

5. Friction In Solids & Liquids

- **Friction** – Friction is the property due to which a force is set up at the surface of contact of two bodies, preventing any relative motion between them.
- **Cause of friction** – Irregularities of the two surfaces get interlocked restricting the motion when one body moves or tends to move over the other.
- **Types of friction:**
 - Sliding friction
 - Rolling friction
- **Sliding friction** – Whenever a body slides or tends to slide over the surface of another body, the friction that comes into play is called sliding friction. It is of two types:
 - **Static friction** – It is the opposing force that comes into play when a body tends to slide over the surface of another body.
 - **Dynamic friction** – It is the opposing force that comes into play when a body is actually sliding over the surface of another body. Dynamic friction is also called kinetic friction.

The maximum value of static friction that comes into play when a body is just on the point of sliding is called limiting friction.

Laws of static friction

- The magnitude of the limiting force of static friction (F_s) between any two bodies in contact is given by $F_s = \mu_s N$.

Here, N is the normal reaction between the bodies and μ_s is the proportionality constant and is called the coefficient of static friction.

- The limiting force of static friction depends on the nature of material of the surfaces in contact.

Laws of kinetic friction

- The magnitude of force of kinetic friction (F_k) between any two bodies in contact is directly proportional to the normal reaction (N) between them.

$$F_k \propto N$$

$$F_k = \mu_k N$$

- The force of kinetic friction is independent of the area of contact, as long as the normal reaction between two surfaces in contact remains the same.
- The force of kinetic friction depends on the nature and material of the surfaces in contact.
- The force of kinetic friction is approximately independent of the relative velocity between the surfaces in contact.

- **Pressure:** Average pressure (P_{av}) is normal force (F) acting per unit area (A)



$$P_{av} = \frac{F}{A} \quad (\text{Scalar quantity})$$

- **Pascal's law** : Pressure exerted at any point on a liquid in a container is transmitted undiminished in all directions.
- Applications of Pascal's law
 - Hydraulic brakes
 - Hydraulic lift

- **Effect of gravity on pressure** $\rightarrow P = P_a + h\rho g$.

Here,

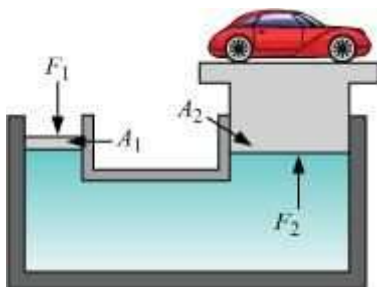
P \rightarrow Absolute pressure at any depth h of a liquid

P_a \rightarrow Atmospheric pressure

ρ \rightarrow Density of the liquid

- The liquid pressure at a point in a liquid depends upon the depth of the point below the liquid surface. This is known as hydrostatic paradox.
- **Hydraulic system** \rightarrow It works on Pascal's Law, according to which, ratio of force exerted to area will be same at all cross-sections.

$$\therefore \frac{F_1}{A_1} = \frac{F_2}{A_2}$$



- Therefore, a large force is experienced in the larger cross-section if a smaller force is applied in the smaller cross-section.

- **Newton's Law of Viscosity:** It states that the shear stress (τ) on fluid layers is directly proportional to the rate of shear strain i.e. $\tau = \eta \frac{dv}{dx}$
- **Viscosity** \rightarrow The viscous force directly depends on the area of the layer and the velocity gradient.

$$F = -\eta A \frac{dv}{dx}$$

Where, η refers to coefficient of viscosity

- **Poiseuille's Formula** $\rightarrow V = \frac{\pi P r^4}{8 \eta l}$
- **Stoke's formula** $\rightarrow F = 6\pi \eta r v$,

Where,

$r \rightarrow$ Radius of the ball

$v \rightarrow$ Terminal velocity attained by the ball

- **Critical velocity** \rightarrow Maximum velocity of flow up to which a liquid can have streamlined flow in a tube

$$v_c = \frac{R_e \eta}{\rho r}$$

Where, R_e is Reynolds's number

- If $R_e < 1000$, then the flow is streamline.
- If $R_e > 2000$, then the flow is turbulent.
- If $1000 < R_e < 2000$, then the flow is unstable.
- **Stream-lined flow** \rightarrow An orderly flow of liquid in which tangents at any point give the direction of flow is called streamlined flow.
- **Equation of continuity** $\rightarrow av = \text{Constant}$

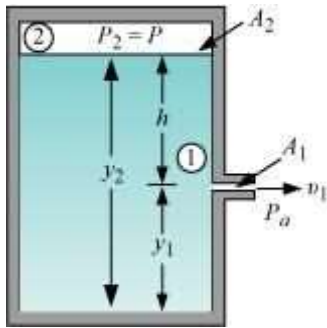
Where,

$a =$ Area of cross-section

$v =$ Velocity of flow

- **Bernoulli's theorem** $\rightarrow P + \frac{1}{2} \rho v^2 + \rho gh = \text{Constant}$

- **Torricelli's law** → Speed of efflux (fluid out flow) from an open tank is given by a formula identical to that of a freely falling body.



$$v_1 = \sqrt{2gh}$$

- **Magnus effect** → When a ball is given a spin in a streamline of air molecules, it will follow a curved path forming a convex towards the greater pressure side.