# Horizontal Plane

1. Friction in due to the interlocking of irregularities between the surfaces in contact with each other.
2. Frictional force is a non-conservative force.
3. Frictional force is electromagnetic in nature.
4. Frictional force acts along the tangent drawn to the surface in contact.
5. **Advantages of friction**
   i) Safe walking on the floor is possible due to the friction between the floor and the feet.
   ii) Nails and screws are driven in the walls due to friction.
   iii) Friction helps the fingers to hold a drinking water tumbler.
   iv) Vehicles move on the roads without sliding due to friction and they can be stopped due to friction.
6. **Disadvantages of friction**
   i) Friction results in the power loss in engines.
   ii) The wear and tear of the machine increases due to the friction.
7. **Methods of reducing friction**
   i) Friction between two surfaces of contact can be reduced by polishing the surfaces.
   ii) A lubricant is a substance which forms a thin layer between two surfaces in contact and reduces the friction.
   iii) Ball bearings reduce the friction because rolling friction is minimum.
   iv) Automobiles and aero planes are stream lined to reduce the air friction.
8. **Methods of increasing the friction**

i) Tyres of a vehicle have irregular projections to increase the friction.

ii) Belts on the wheels of grinding machines are waxed frequently to increase the friction.

iii) Sand in poured on the railway tracks during rainy season to increase the friction.

iv) Wheels of a train (or) rails are smoothened to increase the friction.

v) Vigorous polishing increase the friction due to the increase in the intermolecular forces.

**9. Types of Friction**

**a) Static Friction**

i. The force of friction between the bodies in contact which have no relative motion is called Static friction.

ii. Static friction is a self adjusting force (i.e.) it is equal to the applied force until the body just begins to move.

iii. When the body is ready to slide the static friction becomes maximum and it is called limiting friction.

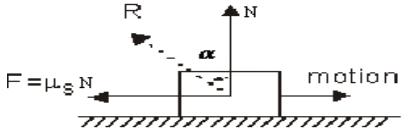
iv. Limiting friction ($F_s$) is independent of the area of contact of the surfaces.

v. $F_s = \mu_s N$ *where* $\mu_s$ is called the coefficient of static friction. It depends upon the nature of the surfaces in contact and their state of roughness.

vi. $\mu_s$ between two given surfaces is independent of the normal force between the two surfaces.

vii. $\mu_s > 0$, it can also be greater than one, but in most of the cases it is less than one

viii. The angle between normal reaction and the resultant of normal reaction and friction is called the angle of friction $\alpha$.



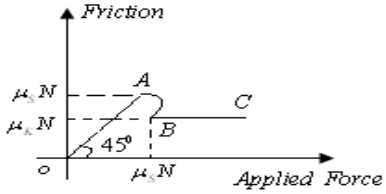
$\text{Tan}\,\alpha = \mu$

**b) Kinetic friction**

- The frictional force that exists between the bodies which are in relative motion with each other in called kinetic (or) sliding friction.
- It is constant and in independent of velocity of the body provided the velocity is low.
- The force of kinetic friction is independent of the area of the surfaces in contact and is proportional to the normal reaction $F_k \propto N$.
  - i. $F_k = \mu_k N$
  - ii. Where $\mu_k$ is coefficient of kinetic friction
- Whenever a body is in motion

  Net force = Applied force - friction force

  $ma = F - f_K$
- Force of kinetic friction may be greater than the static friction but it is




1. Always less than the limiting friction.
2. OA – static friction
3. A – Maximum Static friction
4. BC – kinetic friction

**C) Rolling friction**

i. Rolling friction comes into play when a body rolls on a surface.

ii. Rolling friction arises due to the deformation of the two surfaces in contact with each other.

iii. Greater the deformation greater is the rolling frictional force.

iv. The rolling frictional force is inversely proportional to the radius of the rolling body.

v. If $\mu_R$ is the coefficient of rolling friction

vi. $\mu_R < \mu_k < \mu_s$ for a given pair of surfaces.

**10. Block on a rough fixed horizontal surface**

a) If a force required to just move the body is continuously applied then the acceleration given by

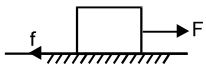
$$a = (\mu_s - \mu_k)\, g$$

b) If the block slides with an acceleration under the influence of an external force F, the acceleration of the block is $a = \frac{F - f_k}{m}$

**11. Motion on a rough horizontal plane**

(a) Pulled with a horizontal force F:

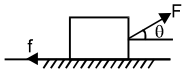
(i) Body moving with uniform velocity $F = \mu_k mg$.



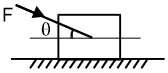

(ii) Body moving with uniform acceleration

$F = m(\mu_k g + a)$.

(b) Pulled with a force F inclined at an angle $\theta$ with the horizontal and the body moving with uniform velocity.




$F = \frac{\mu_k mg}{\cos\theta + \mu_k \sin\theta} = \frac{mg\sin\varphi}{\cos(\theta - \varphi)}$ Where $\phi$ is the angle of friction between the two surfaces.




c) The minimum possible force among all directions required to just move the body is mg sin$\phi$ (or) $\frac{mg\mu_s}{\sqrt{1+\mu_s^2}}$ where $\phi$ is the angle of friction.

c) Pushed with a force F inclined at an angle $\theta$ with the horizontal and the body moving with uniform velocity:

$F = \frac{\mu_k mg}{\cos\theta - \mu_k \sin\theta}$ .Hence pulling is easier than pushing.

12. A uniform chain of length L lies on a table. If the coefficient of friction is $\mu$, then the maximum length of the chain which can overhang from the edge of the table without sliding down is $\frac{\mu L}{\mu + 1}$.

13. If a block is pushed with are initial velocity u and released and if the block comes to rest after traveling some distance s, then

$\frac{1}{2}mu^2 = \mu_k mg$ (Or) $s = \frac{u^2}{2\mu_k g}$

Also, $v = \mu g t$

14. If a vehicle is moving on a curved un-banked road $\frac{mv^2}{r} = \mu_k mg$ (or)

$v = \sqrt{\mu_k rg}$ and $\omega = \sqrt{\frac{\mu g}{r}}$

15. When a bicycle is pedaled (accelerated) the direction of the frictional force on the front and rear wheels are

a) Front wheel - Opposite to the direction of motion

(b) Rear wheel - In the direction of motion

16. When a bicycle is in uniform motion, then the direction of frictional forces is

a) Front wheel - Opposite to the direction of motion

b) Rear wheel - Opposite to the direction of motion

17. A body of mass m is at the back side of an open truck. If the trolley moles forwards with an acceleration 'a', then a pseudo force (ma) acts an the body

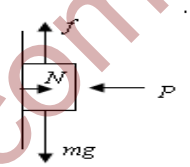
(1) If $ma < \mu_s mg$, the block does not slide, then, Frictional force f = ma

(2) If $ma = \mu_s mg$ . Then the block just slides. Then the frictional force $f = \mu_s mg$

(3) If $ma > \mu_s mg$ . The block moles over the truck in the backward direction with acceleration $a = \mu_k g$

18. If a body is pushed with a force P towards a vertical wall then

1) If the block is at rest $F_x = N - P = 0$ (or) N = P



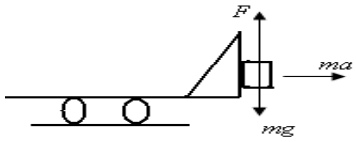

$F_y = f_s - mg = 0$ (Or) $f_s = mg$

$f_s \geq mg\,(or)\,\mu_s P \geq mg$

The block is at rest if $P \geq \frac{mg}{\mu_s}$

$P_{\min} = \frac{mg}{\mu_s}$

19. A vehicle is moving on a horizontal surface. A block of mass 'm' is stuck on the front part of the vehicle. The coefficient of friction between the truck and the block is 'μ'. The minimum acceleration with which the truck should travel, so that the body may not slide down is a = g/μ.




20. If a book is pressed between two hands then $mg = 2\mu F$ where F is the pressing force applied by each hand.