2

GAS LAWS

WHAT WE HAVE LEARNT

- **Matter exists in four states, namely solid, liquid, gas and plasma.**
- **The quantity of matter contained in a substance is called its mass.**
- **Volume is the measure of space occupied by matter.**
- **Gram molecular mass is also called one gram mole of the substance.**
- **The property of intermixing of molecules is called diffusion.**
- **Kinetic energy of molecules increases as temperature increases.**

GAS LAWS

Many phenomena familiar to you are caused by gases that fill the atmosphere. You are able to hear the sound of thunder. Aircrafts can fly in air and you can feel the sea breeze because of certain physical properties of gases. Liquids, solids and gases respond to pressure and temperature differently. This is because density, kinetic energy and the number of molecules contained in a fixed volume is different for each state of matter. Many gaseous substances are used in chemistry. Scientists have hence formulated many rules about the nature of gases and also ways to measure the properties of gases. Scientists have formulated these rules by observing how gases behave in different situations and linking this to their properties. Based on these laws, changes observed in gaseous substances that are used or produced in chemical experiments can be explained. Various measures for gases are also needed to explain the experiments.

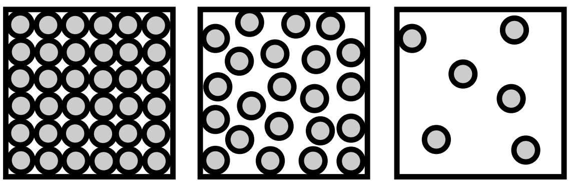
You know that ice, water and steam can be changed from one state to another. How does the following changes occur?

Steam to water

Water to ice

Ice to water

Let us see what happens to the molecular arrangement when such a change occurs. A diagrammatic representation of the molecular arrangement in the three states of matter is given below (figure 2.1).



Solid **Liquid** **Gas**

Figure 2.1

- **Is the molecular arrangement in the three states same?**
- **In which state are the molecules very closely packed?**
- **In which are the molecules very far apart?**
- **In which state is the molecular force of attraction very weak? In which state is the force of attraction very strong and why?**
- **Compare the movement of molecules in gas, liquid and solid and note down your inferences.**
- **On the basis of motion of molecules explain in which state does diffusion take place easily? In steam or in ice?**

From the statements given below select and write down those applicable to gases.

- **Freedom for movement of molecules is limited.**
- **Molecules are far apart.**
- **Molecules are closely packed.**
- **Molecules can move about to some extent.**
- **Molecular motion is very great.**
- **Intermolecular force of attraction is very great.**
- **Intermolecular force of attraction is very weak.**

The molecular arrangement of the three states of matter is given in figure 2.2.

respectively, find out the density. Compare the densities of solids, liquids and gases and complete the table.

Solid	Liquid	Gas
	Density is less than solids	

Table 2.1

Find out the reason why gases have much lower densities and make notes in your science diary.

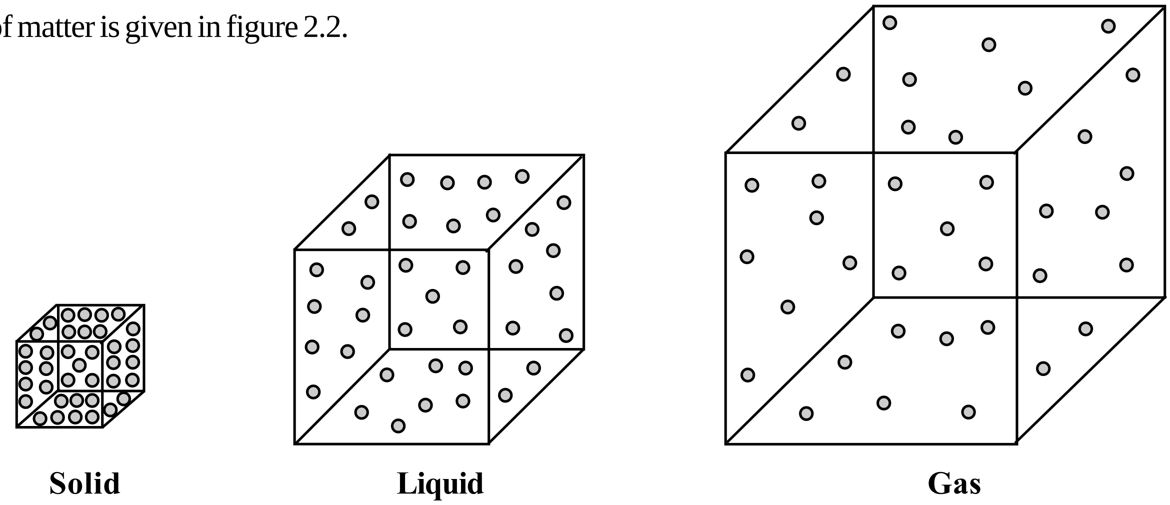


Figure 2.2

See figure 2.2 showing the distribution of the same number of molecules in solid, liquid and gas.

- **Is the volume occupied by the same number of molecules in the three states same? In which state is the volume maximum?**
- **You know that density is the mass per unit volume. If the volume of 2 g of matter in solid, liquid and gas is 4, 4.6 and 400 mL**

If a bottle of perfume is opened in a closed room, its smell spreads to the entire room. As the room is closed air cannot go out. How can the molecules of perfume spread when air molecules fill the room? The molecules of the perfume fill the empty space between molecules of air.

Imagine a gas kept in a closed vessel.

You know that the molecules in a gas are separated from one another by large distances. What will be the force of attraction between the molecules? The molecules are in a state of constant, rapid motion in all directions and during their motion they collide with one another and also with the walls of the containing vessel. As a result, walls of the containing vessel experience an outward force. This force per unit area on the walls is called pressure of the gas. The pressure is expressed in the unit atmosphere (atm).

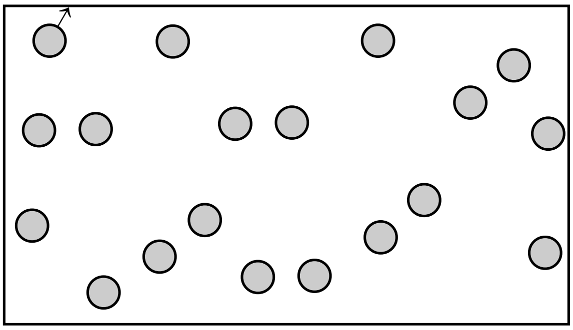


Figure 2.3

How does the kinetic energy of molecules change when temperature is increased? Will the number of collision increase or decrease? What will be the change in pressure? Can you relate gas pressure to intermolecular distance in the following situations?

- **when volume decreases**
- **when the number of molecules increase**

Write a short note for your science diary.

Apply external pressure to the piston of a syringe filled with gas. The experiment is repeated with a syringe filled with a liquid and a syringe filled with powdered solid. Record your observations in your science diary.

In which experiment is the volume decreased due to the application of pressure? Explain your reasons on the basis of intermolecular distance.

Now you have understood that volume of a gas decreases when pressure is applied.

On increasing the temperature of the gas, the molecular motion and kinetic energy of molecules increases. What happens if the temperature is decreased and an external pressure is applied? On the basis of the following, discuss and prepare notes.

- **Kinetic energy of molecules**
- **Molecular motion**
- **Disorder of molecules**
- **Intermolecular space**

When gas molecules come closer, the molecular motion decreases and the molecular arrangement then resembles that of liquid. So gases can be liquefied.

Is it clear why petroleum gas, ammonia, rocket fuels such as hydrogen etc. can be easily liquefied?

Find out more examples for liquefaction of gases and note down in your science diary.

Gas laws

From the above, it is clear that physical behaviour of gases can be described in terms of temperature, volume and pressure. These characteristics of a gas are inter related and these relations are explained in gas laws.

Boyle's law

The experiment of the application of pressure on syringe filled with gas is diagrammatically represented in Figure 2.4.

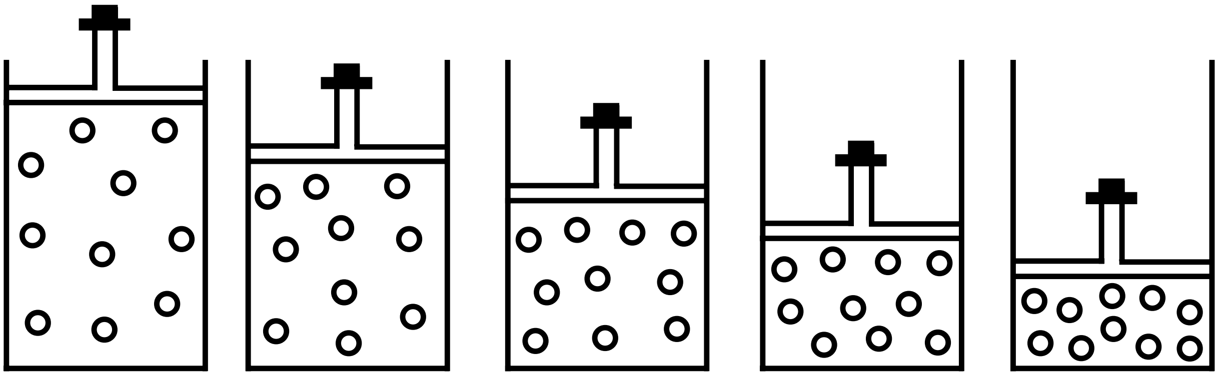


Figure 2.4

The volume of 1 mole of CO_2 at 298K and at different pressures is given in table 2.2.

	1	2	3	4	5
Pressure P (atmosphere pressure)	P_1 **1**	P_2 **1.5**	P_3 **2**	P_4 **2.5**	P_5 **3**
Volume V (Litres)	V_1 **24.46**	V_2 **16.306**	V_3 **12.23**	V_4 **9.78**	V_5 **8.153**

Table 2.2

What happens to the volume of the gas when pressure is increased? Can you find out the relation between pressure and volume?

The relation between pressure and volume

can be mathematically expressed as V

To remove the proportionality sign, multiply with a constant

ie. V = a constant

Find out the value of PV from table 2.2 and record in table 2.2(a) i.e., PV = a constant.

	1	2	3	4	5
	P_1V_1	P_2V_2	P_3V_3	P_4V_4	P_5V_5
PV					

Table 2.2(a)

From the tables given below (2.3 and 2.4) find out whether PV remains a constant when there is a change in the volume, pressure and temperature of the gas.

The volume of 1 mole of CO_2 at 313K and at different pressures.

Pressure (P)(atm)	1	1.5	2	2.5	3
Volume (V)	25.69	17.1315	12.84	10.276	8.5633
PV					

Table 2.3

The volume of 2 moles of CO_2 at 313 K and at different pressures.

Pressure (P)	1	1.5	2	2.5	3
Volume (V)	51.38	34.26	25.68	20.54	17.12
PV					

Table 2.4

What is the value of PV of 1 mol of CO_2 and 2 moles of CO_2 at 1 atm pressure and 313 K?

What happens to the PV value when

- **Amount of gas changes**
- **Temperature changes**

Thus the volume of a given mass of a gas is inversely proportional to its pressure at constant temperature . This is Boyle's law.

From table 2.2(a), the quantitative relationship between the four variables P_1, V_1 P_2 and V_2 is found to be $P_1V_1 = P_2V_2$. This is another statement of Boyle's law.

From the above relation, try to write a formula to find out V_2.

- **A gas occupies a volume of 5 L at 1 atmospheric pressure. What would be the volume of the gas at 2 atmospheric pressure if temperature is kept constant?**

$P_1 = 1$ atm $\qquad V_1 = 5L$

$P_2 = 2$ atm $\qquad V_2 = ?$

According to Boyle's law

$$P_1V_1 = P_2V_2$$

$$V_2 = \frac{P_1V_1}{P_2} = \frac{1 \times 5}{2} = 2.5 \text{ L}$$

Robert Boyle (1627 - 1691)

Robert Boyle, son of a rich industrialist of Ireland was very much interested in science and philosophy. He carried out many experiments on burning, respiration and behaviour of gases and is considered to be the first physical chemist.

- **At room temperature the volume of a gas enclosed in a cylinder at 1 atmospheric pressure is 10 L. What volume will the gas occupy if 20 atmospheres of pressure is applied?**
- **A gas occupies a volume of 15 L at 250 atmospheres of pressure. If the temperature is kept constant and at one atmosphere pressure what volume will the gas occupy?**

Charles Law

Let us examine how the volume of a gas changes with change in temperature. An experiment where a gas in a round bottom flask is heated is shown below.

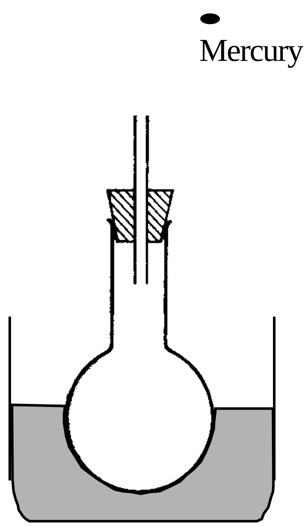


Figure 2.5

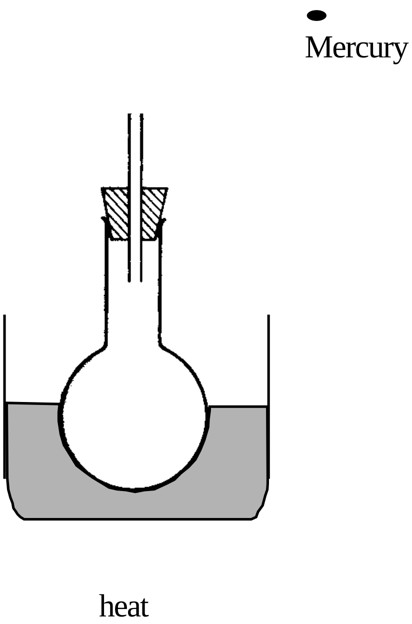


Figure 2.5(a)

Explain when and why the mercury plug moves forward? Discuss how the volume of the gas changes when temperature is increased? What will be the change in volume when temperature is decreased?

A graph showing the variation of volume of a gas with temperature is given below. Find out the volume at different temperatures and complete the table.

Temperature (T)	Volume (V)	
253		
263		
303		
313		

Table 2.4

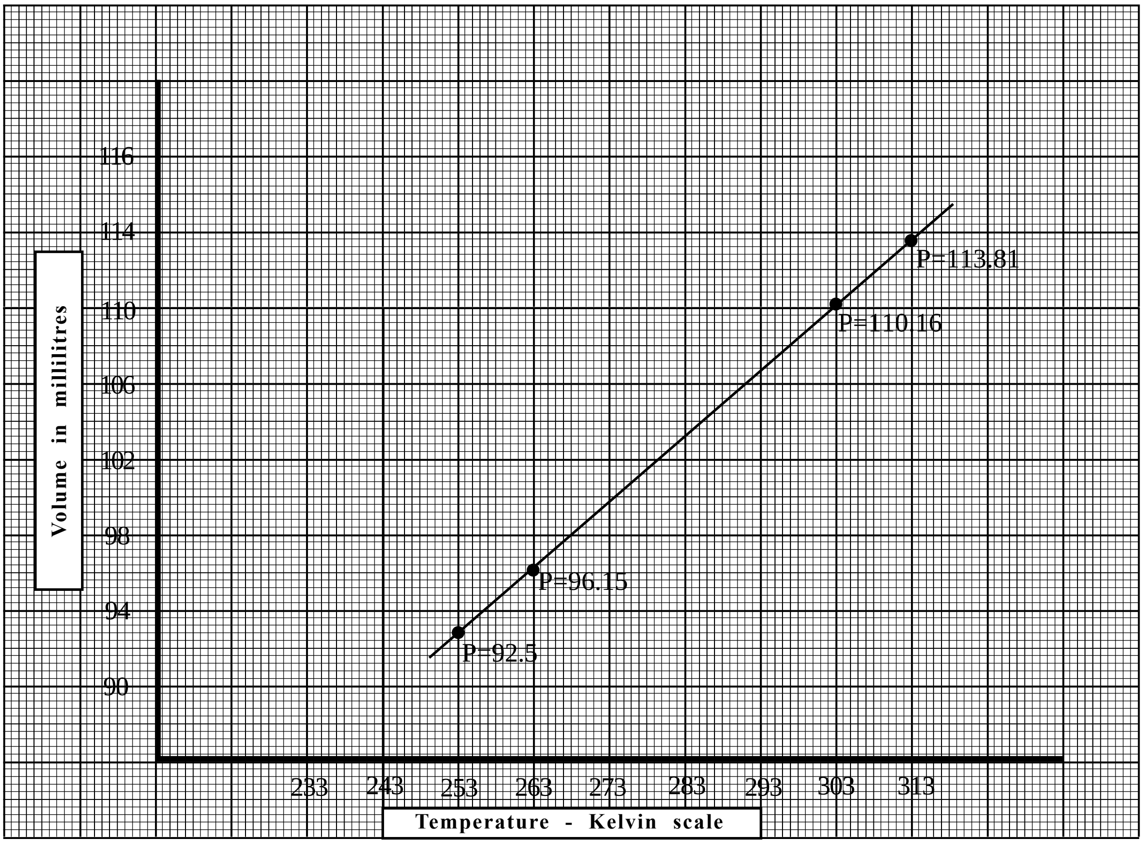


Figure : 2.6

= **constant**

i.e., **V = a constant T**

V ....

The relationship between temperature of a gas and volume occupied by it at constant pressure was first experimentally studied by Jacques Charles.

Pressure remaining constant, the volume of a given mass of gas is directly proportional to its temperature on Kelvin scale. This is Charles law.

Find out a relationship between the four variables (T_1, T_2) and (V_1, V_2).

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

A balloon filled with air when kept in sunlight will burst. Why?

> **Jacques Charles**
>
> **The relationship between temperature of a gas and volume occupied by it at constant pressure was experimentally studied by Jacques Alexander Charles in 1787. On the basis of this he put forward a law which states that "at constant pressure, the volume of a given mass of gas increases or decreases by of its original volume at 0°C for each degree celsius rise or fall in temperature." To get temperature value at Kelvin scale add 273 to the value in degree celcius.**
>
> **ie. 0°C = 0 + 273 = 273 K**

- **If the temperature of 2 L of a gas is increased from 300 K to 310 K at constant pressure, calculate the final volume.**

  T_1=300 K, T_2=310 K, V_1=2L, V_2=?

  According to Charles Law

  $$V_2 = \frac{V_1T_2}{T_1} = \frac{2\times310}{300} = 2.066\ L$$

- **A balloon filled with air has a volume of 500 mL at 298 K and 1 atmospheric pressure. What will be the volume of the balloon if temperature is increased by 10 K?**

- **A gas enclosed in a cylinder fitted with a piston occupies a volume of 5 L at 298 K. To what temperature should the gas be heated to double its volume? Assume that the pressure remains constant.**

Avogadro's Law

Avogadro proposed that under the same conditions of temperature and pressure the volume of a gas varies directly as the number of moles of the gas (n).

Mathematically **V n.**

V = Volume

n = Number of moles

If 'X' molecules of oxygen at 300 K and 1 atm pressure occupies a volume of 10 mL then under the same temperature and pressure 'X' molecules of nitrogen also occupies a volume of 10 mL. Also 10 mL CO_2 at 300 K and 1 atmospheric pressure contains 'X' molecules.

(Complete the table 2.5 A - B, C - D and E - F can be considered in pairs.)

Gas	Temperature (K)	Pressure (atm)	No. of molecules × 10^{20}	Volume (mL)
A	313	1.5	10,000	0.5
B	313	1.5	10,000	……
C	…….	……..	25,000	0.025
D	293	2	25,000	0.025
E	303	1	15,000	0.01
F	303	……	………	0.01

Table 2.5

From the above, it is understood that under the same conditions of temperature and pressure equal volume of all the gases contains equal number of molecules.

The volume of gases is dependent on pressure and temperature. A standard measure of these values is needed to state the volume of gases. 273 K and 1 atmospheric pressure is taken as standard. These conditions are termed Standard Temperature and Pressure, abbreviated as STP.

The volume, number of moles and number of molecules of certain gases at STP are given below.

The volume of one mole of any gas is called molar volume. It has been experimentally proven that the volume of 1 mole of any gas at S.T.P is 22.4 litres.

Relate molar volume with number of particles and molecular mass.

22.4 litre of H_2 at STP = 1 gm mol
= .... gm
= .... number of molecules
= ....atoms

$$\text{Number of moles} = \frac{\textbf{Volume of gas in litres}}{\textbf{22.4}}$$

Gas	Number of moles	Volume (L)	Number of molecules
N_2	1	22.4	6.022×10^{23}
O_2	2	44.8	$2 \times 6.022 \times 10^{23}$
CO_2	.....	67.2	....
H_2	1	22.4	....

Table 2.6

- **Find out the volume at STP of**

  (a) 10 mol hydrogen gas

  (b) 10 gm hydrogen gas

- **Calculate the number of moles and number of molecules in 44.8 L of CO_2 at STP.**

  Number of moles ....

  Number of molecules ....

Ideal Gas Equation

The above three laws may be combined to derive a general relationship.

Boyles law $V \alpha$ (n, T constant)

Charles law (n, P constant)

Avogadro's law (P, T constant)

Combining the three

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

ie. $V \alpha \frac{nT}{P}$ or $V =$ a constant $\times \frac{nT}{P}$

This constant is known as universal gas constant and is denoted as R.

Then $V = \frac{R \times n \times T}{P}$

PV = $n \times R \times T$

i.e., PV = nRT

This equation is called ideal gas equation. A gas that obeys the ideal gas equation strictly at all temperatures and pressures is called an ideal gas.

From the table given below, calculate

1.

2. Relation between $\frac{P_1V_1}{T_1}$ and $\frac{P_2V_2}{T_2}$ for each gas.

PV = nRT can also be written as $\frac{PV}{T} = nR$

If n and R are constant, then $\frac{PV}{T}$ will also be a constant.

Gas	Presure (P atm)	Volume (V) mL	Temperature T (K)	$\frac{PV}{T}$
Nitrogen	1(P_1) 0.825(P_2)	320 (V_1) 482 (V_2)	273 (T_1) 339 (T_2)	....
Helium	2.5 (P_1) 15.16 (P_2)	285 (V_1) 27.5 (V_2)	298 (T_1) 1744.3 (T_2)	....

Table 2.7

SUMMARY

- Mass, volume, density, temperature and pressure are some measurable properties of all gases.
- Gases have much lower densities compared to solids or liquids
- Molecules in a gas are far apart and the force of attraction between the gas molecules is negligibly small.
- Gases can be liquified at lower temperature by applying high pressure.
- Temperature remaining constant, the volume of a given mass of gas is inversely proportional to its pressure.

$$V \alpha \frac{1}{P} \qquad P_1V_1 = P_2V_2$$

- Pressure remaining constant, the volume of a given mass of gas is directly proportional to its absolute (Kelvin) temperature.

$$V \alpha T \text{ (P, n constant)}$$

- Under the same conditions of temperature and pressure, equal volume of all gases contains the same number of molecules.

$$V \alpha n \text{ (P, T constant)}$$

- The equation that relates pressure, volume, temperature and number of moles of a gas is called the general gas equation.

(n constant)

MORE ACTIVITIES FOR YOU

1. Gases have no definite shape or volume compared to solids and liquids. Why?
2. A bottle of liquid ammonia is cooled before opening the seal. Explain the reason.
3. Weather balloons become larger and larger as they ascend to higher altitude. Why?
4. Tyres of automobiles are inflated to lesser pressure in summer than in winter. Why?
5. Find the volume of 1 mol of gas at STP (R=0.0821 litre atm $mol^{-1}K^{-1}$)
6. The following table shows the effect of changing pressure on the volume of a sample of gas when temperature is constant. Plot the graph for
   1. P Vs V
   2. P Vs $\frac{1}{V}$
   3. PV Vs P
7. The volume of a hydrogen filled weather balloon is 175 L at 1 atm pressure. What will be the volume of the balloon when it rises to an altitude of 200 m where the pressure is 0.8 atm? (Temperature remaining constant)
8. The volume of a gas at 300 K and constant pressure is 350 mL. What will be the volume of the gas if it is cooled to 260 K? (Pressure remaining constant.)
9. A sample of gas at 340 K is heated until the pressure is doubled. What will be the final temperature?
10. What will be the final volume if 320 mL of a sample of gas at 340 K is heated to 66^0C and pressure is maintained at 0.825 atmospheres?

Pressure(P) (Atm)	1.00	0.9	0.85	0.75	0.65	0.55	0.45	0.30	0.20
Volume (V) (L)	22.4	24.9	26.3	29.9	40.2	40.7	49.8	74.7	112

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