"3rd SEM - Physical"

Transport Process :-

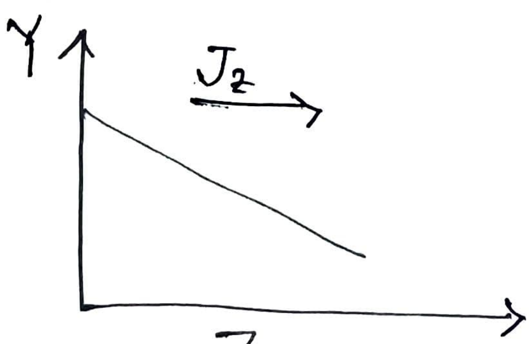
Fick's Law: Flux, force, phenomenological coefficient & their - relationship (general form), different examples of transport properties.

Viscosity : General features of fluid flow (steamline flow and turbulent flow); Newton's equation, viscosity Coeffi ; Poiseuille's equation, principle of determination of viscosity of liquids and comparison with that of gas.

"Transport Properties" :-

It is a process in which some physical quantity such as mass or energy or momentum or electric charge is transported from a region of a system to another. Heat transported from higher temperature to lower temperature through a metal bar, electric charge transported from higher electric potential to lower, through conductor, mass transported through a pipe of higher pressure end to lower pressure end or mass transported at higher concentration to lower concentration all are transport phenomenon.

In all cases the flow, the amount of the physical quantity transported in unit time through a unit area perpendicular to the direction of flow is proportional to the negative gradient of some other physical property such as temperature, pressure or electric potential.



choosing the z-axis as the direction of flow, ~~is~~ ~~determined by the transport of momentum in~~

the general law ~~of~~ for transport is -

$$J_z = L\left(-\frac{\partial Y}{\partial z}\right)$$

where J_z : amount of the quantity transported to z direction at unit time by unit cross section ; L = proportionality constant ~~Y' property change~~ $\left(\frac{\partial Y}{\partial z}\right)$ is (-)ve gradient at 'Y' direction.

eg Heat: $J_z = -K_T \frac{\partial T}{\partial z}$ (Fourier's Law)

Electrical constant $J_z = -K \frac{\partial \phi}{\partial z}$ (Ohm Law)

Fluid flow $J_z = -C \frac{\partial p}{\partial z}$ (Poiseuille's law)

Diffusion $J_z = -D \frac{\partial \tilde{N}}{\partial z}$ (Fick's Law)

K_T = thermal conductivity coefficient

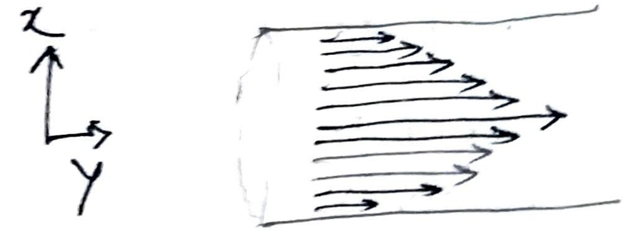
K = electrical conductivity

C = frictional coefficient related to viscosity.

D = Diffusion coefficient.

Viscosity of fluid :-

The property that characterizes a fluid's resistance to flow is its viscosity (η). The speed of flow through a tube is inversely proportional to the viscosity.



Surface area A.

Suppose a fluid is flowing through a tube, the ~~velocity~~ speed of fluid ~~is~~ have maxima at the centre of the tube and gradually decrease towards the wall of the tube i.e x axis where Y axis is the direction of the flow. The layer of fluid exactly vicinity of the wall is stationary. That is there is a (−)ve gradient of velocity from centre of the tube to wall of the tube.

Consider an imaginary surface area 'A' drawn between and parallel to the layers of the ~~so~~ fluid. Now if 'P' the pressure of the fluid then force exerted to the wall PA and the there is frictional force among the imaginary layers of the fluids that retard the flow of the fluid acts opposite to the direction of the flow. This is denoted as F. And f is proportional to the ~~surf~~ frictional area A and velocity gradient towards the wall of tube.

i.e. $F \propto -A\left(\frac{dv_y}{dx}\right)$

or $F = -\eta A\left(\frac{dv_y}{dx}\right)$

This is Newton's ~~law~~ law of viscosity.

when $A = 1$ unit $\left(\frac{dv_y}{dx}\right) = 1$ unit

Then $F = -\eta$.

i.e. the frictional force against the direction of the fluid acting at unit area and unit velocity gradient is called viscosity coefficient.

* when a fluid obey's the Newton's law of viscosity i.e. imaginary layers have a velocity gradient are in laminar flow or streamline flow. For this, the fluid must be slow flow rate and steady flow rate. When the flow rate is higher then the Newton's Law of viscosity does not follow. Then the flow will be called turbulent.

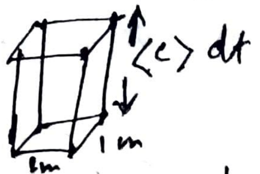
* As we know force (F) = mass (m) x accelaration (f)

$$F = mf$$
$$= m\frac{dv}{dt} \quad \left(\because f = \frac{dv}{dt}\right)$$
$$= \frac{d(mv)}{dt}$$
$$= \frac{dp}{dt} \quad (p \text{ is momentum})$$

i.e. the molecular explanation of viscosity is that it is due to a transport of momomentum accorss the layers. The molecules of adjucent layers have different average speed i.e. different average momentum. when some molecules jumps from higher speed layers, that colloids to the slower speed molecule and speed up the molecules and vice-versa. So slower speed molecules of higher speed molecules.
drag the layer

The General equn for transport.

If any physical quantity is transported, the amount transported through unit area in unit time is the number of molecules passing through the unit area in unit time multiplied by amount of the physical quantity carried by each molecule ie



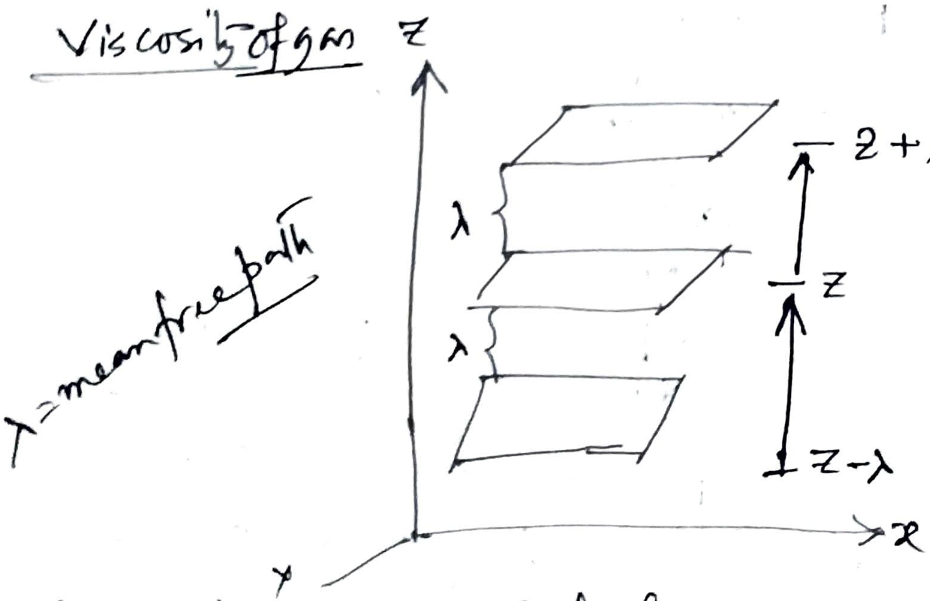
$$j = N' q$$

j = flow per N^2 sec, N' = no. of molecule passes through unit area in unit sec.

Now if the molecules have $\langle c \rangle$ velocity in all direction then the distance travelled by the molecule in unit time $\langle c \rangle dt$. Now if $\tilde{N}$ is the number of molecules per unit metere cube volum, then at unit time no. of molecule passes $\tilde{N}\langle c \rangle$

$$\therefore \; j = \tilde{N}\langle c \rangle q.$$

Viscosity of gas



$$u_{z+\lambda} = \frac{du}{dz}(z+\lambda)$$

$$u_z = \frac{du}{dz} z$$

$$u_{z-\lambda} = \frac{du}{dz}(z-\lambda)$$

Consider parralel plates of fluid layer above xy plane One is situated on z distance from wall (ie the plane). If the flow pulls the plate with velocity v and the ~~the~~ adjuecent plate to xy plane stationary. it creates a drags the moving plate, This is viscous drag.

We can also consider several plates parallel to the plate having velocity z and ~~its~~ their velocity gradually increase towards z direction.

If the z layer have velocity u_z then

$$u_z = \frac{du}{dz} z.$$

At ~~0~~ $z = Z$; $u = U$; $\frac{du}{dz} = \frac{U}{Z}$

Now molecules can jump from one layer to another. The number of molecules passing downwards per square meter of ~~area~~ area and unit time is $\frac{1}{6} \tilde{N} \langle c \rangle$.

Now the momentum transfer from middle to upper -

$$m u_{z+\lambda} = m \frac{du}{dz} (z+\lambda)$$

and momentum tranfer from lower middle -

$$m u_{z-\lambda} = m \frac{du}{dz} (z-\lambda)$$

Now change of momentum

$$m u_{z+\lambda}\downarrow - m u_{z-\lambda}\uparrow = \frac{1}{6} \tilde{N} \langle c \rangle m \left(\frac{du}{dz}\right)(z+\lambda) - \frac{1}{6} \tilde{N} \langle c \rangle m \left(\frac{du}{dz}\right)(z-\lambda)$$

$$= \frac{1}{3} \tilde{N} \langle c \rangle m \lambda \frac{du}{dz}.$$

Now momentum tranfer at unit time is force

$$f = \frac{1}{3} \tilde{N} \langle c \rangle m \lambda \frac{du}{dz}$$

But from Newton's law for $1 m^2$ area - ie $A = 1$; then $f = -\eta \left(\frac{du}{dz}\right)$

The force is acting opposite to obtain the plate stationary so it must be (+)ve.

$$\therefore \eta \frac{du}{dz} = \frac{1}{3} \tilde{N} \langle c \rangle m \lambda \frac{du}{dz}.$$

$$\boxed{\therefore \eta = \frac{1}{3} \tilde{N} \langle c \rangle m \lambda}$$

$$\boxed{\eta = \frac{1}{3} \tilde{N} \langle c \rangle \rho}$$

$\rho = \tilde{N} m$ (density of the gas)

Putting the value of λ & $\langle c \rangle$ —

$$\langle c \rangle = \sqrt{\frac{8kT}{\pi m}} \qquad \lambda = \frac{1}{\sqrt{2}\pi \sigma^2 \tilde{N}}$$

$\sigma =$ molecular diameter.

$$\eta = \frac{2}{3} \frac{\sqrt{mkT}}{\pi^{3/2} \sigma^2} = \frac{2}{3} \frac{\sqrt{MRT}}{\pi^{3/2} N_A \sigma^2}$$

Here you can see that $\eta \propto \sqrt{T}$

ie with increase of 'T'; η increase for gases. Similarly $\eta \propto \sqrt{M}$; and with increase of 'M' (molecular wt) viscosity coefficient increase.