VISCOSITY :

By viscosity is understood the internal friction between layers of fluid as they pass over each other when moving with different velocities.

This property is exhibited by gases as well as liquids.

It would be easier to understand this first with a flowing liquid. When a liquid is flowing steadily over a fixed horizontal surface (i.e. the flow is streamline), its layer in immediate contact with the fixed surface is stationary & the velocity of layers increases with the distance from the fixed surface (Fig. 1)

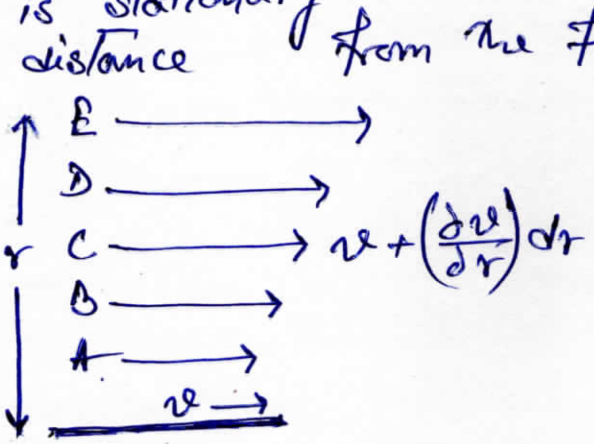

Fig. 1

The layer immediately beneath any layer will try to retard it while the layer above will accelerate it. Thus, there is a tendency to destroy the relative motion as if there is a tangential force dragging backwards. This is the viscous force. Newton showed that this force of internal friction 'f' is directly proportional to the area of contact 'A' & the velocity gradient $\frac{dv}{dr}$

Hence, $f = -\eta A \frac{dv}{dr} \rightarrow$ ①

The negative sign is indicative of the fact that the force is opposite to the direction of flow.

The relation ① is true for both gases & liquids & is applicable only when the flow is laminar & steady & not turbulent & disorderly.

The proportionality constant η is called the 'coefficient of viscosity'.

when $A = 1$ & $\frac{dv}{dr} = 1$, $\eta = -f$.

Hence, coefficient of viscosity can be defined as the tangential force required per unit area to maintain a unit velocity gradient i.e., to maintain unit difference of velocity between two layers unit distance apart. It is expressed in unit of 'poise', which in cgs system is dynes sec per sq. cm.

STOKES' LAW:

When a body moves through a viscous medium, its motion is opposed by the frictional resistance. In order to maintain a uniform velocity, a driving force is applied to overcome the viscous drag. It was shown by Stokes that when a body of radius 'r' moves with a constant velocity u through a medium having coefficient of viscosity η, then the driving force (f) which just balances the frictional resistance, is given by the relation

$$f = 6\pi\eta r u$$

If the spherical body falls under gravity, then

$$f = \left(\frac{4}{3}\right)\pi r^3 (d - d_L)\, g$$

where, d & d_L are the densities of the solid sphere & the liquid respectively

$$\text{Hence, } \overset{3}{\cancel{6}}\cancel{\pi}\eta \cancel{r} u = \left(\frac{\overset{2}{\cancel{4}}}{3}\right)\cancel{\pi}\overset{r^2}{\cancel{r^3}}(d - d_L)\, g$$

$$\text{or } u = \frac{2}{9}\frac{r^2 (d - d_L) g}{\eta}$$

This is Stokes' law.

REYNOLD'S NUMBER:

The expression for viscosity deduced [eq^n ①] relate to the laminar flow of the liquids i.e., each layer slipping smoothly past another & there is no turbulence during the flow. But, if the flow-rate is high & especially when the liquid flows ~~tough~~ through a wider tube, the flow becomes turbulent & eddies are formed. This type of flow is often ascertained empirically by finding the Reynold's Number (R) given by

$$R = \frac{d u \rho}{\eta}$$

where, d = diameter of the tube
u = average rate of flow of the liquid
ρ = density of the liquid
η = coefficient of viscosity

It is just a number & if its magnitude is less than 2100, the flow is taken as laminar. When the value is above 4000, it is definitely turbulent. In the intermediate range, there is minor turbulence in flow.

[Co-efficient of viscosity (η): It has been defined as the tangential force per unit area required to maintain unit difference of velocity between two layers unit distance apart. It is expressed in dynes/cm²]

GAS LAWS:

(1) AVOGADRO'S LAW:

The vol. (v) of a gas depends not only upon the quantity of the gas (n) but also on its pr. (p) & its temp. (T).

It is common knowledge that at any given temp. & pr., the vol. of a gas will be directly proportional to the quantity. That is,

$v \propto n$, when p & T are constant

$v = k_1 n$ (where k_1 is proportionality constant)

The quantity n is usually expressed in gm-moles. Avogadro (1811) was responsible for discovering a law of nature for the gases (commonly called Avogadro's law) which states:

"Measured at a common temp. & pr., the vol. of the same no. of gm-moles of different gases, would be the same."

That is, at the same temp. & pr., the vol. of ~~x~~ n gm-moles of any gas will be the same.

(2) BOYLE'S LAW:

The vol. of a given quantity of gas at a constant temp. is large at low pr. & small at high pr. In ~~1962~~, 1662, Robert Boyle measured carefully the variation of the vol. of a gas with pr. & established the relation which is known as the Boyle's law. The law may be stated as:

"At a constant temp., the vol. of a given mass of gas varies inversely as its pr." That is,

$v \propto \frac{1}{p}$, when n & T are constant

or $pv = k_2$ (proportionality constant).

(3) GAY-LUSSAC'S or CHARLES' LAW :

The influence of variation of Temp. on the vol. of a gas was investigated by Charles (1787) & also by Gay Lussac (1802) independently. The quantitative relation derived from their experiments known as Gay-Lussac's Law or Charles' Law may be stated as,

"At constant pressure, the vol. of a given mass of gas expands by a constant fraction of its vol. at 0°C for 1 degree rise in Temp."

If v_0 be the vol. at 0°C & v at t°C of a given mass of gas at a constant pressure (P) then,

$$v - v_0 = \alpha t v_0$$

$$\text{or } v = v_0 + \alpha t v_0 \quad \text{or } v = v_0(1+\alpha t)$$

where α is the 'coefficient of expansion'. Unlike that in solids or liquids, the value of α is approximately the same for all gases.

THE EQUATION OF STATE :

The gas laws may be summarised :

(i) Avogadro's Law : $v \propto n$ when P & T are constant

(ii) Boyle's Law : $v \propto \frac{1}{P}$, when n & T are constant

(iii) Gay Lussac's Law : $v \propto T$ when n & P are constant

In other words, when all the functions vary independently we have,

$$v \propto \frac{nT}{P} \quad \text{or} \quad v = R\frac{nT}{P}, \text{ where } R \text{ is a constant}$$

$$\text{i.e. } \frac{Pv}{T} = nR \quad \text{or} \quad Pv = nRT$$

For 1 gm-mole of any gas, then $\frac{Pv}{T} = R$

At any given Temp. & pr., the vol. (v) of a gm-mole of any gas will be the same, i.e., 'R' is a universal constant.