# FRICTION

## Introduction:

If we push a body on the surface it will moves a certain distance and comes to rest. But according to Newton's first law the body should have continued to move with uniform velocity. Thus an opposing force must be acting on the body. This force is always normal to the surfaces in contact and opposite to the motion of the body. This force is known as frictional force (or) friction.

## Friction:

The force which opposes the relative motion between the two surfaces in contact is called the force of friction. (or)

The force opposing the motion of one body over the surface of another body in contact is known as the force of friction.

## Cause of friction:

In the universe there is no perfectly smooth surface of a body. When viewed through a powerful microscope every body has irregularities (and projections) on its surface. When a body is placed on another body at the contact of surfaces, local welding (adhesions) takes place due to surfaces of given bodies.

## Laws of friction:

1) Friction opposes the relative motion between two surfaces in contact.

2) Friction is independent of the area of contact between the surfaces.(As long as the normal reaction doesn't change).

3) Friction depends on nature of surface in contact and lubricants in between the surfaces.

4) Friction is directly proportional to normal force.

$f \propto N \Rightarrow f = \mu N$ here $\mu$=coefficient of friction(constant).

## Advantages (or) uses (or)Necessity of friction:

1) Due to the friction we can walk and run on the floor.

2) Friction is necessary to hold the objects in hand.

3) A match stick is lighted because of friction.

4) Machines works with motors by a friction belt.

5) Friction between wheels and brakes is necessary to stop the vehicles.

6) Friction is useful to fix the nails in walls and wooden blocks.

7) If sand is spread on wet ground, so that the friction is increased due to roughness and avoids slipping.

**Disadvantages (or) Loses of friction:**

1) Due to the friction the parts of a body will damage in accidents (or) collisions.

2) Friction among different parts reduces the life of a machine.

3) Due to the friction between different parts of an engine, the energy will loses and the efficiency of the engine decreases.

4) Friction between rotating parts of a machine produces heat due to this the power of a machine will decreases.

**Minimizing(reducing) methods of friction:**

1) Polishing: Friction between two surfaces can be reduced by polishing them. Due to this the inter locking and projections are minimized.

2) Lubricants: Applying substances like oils and grease as lubricants between the surfaces fills the irregularities on the surfaces and reduces friction.

3) Rolling bodies: Rolling bodies like wheels and ball bearings reduces the friction, because rolling friction is less than sliding (kinetic) friction.

4) Streamlining: The friction due to air is reduced by giving suitable shape to automobiles and aeroplanes.

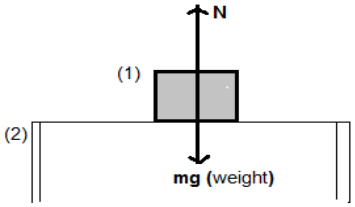
**Normal reaction (or) Normal force:**----->(component of weight of the body)

"It is the reaction force pointing perpendicular to the surface".

[frictional resistance to the relative motion of two solid objects is usually proportional to the force which presses the surfaces together as well as the roughness of the surfaces. This force is known as normal force and it is normal to the surfaces.]

**Case(1)**: Suppose a 1st body is placed on 2nd body without any external force. The weight (gravitational force) 'mg' of 1st body is in downward direction. But according to Newton's third law there is an equal and opposite force to this, that is force applied by the 2nd body on 1st body.

This opposite force is known as normal force which is normal to the surface of contact.




That is Normal force **N** = – **mg** in directionally

**N** = **mg** in magnitude

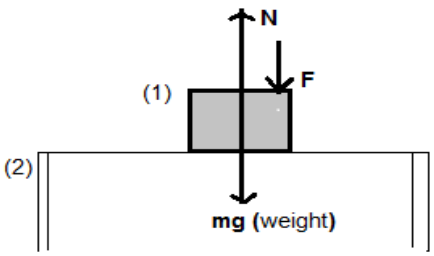
and the resultant force on a body is Zero that is body is at rest (not moving). That is net force→N + **mg** = 0

**Case(2):** If a force F acts downward on the 1st body then

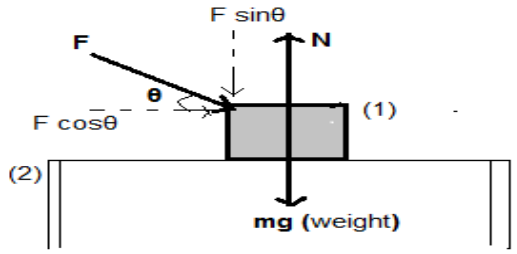
the normal force is greater than the weight,

and it is equal to N = **mg**+F. Here also body is at rest.

N↑ and f↑



**Case(3):** If a force f pushes downward on the 1st body




with an angle 'θ' then the normal force is N = **mg** + F sinθ.

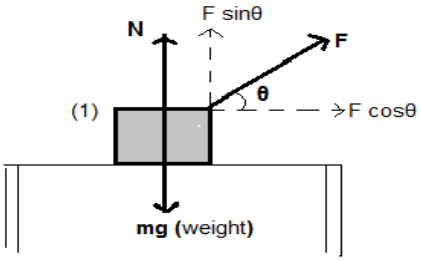
N↑ and f↑

**Case(4):** If a force F pulls upward on the 1st body with

An angle 'θ' then the normal force is less than the weight.

N + F sinθ = **mg**

N = **mg**-F sinθ N↓ and f↓



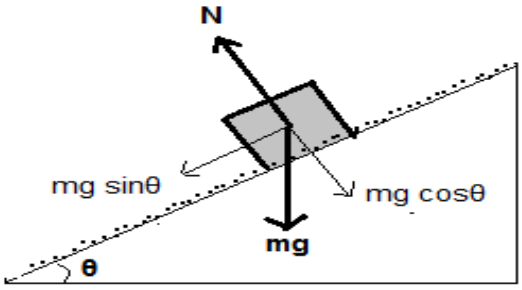

**Note:** normal force decreases while pulling the body and it is increases while pushing the body. Since the frictional force is proportional to normal reaction , it is easier to pull an object than to push it.

**Case (5)**: for an object sitting on an incline plane, then

the normal force is less than the weight.

θ≠0°, θ>0° normal force N = **mg** cosθ < **mg**

that is N↓ weight ↓ and f↓




**Types of friction:**

Depending on the behaviour of surfaces friction is classified into three types.

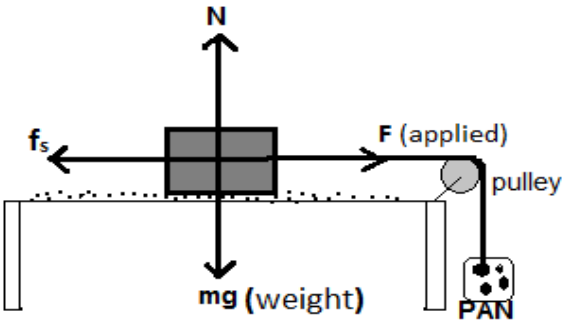
1)Static friction
2)Kinetic friction (or) dynamic friction
3)Rolling friction

**(1)Static friction:**

Static friction is a force which resists the relative movement of two objects which are touching each other. (or) Friction between surfaces when they are at rest even when an external force acts is called the static force.

Let a body of weight 'mg' is placed on a surface and it is connected to a PAN by a pulley.

When an applied force F is increased gradually y adding the weights in a PAN, friction also increases by same amount and the body is remains in rest . This friction is known as static friction. $F_{static} = F_{applied}$.




"for maximum static friction the body will just starts to move then the friction is known as limiting friction."

**Laws of static friction (or) Limiting friction:**

(a)static friction depends on the nature of surfaces in contact.

(b)Static friction act tangentially along the surfaces in contact.

(c)Static friction is independent of area of contact between the surfaces.

(d)static friction is directly proportional to Normal force.
that is $f_s \alpha N$ -----> $f_s = \mu_s N$ here $\mu_s$ = coefficient of static friction.

**(2)Kinetic friction:**

'A frictional force present when one body slides (moving) over another body is known as dynamic friction (or) kinetic friction. Kinetic friction is always less than static friction.

Let a body will just starts to move then it has limiting friction. Now, if we add extra weights in a PAN that is applied force increased then friction will be fixed (decreased) and the body continues to move, then the friction is known as kinetic friction.

**Laws of kinetic friction (or) dynamic friction:**

(a)Kinetic friction depends on nature of surfaces in contact.

(b)Kinetic friction act tangentially along the surfaces in contact.

(c)Kinetic friction is independent of area of contact and velocity of sliding (moving).

(d)Kinetic friction is directly proportional to normal force.
that is $f_k \alpha N$ -----> $f_k = \mu_k N$ here $\mu_k$ = coefficient of kinetic friction.

**(3)Rolling friction:**

When a body like a wheel rolls over the surface of another body, then the friction is known as rolling friction. (OR) 'A force apposing rolling of one body over the surface of another body is called rolling friction.'

Rolling friction is far less than limiting and kinetic friction. Bodies like cylindrical rollers and spheres roll over other surfaces in contact. If two bodies are not deformed there exist a single point (or) line of contact between the surfaces. But in real one of the surface get deformed and exist some area of contact.

This gives friction known as rolling friction.

*Degree of deformation*:-----> Deformation is treated as the displacement of a continuum body (or) is a condition in which a part of the body is not the normal shape because of injury.
Ex: baby born with deformed hands.

**Laws of rolling friction:**

(a)Rolling friction depends on nature and state of surfaces.

(b)Rolling friction depends on degree of deformation of surfaces in contact.

(c)Rolling friction acts tangentially along the surfaces in contact.

(d)Rolling friction is inversely proportional to radius of the rolling bodies.

(e)Rolling frictional force is directly proportional to normal force of the body.
that is $f_r \alpha N$ -----> $f_r = \mu_r N$ here $\mu_r$ = coefficient of kinetic friction.

**Coefficient of friction:**

In general any frictional force is directly proportional to normal force.

that is $f \propto N$ -----> $f = \mu N$ -----> $\mu = f/N$ here $\mu$ = coefficient of friction(constant)----> no units.

Steel on steel --------> $\mu_s = 0.6$ , $\mu_k = 0.2$

Leather on wood -------> $\mu_s = 0.5$ , $\mu_k = 0.125$

Rubber tyre on dry road --------> $\mu_s = 1$ , $\mu_k = 0.7$ [less value of μ means high elasticity]

**Coefficient of static Friction:**

Ratio of the static frictional force to the normal force is known as coefficient of static friction.

That is $\mu_s = \frac{f_s}{N}$ -------> no units

**Coefficient of Kinetic Friction:**

Ratio of the Kinetic frictional force to the normal force is known as coefficient of static friction.

That is $\mu_k = \frac{f_k}{N}$ -------> no units

**Coefficient of Rolling Friction:**

Ratio of the Rolling frictional force to the normal force is known as coefficient of static friction.

That is $\mu_r = \frac{f_r}{N}$-------> no units

**Note:** (1)In general for a given pair of surfaces $\mu_s > \mu_k > \mu_r$ that is $f_s > f_k > f_r$

(2)Any $\mu$ is in between 0 and 1 that is $\mu_s > 0$ , $\mu_k > 0$ , $\mu_r > 0$

(3)Coefficient of friction $\mu$ is used to estimate the smoothness(or)roughness of surfaces in contact.

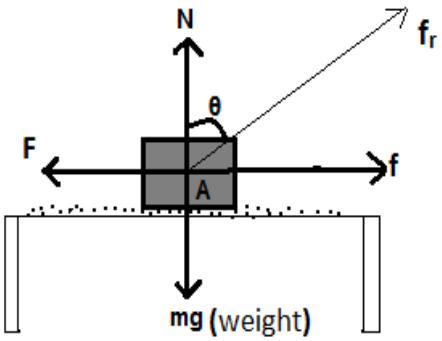
(4)$\mu$ value depends on nature of pair of surfaces in contact.

(5)$\mu$=0 means no applied force. $\mu > 0$ means there is an applied force.

**Angle of friction of a body on Horizontal surface :**

"angle of friction 'θ' is the angle between the normal reaction and the resultant of friction and normal reaction."

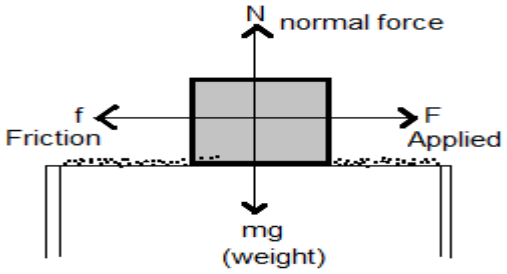
When a body of mass 'm is placed on a surface a normal reaction N exists which is equal and opposite to weight. When a force 'F' tries to move the body a frictional force 'f' opposes this motion.




If 'θ' is angle of friction then $\tan\theta = \frac{Nf_r}{AN} = \frac{Af}{AN} = \frac{frictional\ force}{Normal\ force} = \mu$

$$\theta = \tan^{-1}(\mu) = \tan^{-1}(\frac{f}{N})$$

**Motion of a body on a Rough Horizontal Plane: (one dimensional motion)** When a force F acting on a body of mass 'm' moves it on a rough horizontal surface with a velocity 'U'. Due to frictional force 'f' the body will be continuously retarded and finally it will come to rest, so acceleration of the body is known as retardation.




Force acting on a body F=ma

Frictional force $f \alpha N$ -------> $f = \mu N = \mu m$

In static condition $F = -f$ ----> $ma = -\mu mg$

-----> $a = \mu g$ is the body retardation

$a = -\mu g$ is the acceleration of the body.

In this case equations of motion are $V = U - (\mu g)t$

$$V^2 - U^2 = -2\mu g S$$

$$S = Ut - \frac{1}{2}\mu g\, t^2$$

$$S_n = U - \mu g(n - \frac{1}{2})$$

If body moves with initial velocity 'U' and time taken for the body to come to rest is obtain by V = 0, $a = -\mu g$ , U=U --------> V = U + at -------> 0 = U –(μg)t --------> $\mathbf{t = \frac{U}{\mu g}}$

And distance travelled by the body before coming to rest obtain by V = 0, $a = -\mu g$ , U=U

Then $V^2 - U^2 = 2aS$ ------> $0 - U2 = -2\mu g S$ ------> $\mathbf{S = \frac{U^2}{2\mu g}}$

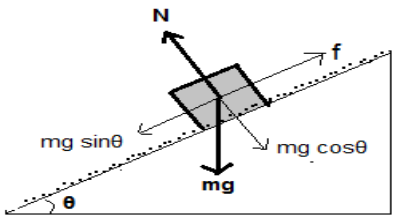
And work done by a frictional force $W = fS = \mu mgS = \frac{1}{2} mU^2$

**Inclined Plane: (two dimensional motion)**

An inclined plane is a flat surface set at an angle (other than a right angle) against a horizontal surface. (or) Any plane surface which makes an angle 'θ' (such that $0^o < \theta < 90^o$) with the horizontal surface is called inclined plane.

Motion of a body on an incline plane is governed by the angle of incline and nature of surfaces in contact. Inclined plane is used to reduce the weight of the body without using external force. Inclined plane is may be Rough (with friction) (or) Smooth (without friction) surfaces.

**Angle of repose: (angle of friction in the case of inclined plane)**




"It is the minimum angle of inclination o a plane a body placed on it starts sliding is called the angle of Repose."

Static friction exist below this angle. When a body of mass 'm' is placed on inclined plane, the static frictional force acts between body and plane.

$mg \sin\theta_r = f_r = \mu_s N$ -----> $\cancel{mg} \sin\theta_r = \mu_s \cancel{mg} \cos\theta_r$

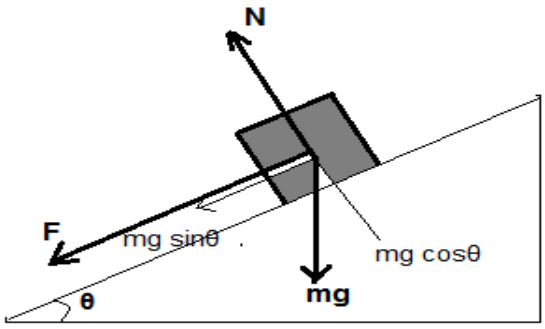
$$\frac{\sin\theta r}{\cos\theta r} = \mu_s$$

$\text{Tan}\theta_r = \boldsymbol{\mu_s}$ ----------> $\theta_r = \tan^{-1}(\boldsymbol{\mu_s})$

Once the motion starts, the body continues to slip even if the angle of inclination is reduced by a small amount.

At a particular angle $\theta_k$ less than angle of repose $\theta_r$, the body slides down with uniform speed. This angle is called 'angle of uniform slip ($\theta_k$).

**Coefficient of friction in the case of inclined plane:**




"Coefficient of friction between the body and inclined plane is equal to tangent of the angle of inclination ( $\theta$ , $\theta_k$ --------)."

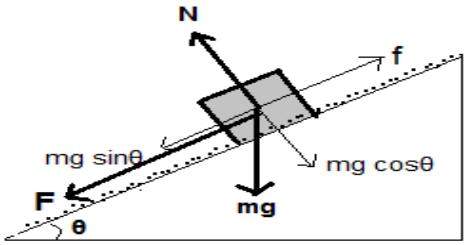
When the body of mass 'm' is placed on a rough inclined surface with angle o inclination 'θ'.

A force which is used to come down the body is mgsinθ , it is balanced by frictional force.

Then coefficient of friction $\mu = \frac{f}{N} = \frac{\boldsymbol{mg}\, sin\theta}{\boldsymbol{mg}\, cos\theta}$ ------> $\boldsymbol{\mu} = \tan\theta$

**Motion of a body on an Rough (with friction) inclined plane when body sliding down:**

Consider a block of mass '**m**' placed on an Rough inclined plane, which makes an angle 'θ' with the horizontal plane. The weight W = **mg** (gravitational force) of the block is acting vertically down ward. The weight of the block can be resolved into two rectangular components that is **mg**cosθ and **mg**sinθ. Other forces acting on the block are




(1)normal reaction N which is perpendicular to the inclined plane of contact.

(2)frictional force which is opposite to the direction of motion (ma) of block.

Let motion of a block on inclined plane as x,y coordinate system. If block slides down with acceleration 'a' then the resultant force in x-direction is $\sum F_x = \boldsymbol{m}a$ and resultant force in y-direction is $\sum F_y = 0$

$\sum F_x = \boldsymbol{m}a$

$\boldsymbol{mg}\sin\theta - f_s = \boldsymbol{m}a$

$\boldsymbol{mg}\sin\theta - \boldsymbol{\mu_s}N = \boldsymbol{m}a$

$\boldsymbol{mg}\sin\theta - \boldsymbol{\mu_s}\,\boldsymbol{mg}\cos\theta = \boldsymbol{m}a$

$\sum F_y = 0$

$\boldsymbol{mg}\cos\theta - N = 0$

$N = \boldsymbol{mg}\cos\theta$

$a = \boldsymbol{g}\sin\theta - \boldsymbol{\mu_s}\,\boldsymbol{g}\cos\theta$ ---------> here $\theta > \theta_r$ for block slide down

if $\theta < \theta_r$ then block doesn't slides down.

**Motion of a body on an smooth (without friction) inclined plane when body moving down:**

Consider a block of mass '**m**' place on an smooth inclined plane, which makes an angle 'θ' with the horizontal plane. The weight w = **mg** (gravitational force) of the block is acting vertically downward. The weight of the block can be resolved into two rectangular components that is **mg**cosθ and **mg**sinθ. Other forces acting on the block are

1)normal reaction N which is perpendicular to the inclined plane of contact.

2)frictional force which is opposite to the direction of motion (**m**a) of block.

Let motion of a block on inclined plane as x,y coordinate system. If block slides down with acceleration 'a'

then the resultant force in x-direction is $\sum F_x = \mathbf{m}a$

$$\mathbf{mg}\sin\theta - 0 = \mathbf{m}a$$

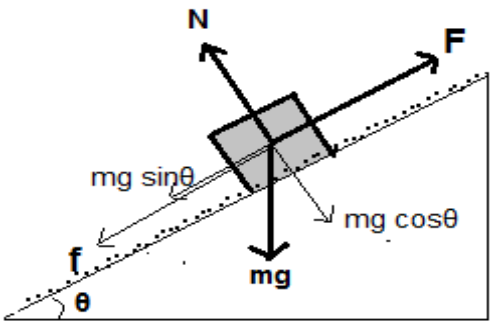
$$\boxed{a = \mathbf{g}\sin\theta}$$

in y-direction is $\sum F_y = 0$ --------> $\mathbf{mg}\cos\theta - N = 0$ -------> $N = \mathbf{mg}\cos\theta$

If the block starts from point A to point B of plane length 'L' then U = 0, V = V, S = L, a = **g**sinθ

**Motion of body on an Rough (with friction) inclined plane when body moving up:**

Consider a block of mass '**m'** placed on an Rough inclined plane, which makes an angle 'θ' with the horizontal plane. The weight W = **mg** (gravitational force) of the block is acting vertically downward. The weight of the lock can be resolved into two rectangular components that is **mg**cosθ and **mg**sinθ. Other forces acting on the block are




1)Normal reaction N which is perpendicular to the inclined plane of contact.

2)frictional force which is opposite to the direction of motion(ma) of block.

Let motion of a block on inclined plane as x,y coordinate system. If the block moving up with the use of pulley and PAN with acceleration 'a'

then the resultant force in x-direction is $\sum F_x = \mathbf{m}a$ , and resultant force in y-direction is $\sum F_y = 0$

$\sum F_x = \mathbf{m}a$

$-\mathbf{mg}\sin\theta - f_s = \mathbf{m}a$

$-\mathbf{mg}\sin\theta - \mu_s N = \mathbf{m}a$

$-\mathbf{mg}\sin\theta - \mu_s \mathbf{mg}\cos\theta = \mathbf{m}a$

$\sum F_y = 0$

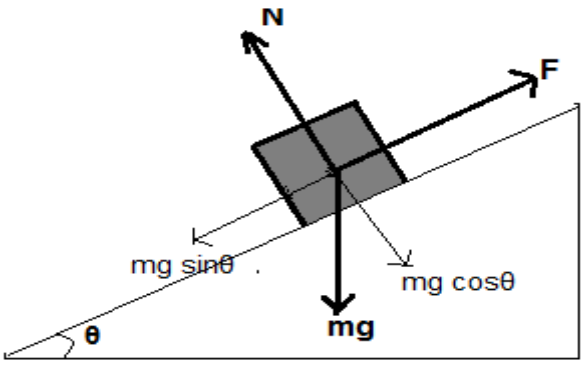
$\mathbf{mg}\cos\theta - N = 0$

$N = \mathbf{mg}\cos\theta$

$\boxed{a = -\mathbf{g}\sin\theta - \mu_s \mathbf{g}\cos\theta}$ --------> is the retardation of the body.

**Motion of body on an smooth(without friction) inclined plane when body moving up:**

Consider a block of mass 'm' placed on an smooth inclined plane, which makes an angle 'θ' with the horizontal plane. The weight w = mg (gravitational force) of the lock is acting vertically downward.




The weight of the lock can be resolved into two rectangular components that is **mg**cosθ and **mg**sinθ.

1)normal reaction N which is perpendicular to the inclined plane of contact.

2)frictional force which is opposite to the direction of motion (ma) of block.

Let the motion of a block on inclined plane as x,y coordinate system. If block slides down with acceleration 'a'

then the resultant force in x-direction is $\sum F_x = \mathbf{m}a$ ------> $-\mathbf{mg}\sin\theta - 0 = \mathbf{m}a$

$$\boxed{a = -\mathbf{g}\sin\theta}$$ ------> a is retardation

in y-direction is $\sum F_y = 0$ --------> $\mathbf{mg}\cos\theta - N = 0$ -------> $N = \mathbf{mg}\cos\theta$

If the block starts moving up from point 'B' with initial 'U', after travelling length of plane 'L' it has Zero final velocity at point 'A'. That is U = U , V = 0 , S = L , $a = -\mathbf{g}\sin\theta$

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**PROBLEMS:**1)Find the force of friction on a body of mass 1000kg when it just start sliding on horizontal surface if $\mu = 0.41$ (Hint: $f = \mu mg$ **Ans:** 4018N)

2)A body is sliding **down** on a rough inclined plane which makes an angle 30° with horizontal. Find acceleration. Take $\mu = 0.1414$ (Hint: $a = g(\sin\theta - \mu\cos\theta)$ **Ans:** $a=3.699 m/sec^2$)