4.1 FRICTION

Whenever there is tendency for relative sliding motion or actual relative sliding motion of one contacting surface with respect to the other.

• The tangential force which is developed between the two surfaces in contact is called **frictional force.**

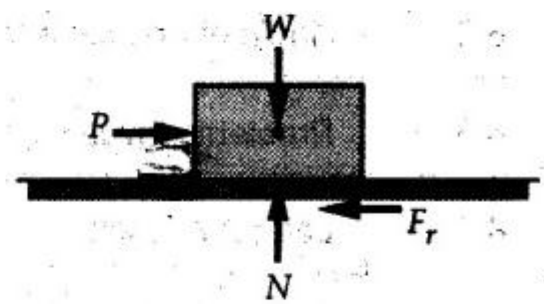
• The direction of frictional force is such that it always opposes the tendency for relative motion between two surfaces in contact.

• There are two types of friction: **Dry friction** (also called Coulomb friction) and fluid friction.

• Dry friction exists between two solid surfaces in contact when there is tendency for relative sliding motion between them whereas fluid friction exists between two layers of fluid for a similar situation.

Dry Friction and Coefficients of Friction

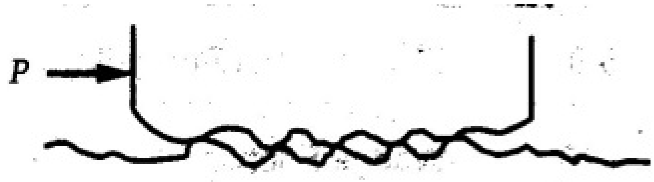
Suppose a block of weight 'W' is kept on a rough horizontal surface and a horizontal force 'P' is applied to it as shown in Fig.



• When force 'P' is small, the block does not move.

• This is because of the frictional force which balances P.

The frictional force is largely due to interlocking of irregularities in the two surfaces in contact as shown in Fig.

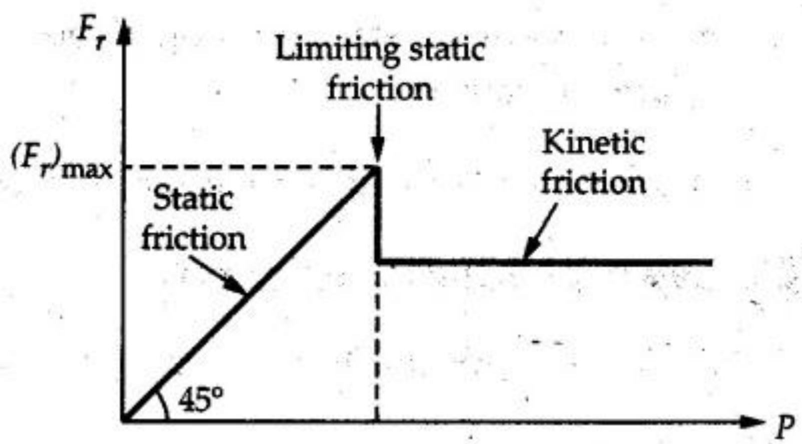


The frictional force is also, to a small extent, due to the molecular forces of attraction between the two surfaces in contact.

• If force P is increased, friction force F_r increases and remains equal to P as long as the object is static.

• When P is increased beyond a certain value $(F_r)_{max}$, the object starts moving, the frictional force decreases and then remains nearly constant.

This variation in magnitude of frictional force with the applied force P is shown in Fig.



From the above discussion, we conclude the following points which are important while solving. problems:

1) As long as object is static, the frictional force has same magnitude as the net force trying to move the object and has opposite direction.

2) Motion impends when net force trying to move the object becomes equal to the maximum frictional force (F) max known as the limiting static friction force.

3) When object starts moving, the frictional force is constant, independent of the net applied force.

• Experimental evidence shows that the maximum value of frictional force (the limiting static friction force) is proportional to the normal component of reaction N. i.e.,

$$(F_r)_{max} \propto N$$

$$\therefore \quad (F_r)_{max} = \mu_s N$$

Where μ_s is a constant known as coefficient of static friction.

• Similarly, the magnitude of the kinetic friction force is expressed as

$$F_K = \mu_k N$$

Where μ_k is a constant known as coefficient of kinetic friction.

• The coefficients μ_s and μ_k do not depend on the surface area in contact but depend on the nature of the surfaces in contact.

Laws of Static Friction

1. Under static conditions, the friction force opposes tendency for relative motion between the two surfaces in contact and acts tangential to the surfaces.

2. The limiting static friction force, which is the maximum value of friction force, is directly proportional to the normal reaction between the two surfaces in contact i.e.

$$(F_r)_{max} \propto N$$

$$\therefore \quad (F_r)_{max} = \mu_s N$$

where μ_s is the coefficient of static friction.

3. Limiting force of static friction is independent of the area of the two surfaces in contact

4. Limiting force of static friction depends on the nature and material of the two surfaces in contact.

Note:

Friction force and normal reaction are always perpendicular to each other.

Laws of Kinetic Friction

1. The force of kinetic friction opposes the relative motion between two surfaces in contact.

2. The force of kinetic friction is directly proportional to the normal reaction between the two surfaces in contact i.e.,

$$F_k \propto N$$

$$\therefore \quad F_k = \mu_k N$$

where μ_k is the coefficient of kinetic friction.

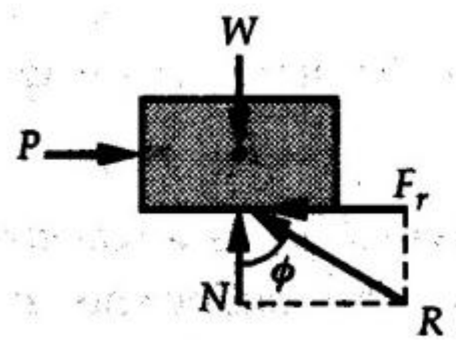
3. Force of kinetic friction is independent of the area of the two surfaces in contact.

4. Force of kinetic friction depends on the nature and material of the two surfaces in contact.

5. Force of kinetic friction is independent of velocity for small velocities.

Angle of Friction and Resultant Reaction

The normal reaction N and the frictional force F_r can be confined to give a resultant R called the **resultant reaction** as shown in Fig.



The angle made by this resultant R with normal reaction N is called the **angle of friction** ϕ.

- For impending motion, $F_r = (F_r)_{max} = \mu_s N$

Then, $\tan \phi_s = \frac{\mu_s N}{N} = \mu_s$

$$\therefore \quad \boxed{\tan \phi_s = \mu_s}$$

where ϕ_s is called the **angle of static friction.**

- If motion takes place,

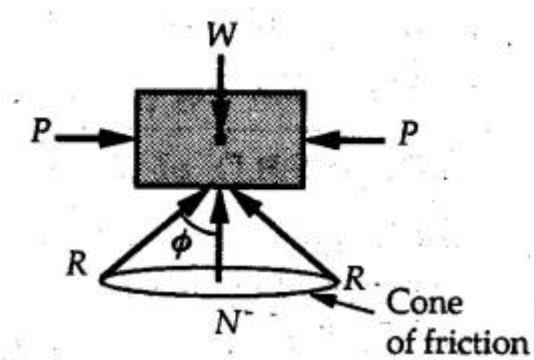
$$\tan \phi_k = \frac{F_k}{N} = \frac{\mu_k N}{N}$$

$$\therefore \quad \boxed{\tan \phi_k = \mu_k}$$

where ϕ_k is called **angle of kinetic friction.**

If direction of applied force P is changed, keeping its angle with the surface of contact same throughout, the resultant R will take different positions in space but making the same angle ϕ with the normal reaction N.

• In such a case, R lies on the surface of a cone known as **cone of friction** as shown in Fig.

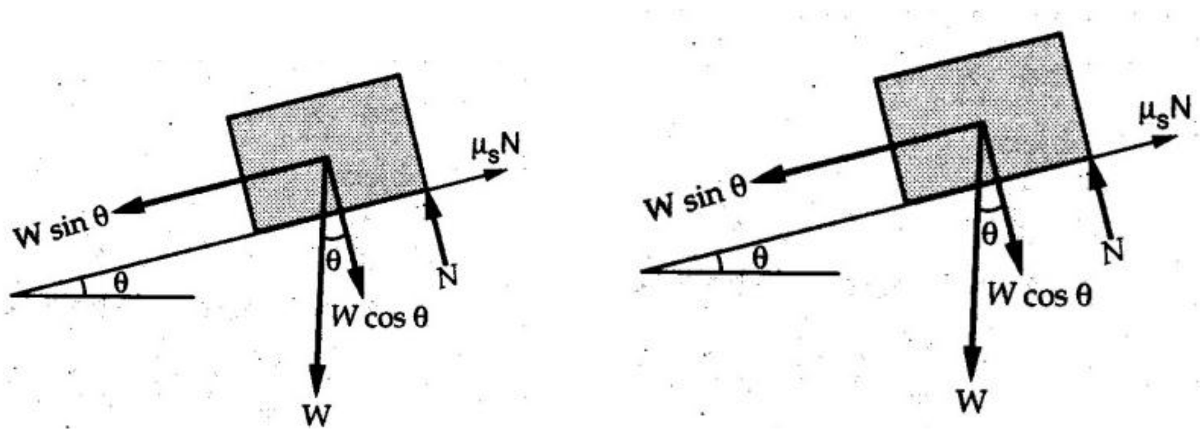


If an object is kept on an inclined plane and the angle of inclination θ is increased, motion impends for a certain value of θ known as **angle of repose.**

• The angle of repose is equal to the angle of friction.

• This can be proved as follows:

• Consider F.B.D. of an object kept on an inclined plane of angle θ equal to the angle of Repose as shown in Fig.



$$\sum F_y = 0$$

$$N - W\cos\theta = 0$$

$$N = W\cos\theta$$

$$\sum F_x = 0$$

$$\mu_s N - W\sin\theta = 0$$

$$\mu_s (W\cos\theta) = W\sin\theta$$

$$\mu_s = \tan\theta$$

But

$$\mu_s = \tan\phi_s$$

$$\tan\phi_s = \tan\theta$$

$$\boxed{\phi_s = \theta}$$

Problems involving dry friction can be solved using either N and F_r or using R and ϕ_s.