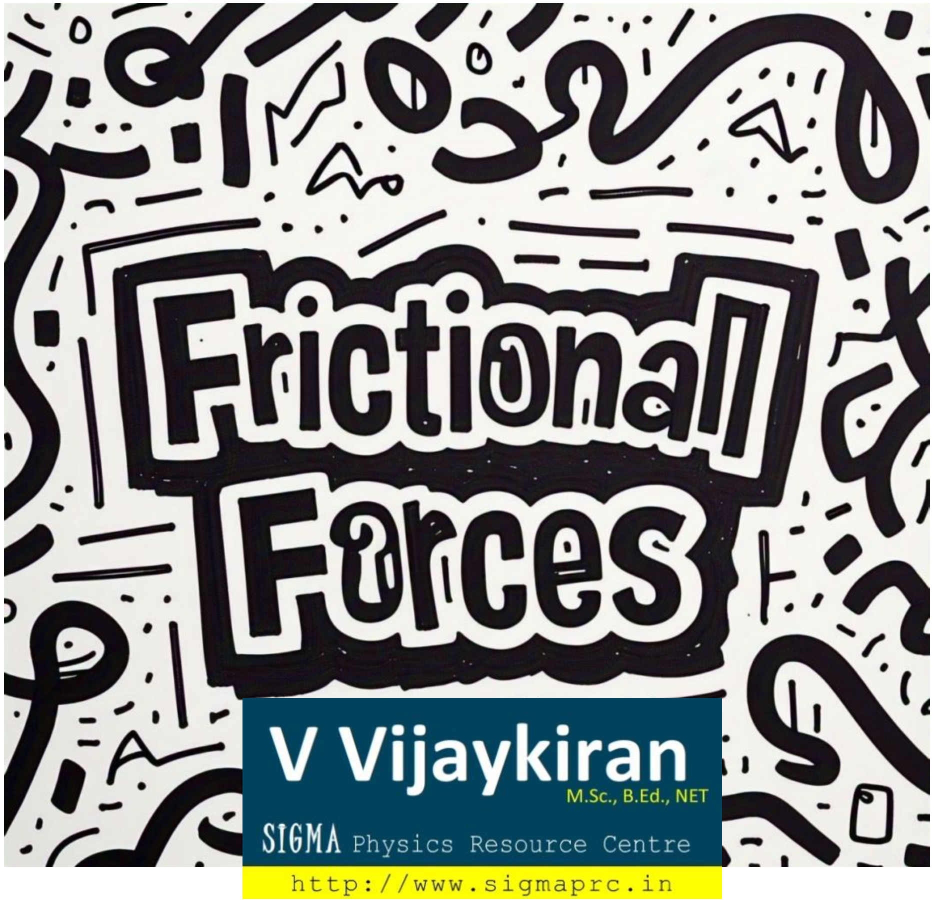
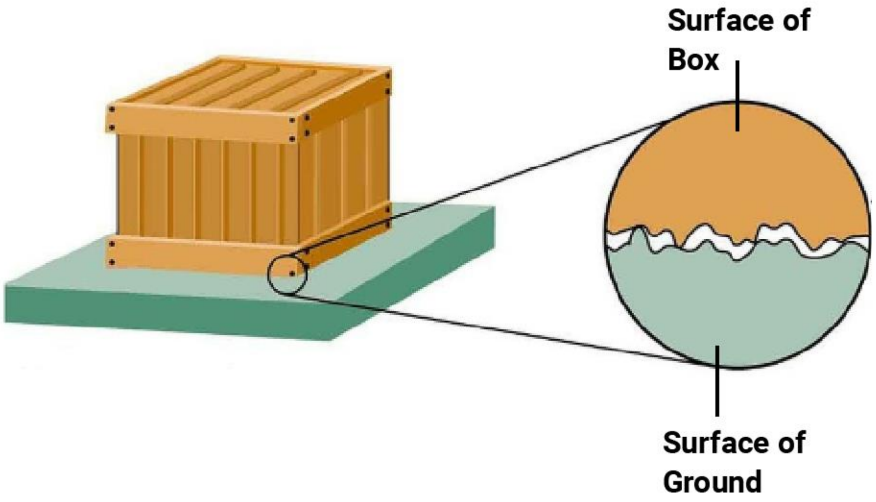


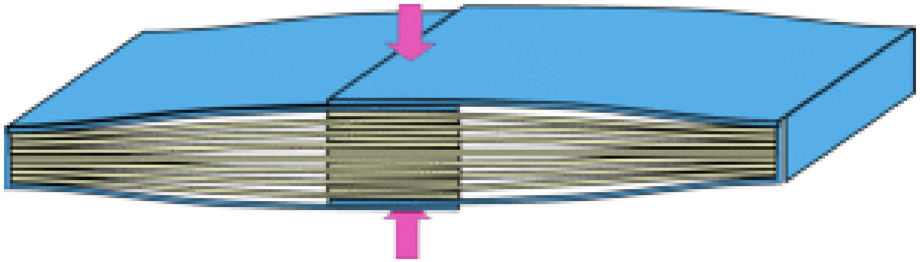
Note : The notes given in this file is no substitute to the much detailed discussion held in the online/contact classes with active participation of students. It , at best, serves the purpose of ready reference for important concepts/derivations covered in the classes.

Friction

Friction is a tangential force that tends to oppose the relative motion between the bodies in contact.

- Friction arises due to irregularities on the surfaces (on microscopic scale)
- Friction is also due to continuous making and breaking of bonds between the surface atoms/molecules of the surfaces in contact

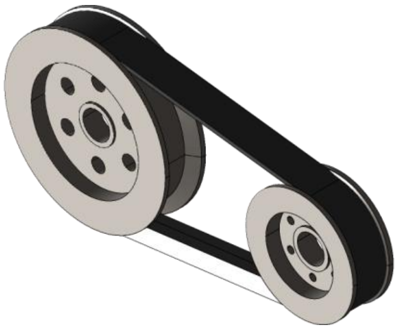




Inseparable books !

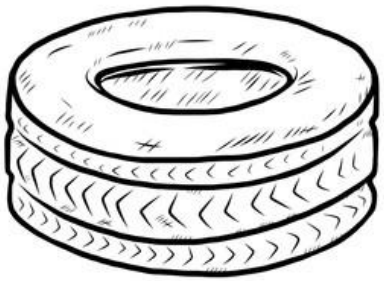
Advantages of friction

- Friction helps us walk, run, stop…
- Heat generated by friction is used in making fire
- We are able to hold our pen and write this sentence due to friction
- Mechanical transmission of power is possible due to friction



Disadvantages of friction

- Friction leads to loss of power as energy is dissipated in the form of heat
- Friction leads to wear and tear of mechanical parts of a machine



Methods of minimizing friction

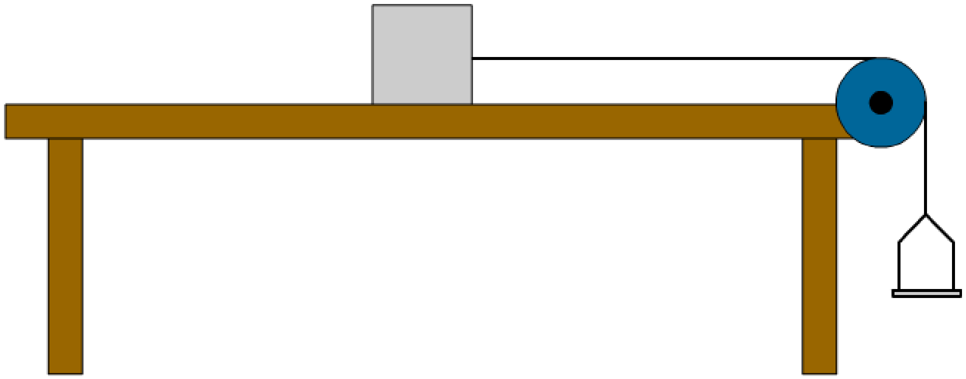
- Friction can be minimized by making the contact surfaces smooth.
- Friction can be minimized by lubricants.
  Lubricants form a thin fluid layer between the solid parts of machinery which results in reduction of friction.
- Friction can be minimized by streamlining.
  Streamlining leads to lesser force exerted by the body on the medium and as a reaction the medium also exerts lesser force on the object.
- Friction can be minimized by introduction of ball bearings.
  Introduction of ball bearings changes the nature of friction between the surfaces from sliding friction to rolling friction (which is about 2 to 3 orders of magnitude less than sliding friction).

Types of friction

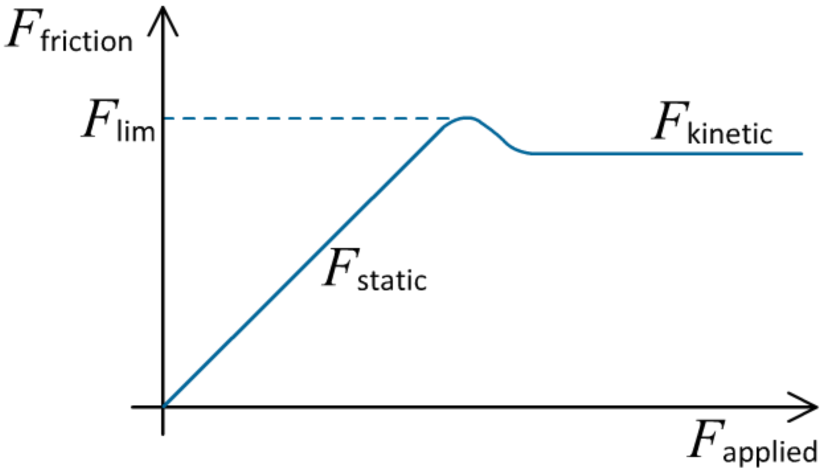
- Static friction (when a body is at rest)
- Kinetic or sliding friction (when the relative motion between the surfaces is due to sliding)
- Rolling friction (when a body rolls over another body or a surface)

An investigation

A block, placed on a table is connected to a weight hanger by a string passing over a pulley. Weights are gradually added to the weight hanger and subsequent motion is observed.



Click here for simulation



- ❑ When weights are added, the block continues to remain stationary initially
- ❑ When more weight is added then the block undergoes acceleration

Static friction

- Frictional force between surfaces which are at rest relative to each other is called static frictional force.
- Static frictional force is directly proportional to the normal reaction
- Static frictional force depends on the nature of surfaces in contact.
- Static frictional force is self adjusting in nature
- The maximum possible value of static friction is called limiting friction

$$F_s \propto N$$

$$\boxed{F_s = \mu_s N}$$

  - μ_s is called coefficient of static friction
  - It depends on the nature of surfaces in contact

Note : $\boldsymbol{F}_s$ mentioned above is ***limiting*** frictional force

Angle of friction

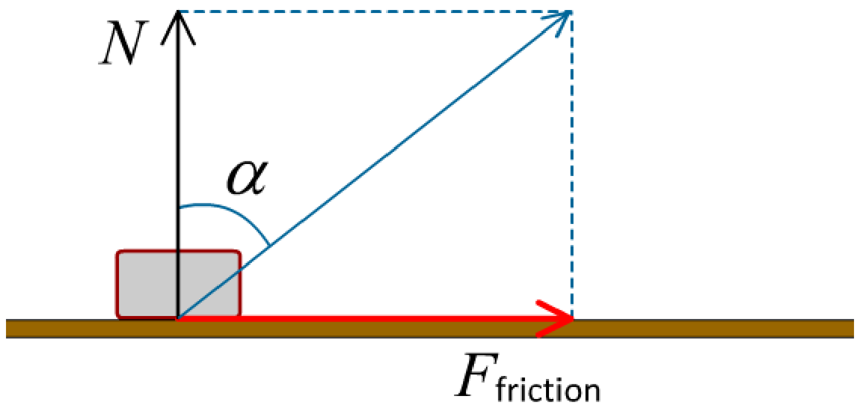
It is the angle between the normal reaction and the resultant of frictional force and normal reaction on the body

$$\tan(\alpha) = \frac{\text{opp}}{\text{adj}}$$

$$\tan(\alpha) = \frac{F_{\text{friction}}}{N}$$

$$\tan(\alpha) = \frac{\mu N}{N}$$

$$\boxed{\tan(\alpha) = \mu}$$



Click here for simulation

Angle of friction may also be defined as the angle between the contact force and the normal reaction

Kinetic friction

- Frictional force between bodies which are sliding relative to each other is called sliding frictional force.
- Kinetic frictional force is constant for moderate velocities
- Kinetic frictional force is directly proportional to the normal reaction
- Kinetic frictional force depends on the nature of surfaces in contact.

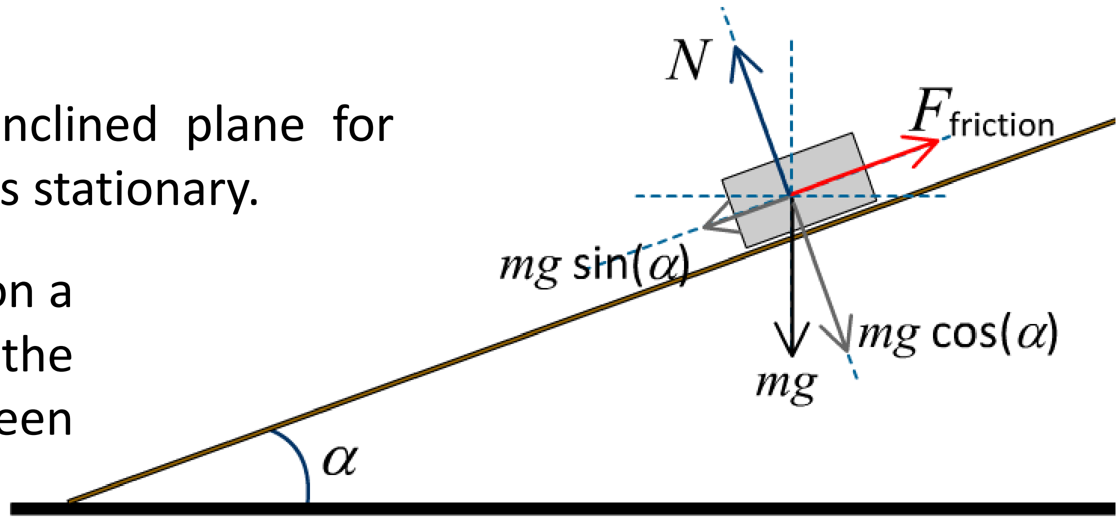
$$F_k \propto N$$

$$\boxed{F_k = \mu_k N}$$

  - μ_k is called coefficient of kinetic friction
  - $\mu_k < \mu_s$
  - It depends on the nature of surfaces in contact

Angle of repose

It is the maximum angle of an inclined plane for which the body placed on it remains stationary.



Consider a body of mass m placed on a rough inclined plane. Let μ_s be the coefficient of static friction between the body and the ground.

Click here for simulation

Considering component of forces perpendicular to the plane

$$N - mg\cos(\alpha) = 0$$

$$N = mg\cos(\alpha) \qquad \text{(i)}$$

Considering component of forces parallel to the plane

$$mg\sin(\alpha) - F_{\text{friction}} = 0$$

$$mg\sin(\alpha) - \mu_s N = 0$$

Substituting N from equation (i)

$$mg\sin(\alpha) - \mu_s mg\cos(\alpha) = 0$$

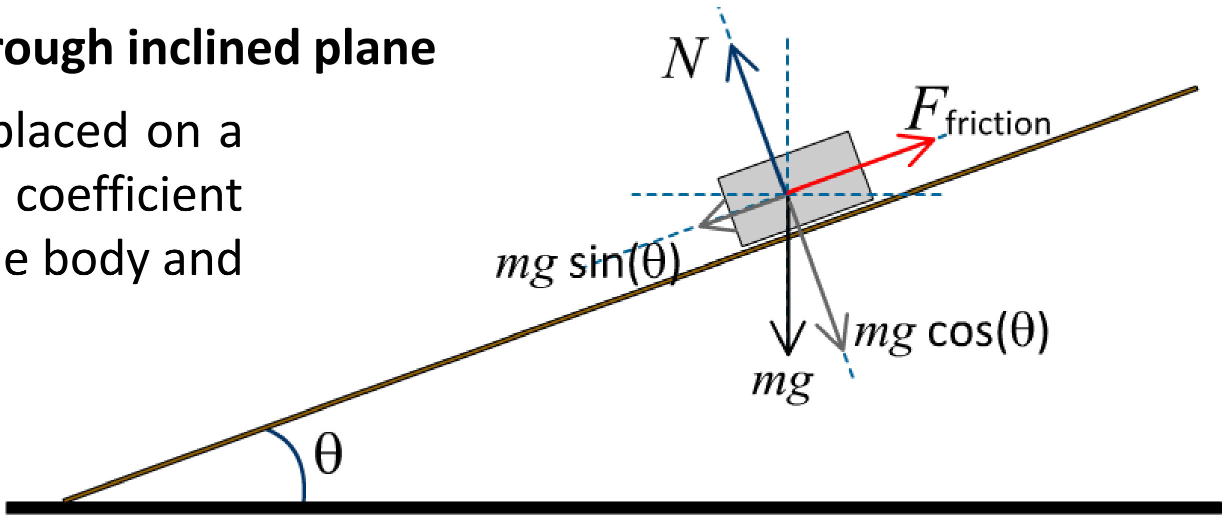
$$mg\sin(\alpha) = \mu_s mg\cos(\alpha)$$

$$\sin(\alpha) = \mu_s \cos(\alpha)$$

$$\boxed{\tan(\alpha) = \mu_s}$$

Acceleration of a body on a rough inclined plane

Consider a body of mass m placed on a rough inclined plane. Let the coefficient of kinetic friction between the body and the plane be μ_k.



Click here for simulation

Considering component of forces perpendicular to the plane

$$N - mg\cos(\theta) = 0$$

$$N = mg\cos(\theta) \quad \text{(i)}$$

Considering component of forces parallel to the plane

$$mg\sin(\theta) - F_{\text{friction}} = ma$$

$$mg\sin(\theta) - \mu_k N = ma$$

Substituting N from equation (i)

$$mg\sin(\theta) - \mu_k mg\cos(\theta) = ma$$

$$a = g\sin(\theta) - \mu_k g\cos(\theta)$$

$$\boxed{a = g[\sin(\theta) - \mu_k\cos(\theta)]}$$

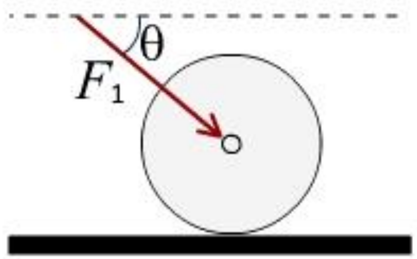
Laws of motion

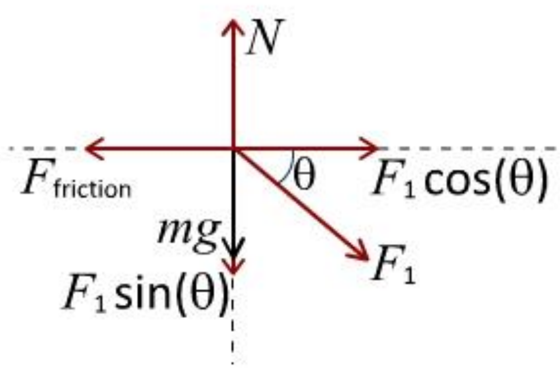
Pulling is easier than pushing

Consider a lawn roller placed on a horizontal surface. Let μ be the coefficient of friction between the lawn roller and the ground.

<u>Case I : pushing the lawn roller</u>

A force $\boldsymbol{F}_1$, applied at an angle θ w.r.t. the horizontal, is used to push the lawn roller.





Considering vertical component of forces

$$N + (-F_1 \sin(\theta)) + (-mg) = 0$$

$$N = F_1 \sin(\theta) + mg \qquad \text{i}$$

Considering horizontal component of forces

$$F_1 \cos(\theta) + (-F_f) = 0$$

$$F_1 \cos(\theta) = \mu_s N$$

Substituting N from eq (i) we get

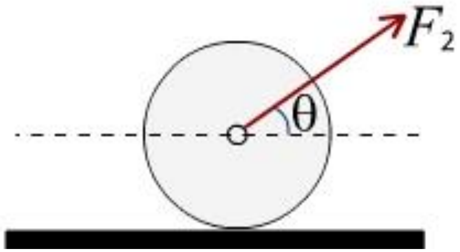
$$F_1 \cos(\theta) = \mu_s \left[F_1 \sin(\theta) + mg\right]$$

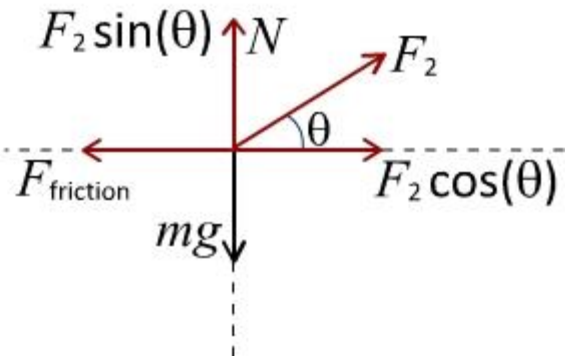
$$F_1 = \frac{\mu_s mg}{\left[\cos(\theta) - \mu_s \sin(\theta)\right]} \qquad \text{ii}$$

Pulling is easier than pushing

Case II : pulling the lawn roller

A force $\boldsymbol{F}_2$, applied at an angle θ w.r.t. the horizontal, is used to pull the lawn roller.





Considering vertical component of forces

$$N + F_2\sin(\theta) + (-mg) = 0$$

$$N = mg - F_2\sin(\theta) \qquad \text{iii}$$

Considering horizontal component of forces

$$F_2\cos(\theta) + (-F_f) = 0$$

$$F_2\cos(\theta) = \mu_s N$$

Substituting N from eq (iii) we get

$$F_2\cos(\theta) = \mu_s\left[mg - F_2\sin(\theta)\right]$$

$$F_2 = \frac{\mu_s mg}{\left[\cos(\theta) + \mu_s\sin(\theta)\right]} \qquad \text{iv}$$

Comparing equations (ii) & (iv) it is observed that $F_1 > F_2$. Therefore pulling a lawn roller is easier than pushing it.

Rolling friction

- Frictional force between bodies in which one body is rolling over the other is called rolling frictional force.
- Rolling frictional force is directly proportional to the normal reaction
- Rolling frictional force depends on the nature of surfaces in contact.

$$F_r \propto N$$

$$\boxed{F_r = \mu_r N}$$

- μ_r is called coefficient of rolling friction
- $\mu_r < \mu_k < \mu_s$

During rolling, the surfaces in contact get momentarily deformed a little, and this results in a finite area (not a point) of the body being in contact with the surface. The net effect is that the component of the contact force parallel to the surface opposes motion.