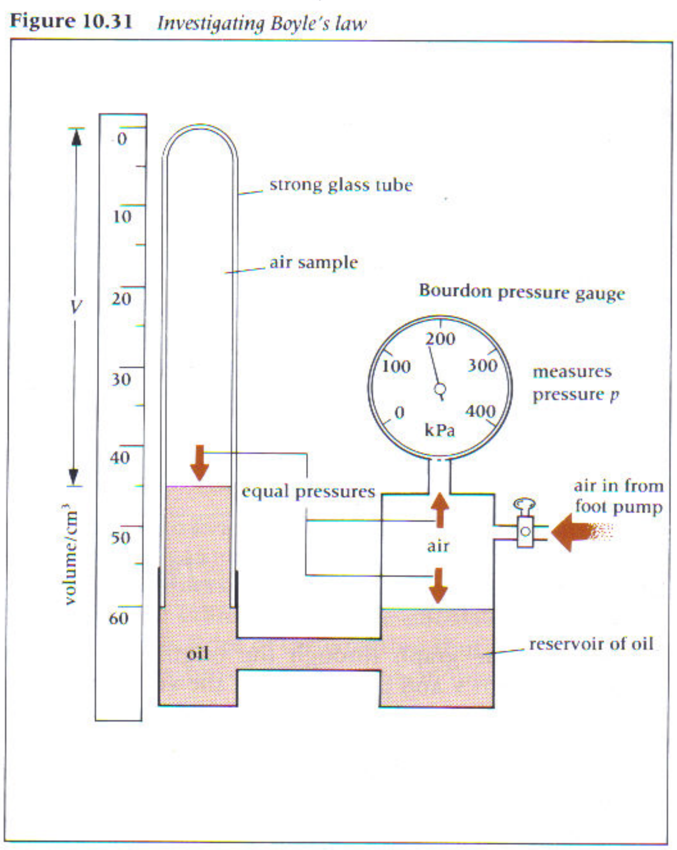
# GAS LAWS

## Boyle's Law:

**Investigating the dependence of Volume on Pressure (Temperature kept constant)**

The diagram below shows the apparatus which gives a direct reading for both the volume and pressure of a fixed mass of gas.




Air is trapped in a glass tube by a column of oil. The oil is supplied from a reservoir, where it can be pressurized by using a tyre pump. The pressure above the oil in the reservoir is read by using a Bourdon pressure gauge. The pressure above the oil in the reservoir is transferred to the trapped air in the glass tube. The experiment is performed at room temperature to keep the temperature constant.

Since no air is pumped into the reservoir, the gauge reads atmospheric pressure, (100 KPa). The pressure, ***P***, is increased by pumping air and the volume, ***V***, is recorded from the vertical scale.

The graphs below demonstrate the relationship between pressure, ***P***, and Volume, ***V***.

Fig 7.1 and 7.2 illustrate two ways in which the results maybe presented.

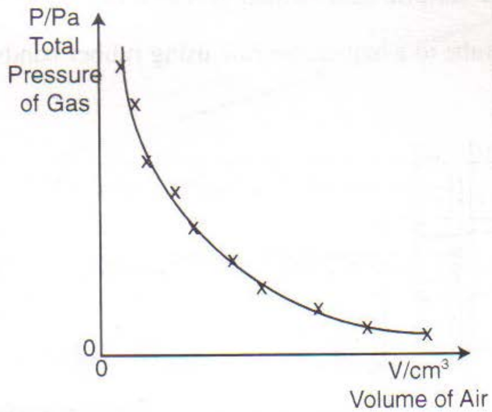



*Fig 7.1* *P vs V for air*

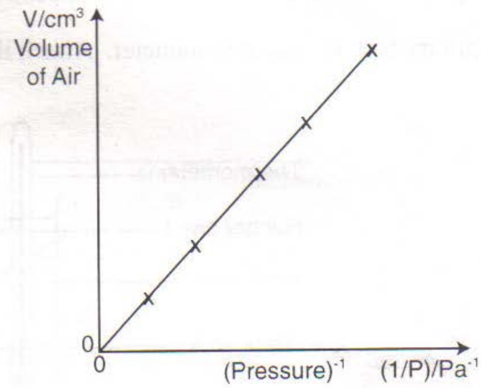



*Fig. 7.2* ***Graph of V vs (1/P).***

The linear relationship indicated by Fig. 7.2 suggests that the pressure, P, of a gas and its volume, V, are inversely related

i.e. $V \propto \left(\frac{1}{P}\right)$ (T kept constant)

or PV = constant (at constant temperature)

This relationship is stated as Boyle's Law:

***The volume of a fixed mass of gas is inversely proportional to its pressure if the temperature is constant.***

**Boyle's Equation:**

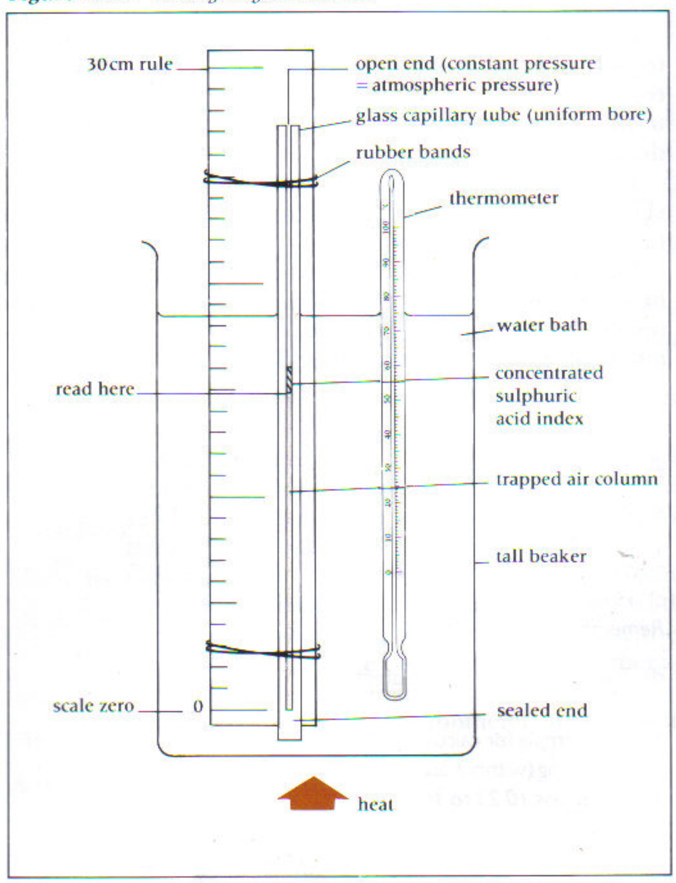
$$\mathbf{P_1 V_1 = P_2 V_2}$$

## Charles' Law:

**Investigating the variation of the Volume of a gas with Temperature (Pressure kept constant)**

The diagram below shows the apparatus which gives a direct reading for both the volume and temperature of a fixed mass of gas.

**Figure 10.29** *Investigating Charles' law*




A column of air is trapped by a bead of concentrated sulfuric acid in a capillary tube. The tube was then attached to a half-meter rule by using rubber bands.

This apparatus is placed inside of a beaker containing water and it is kept upright by using a clamp-stand. The water surrounding the capillary tube is heating with a bunsen burner, while stirring with the thermometer. The readings of the thermometer, ***T***, and the volume, ***V***, were taken at 15$^{o}$C intervals.

The graphs below demonstrate the relationship between Volume, ***V***, and Temperature, ***T.***

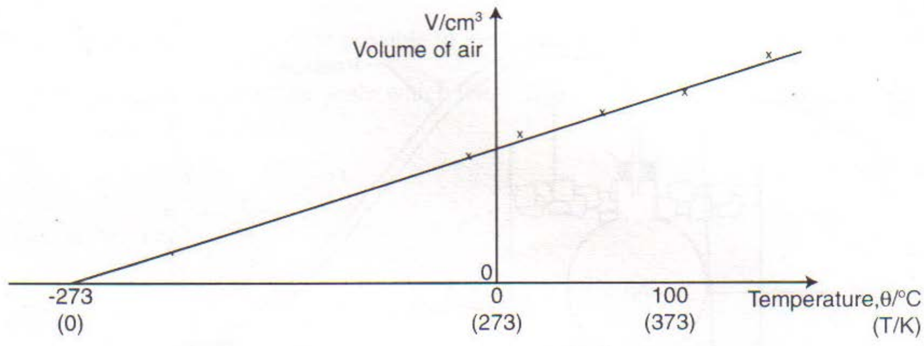



***Fig. 7.4*** ***Volume, V/cm3 against Temperature, θ/°C***

If you extrapolate the graph backwards you should note that the straight line cuts the temperature axis at about - 273°C. This suggests that if you were able to decrease the temperature of the gas, without causing it to liquefy, its the volume would decrease to zero at -273°C.

It should be noted also that the graph would pass through the origin if an arbitrary temperature scale which has its zero at -273°C were chosen. Then there would be a simple proportionality between the volume, V and the temperature expressed on that scale. We shall represent temperature on this scale, called the ideal gas temperature scale, by T/K.

so $V \propto (\theta + 273)$; **i.e.** $V \propto T$

or $\frac{V}{T}$ = constant (at constant pressure) for a fixed mass of gas.

This relationship is stated as Charles' Law:

***The volume of a fixed mass of gas is directly proportional to its absolute temperature (on the Kelvin scale) if the pressure is constant.***

**Charles' Equation:**

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

**Pressure Law:**

**Investigating the variation of the Pressure of a gas with Temperature (Volume kept constant)**

The diagram below shows the apparatus which gives a direct reading for both the pressure and temperature of a fixed mass of gas.

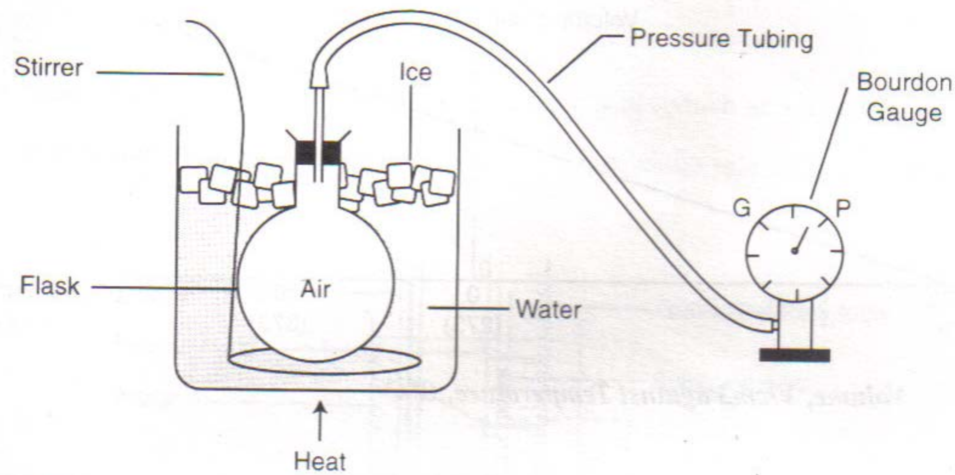
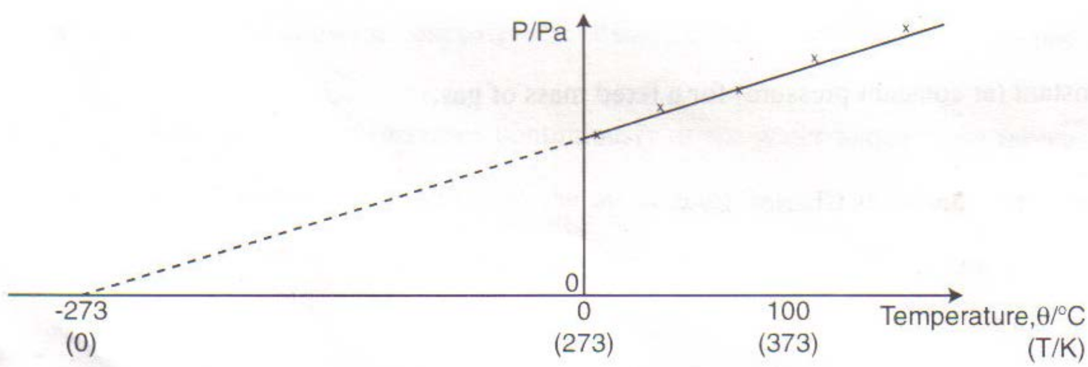



*Fig. 7.5* ***Pressure vs Temperature (Constant Volume)***

The apparatus consists of a large flask filled with dry air connected by pressure tubing to a Bourdon pressure gauge. The bulb is placed inside a large container and is completely filled with water. The pressure of the air is recorded over a wide range of temperatures including $0^oC$ and $100^oC$.

The graphs below demonstrate the relationship between Pressure, ***P***, and Temperature, ***T***



We note here also that when the graph is extrapolated backwards, it cuts the temperature axis at approximately -273°C. This notable coincidence, suggests that, as for the volume, the pressure of the gas would be zero if it were possible to lower its temperature to -273°C. The observation also indicates that the temperature scale which uses -273°C as its zero is of fundamental physical significance.

Thus, as before,

$P \propto (\theta + 273)$

i.e. $P \propto T \quad (T/K = (\theta + 273) / °C)$

i.e. $\frac{P}{T}$ = constant (for a constant volume of a fixed mass of gas.)

This relationship is stated as Pressure Law:

***The pressure of a fixed mass of gas is directly proportional to its absolute temperature if its volume is constant.***

**Pressure Equation:**

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

## Gas Law:

The three relationships

$PV = \text{constant}$ (constant temperature): Boyle's Law

$\frac{V}{T} = \text{constant}$ (constant pressure): Charles' Law and

$\frac{P}{T} = \text{constant}$ (constant volume): The Pressure Law

can be combined, for a fixed mass of gas, to give the Equation of State for an Ideal Gas,

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

**Gas Law Equation:**

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

**The Kelvin Scale**

These gas laws and additional experiments led Lord Kelvin to propose a temperature scale. This Ideal Gas Temperature Scale is known as the Kelvin Scale of temperature and 0 K or $-273^{o}C$ is often called "absolute zero".

The relationship between the Kelvin scale and the Celsius scale

$$T = {}^{o}C + 273$$

# KINETIC THEORY

## Brownian Motion

The motion of tiny suspended particles is called Brownian motion. This is easily observed in both liquid and gases.

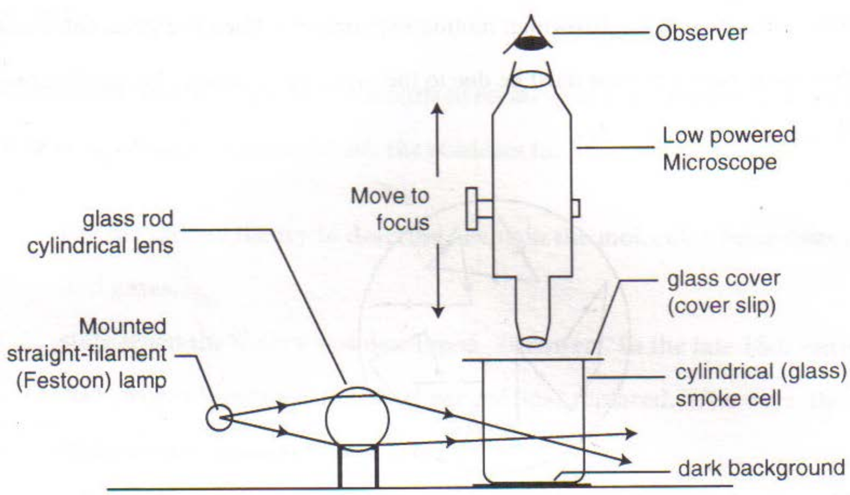



*Fig. 7.8* *Smoke-cell Demonstration of Brownian Motion.*

The illuminated smoke particles which are seen when viewed through a microscope appear as bright specks moving in a jerky and erratic manner. The particles do not collide frequently with each other, but seem to be struck by some other invisible particles. It is believed that these other particles are particles of air (or water) used to suspend the particles. This evidence suggests that particles exist and that they are constantly moving in all directions with different speeds.

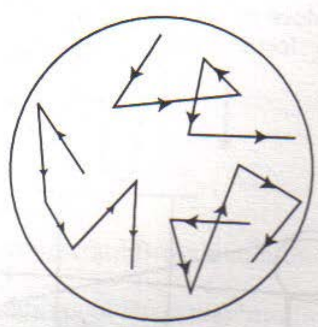


*Fig. 7.10* *Three smoke particles exhibiting Brownian motion over an interval of time.*

Brownian motion is easily observed with smaller particles than larger particles, this is because the movement of larger particles is too low to be observed.

The effect of Brownian motion can be enhanced with increase in temperature. Increasing the temperature causes the average speed of the molecules to increase, therefore the chances of collisions also increases since the particles have more momentum.

**PHYSICAL PROPERTIES OF SOLIDS, LIQUIDS AND GASES**

Read and make notes (also include diagrams) on:

**PFC Page 151 - 156**

- the three states of matter
- a model gas, liquid and solid
- forces on molecules in a liquid
- stretching materials (solids)

**PFC Page 184 - 185**

- evaporation
- vapour pressure
- evaporation and boiling
- effect of pressure on boiling

## Gas Pressure

Gas pressure can be explained in terms of moving molecules. Molecules in gases are far apart and move rapidly filling in available spaces. As they move, they collide with the walls of the container making a large number of collisions per second. The force exerted on the walls produces gas pressure.

## Gas Pressure and Laws Explanation in Terms of Kinetic Theory

### Boyle's Law

Boyles' Law states that the volume of a fixed mass of gas is inversely proportional to its pressure (at constant temperature).

The collision of the molecules of a gas with the walls of the container gives rise to the gas pressure. If the rate of these collisions increases the gas pressure increases. If the volume of a fixed mass of gas is decreased the number of collisions with the wall increases. This happens because more molecules now occupy a smaller space. In fact if the volume is halved the pressure is doubled because the molecules are now twice as crowded together in space.

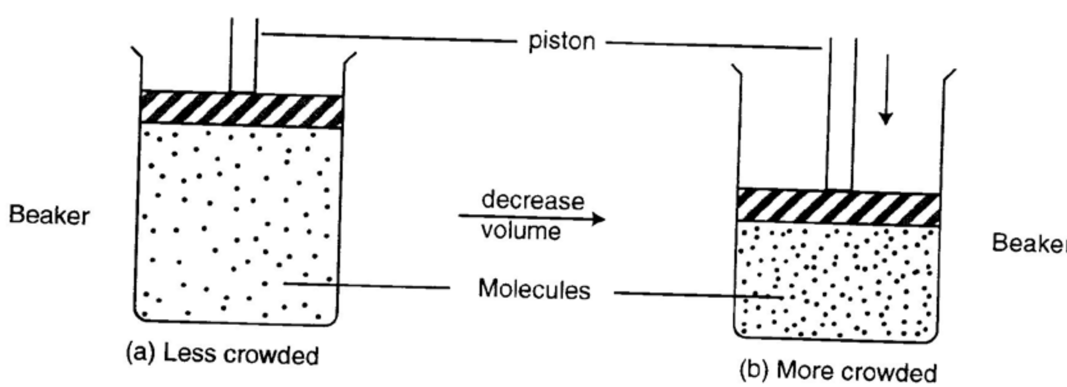



***Fig. 7.16*** ***Decreasing Volume results in more crowding of molecules.***

Charles' Law

This states that the volume of a fixed mass of gas is directly proportional to its absolute temperature (T) at constant pressure.

When a gas is heated its molecules begin to move faster as the temperature of the gas rises. The molecules therefore collide more frequently with the walls of the container. In addition , the molecules strike the wall harder at every collision. The increased rate of collisions and the greater force exerted at every collision with the walls of the container both contribute to an increased pressure exerted by the gas. Thus, if the gas is free to expand, it will do so until its pressure is, once again, equal to the (constant) external pressure. Detailed analysis based on the proposals of the kinetic theory shows that the pressure of a gas at a given temperature is directly proportional to the concentration (number per unit volume) of the molecules and on their mean kinetic energy. The kinetic theory also proposes that the mean kinetic energy of the molecules determines the (Kelvin) temperature of the gas.

Hence if the Kelvin temperature of a gas is doubled (for example) the volume of the gas has to be doubled so that the concentration of molecules is halved in order that the pressure should remain the same.

Pressure Law

This law may be stated as follows:

The pressure of a fixed mass of gas is directly proportional to its absolute temperature (at constant volume). When the volume remains the same and the temperature increases, the kinetic energy of the molecules increases, causing an increase in the speed within the same space. This causes the molecules to hit walls harder and more often.