hence when volumes of gases are taken, the volume of molecules need not be considered.

What about different gases containing the same number of molecules? Isn't it clear that the volumes of different gases at same temperature and pressure will be the same if they contain the same number of molecules? Thus Avogadro's law can be stated in the following way also.

Equal volumes of all gases under the same conditions of temperature and pressure contain same number of molecules.

Thus we have gone through the important laws related to the gaseous state. There are several fields in which these laws are made use of.

- Industry
- Chemical reactions in laboratories
- Forecasting weather
- Health
- Day-to-day life

Collect the details and note them down in the science diary.

Follow up Activities

1. Give reasons.
   (i) Bottles filled with soda are kept under water in summer.
   (ii) Bottles filled with liquid ammonia are opened only after keeping them in ice for some time.
   (iii) In summer motor tyres are filled with air at a lower pressure compared to that in winter.
2. Details of some gases taken at same temperature and pressure are given in the table.

Gas	Volume (in litres)	Number of molecules
Chlorine	20	x
Nitrogen	10	....
Ammonia	20	....
Sulphur dioxide	5	....

   (a) Complete the table.
   (b) State the gas law that you have utilized for completing the table.
   (Hint: x is the number of molecules in 20 L of chlorine gas)
3. The volume of hydrogen at 1 atm pressure and 273 K temperature is 27.3 L. When this gas is completely transferred to another cylinder at 200 K temperature, the pressure increases to 10 atm. Under this condition,
   (a) what will be the changes in the arrangement of hydrogen molecules and their energy?
   (b) what will be the new volume of the gas?

4. The volumes of a gas at same temperature and different pressures are given in the table.

Pressure P (atm)	Volume V (L)
2	11.2
1	22.4
0.90	24.9
0.50	44.8

(a) What will be the volume of the gas at 0.25 atm pressure?

(b) Draw a graph using the data given in the table.

5. Even though an incense stick has fragrance, its fragrance spreads more effectively only when ignited. Can you give an explanation for this experience?

6. The melting point and boiling point of a substance are 203 K and 253 K respectively. From the statements about the substance given below, find out the wrong ones and rewrite them correctly. Also give the reasons.

(i) It is in the liquid state at 273 K.

(ii) It obeys Charles' law at 273 K.

(iii) It obeys Boyle's law at all temperatures.

(iv) It obeys Boyle's law and Charles' law above 253 K.

7. The volume of a gas at a certain pressure is 450 mL at 27 ^{0}C. At what temperature will its volume be reduced to 300 mL, at the same pressure?