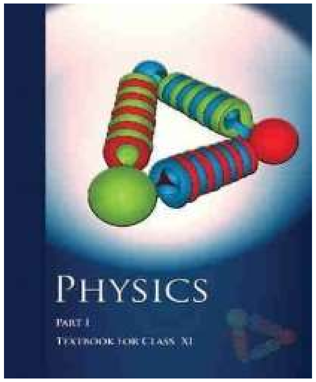

LAWS OF MOTION

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CHAPTER - 5

LAWS OF MOTION

Introduction
Aristotle's fallacy
The law of inertia
Newton's first law of motion
Newton's second law of motion
Newton's third law of motion
Conservation of momentum
Equilibrium of a particle
Common forces in mechanics, friction
Circular motion
Solving problems in mechanics

Removed Topics

Law of inertia, Newton's First law of motion, Newton's second law of motion – momentum, impulse, Newton's Third law of motion.

SUB TOPICS :

- Introduction to laws of motion
- The law of inertia
- Impulse
- Newtons laws of motion
- Conservation of linear momentum
- Equilibrium of a particle
- Common forces in mechanics
- Friction – Types of friction
- Circular motion

INTRODUCTION
TO
LAWS OF MOTION

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Introduction:

External agency is need to provide motion.
Eg: Magnet – Iron

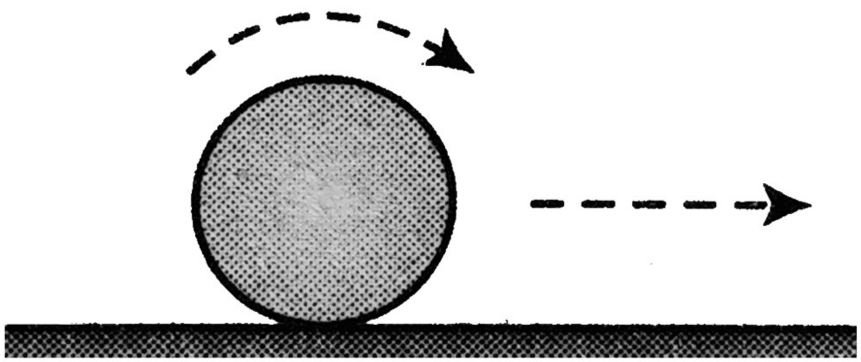
Galileo – External force is required to change the velocity of the body, but no force is needed to maintain the velocity.

Newton – Three laws of motion – while studying the motion, the bodies are treated as point masses.

Aristotle's fallacy:

An external force is required to keep a body in motion.

But there is flaw in Aristotle's argument.



INERTIA

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The law of inertia:

Inertia means resistance to change.

Types of inertia:

1) Inertia of rest

2) Inertia of motion

3) Inertia of direction

Inertia of rest:

It is the inability of a body to change its state of rest by itself.

Eg:

1) Passengers standing in a stationary bus – backward jerk…

2) Horse – rider sitting on a horse at rest…

3) The dust particles on a carpet fall off when it is hit with a stick…

4) When we shake a branch of a mongo tree…

Inertia of motion:

It is the inability of a body to change its state of uniform motion by itself.

Eg:

1) Passengers standing in a moving bus forward jerk…

2) Horse – rider sitting on a moving horse --- stopped suddenly…

3) A person jumping out of a speeding train may fall forward…

4) Long jump…

Inertia of direction:

It is the inability of a body to change its direction of motion by itself.

Eg:

1) When a car moves along a curve suddenly…

2) When a stone tied to one end of a string is whirled in a circle…

3) The rotating wheels of a vehicle throw out mud…

4) When a knife is sharpened by pressing it against a grinding stone…

NEWTON'S LAWS

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Newton's first law of motion:

Every body continues to be in its state of rest or of uniform motion in a straight line unless compelled by some external force.

Importance of 1st law:

1) It gives the concept of inertia and force and enables us to define them.
2) The acceleration of an object is zero if there is no external force acting on it.

Newton’s second law of motion:

The rate of change of momentum of a body is directly proportional to the resultant or net external force acting on the body and takes place in the direction in which the force acts.

$$F \propto \frac{d\vec{P}}{dt} = m\frac{d\bar{v}}{dt} = m\frac{(v-u)}{t}$$

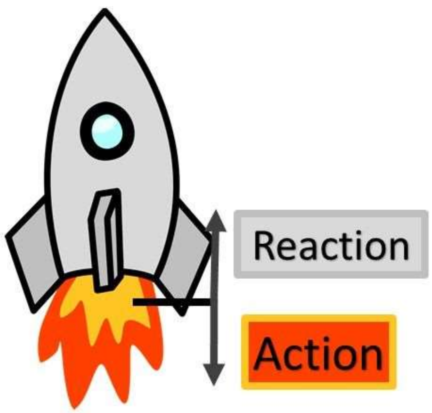
$$F = k \cdot ma \qquad F = ma$$

Importance of 2^{nd} law:

1) This law gives us the measure of force
2) This is the real law of motion because both first and third laws can be derived from this law.

Newton's third law of motion:

To every action, there is always an equal and opposite reaction.



$$F_{action} = -F_{reaction}$$

Image source: https://in.pinterest.com/

IMPULSE

Impulse:

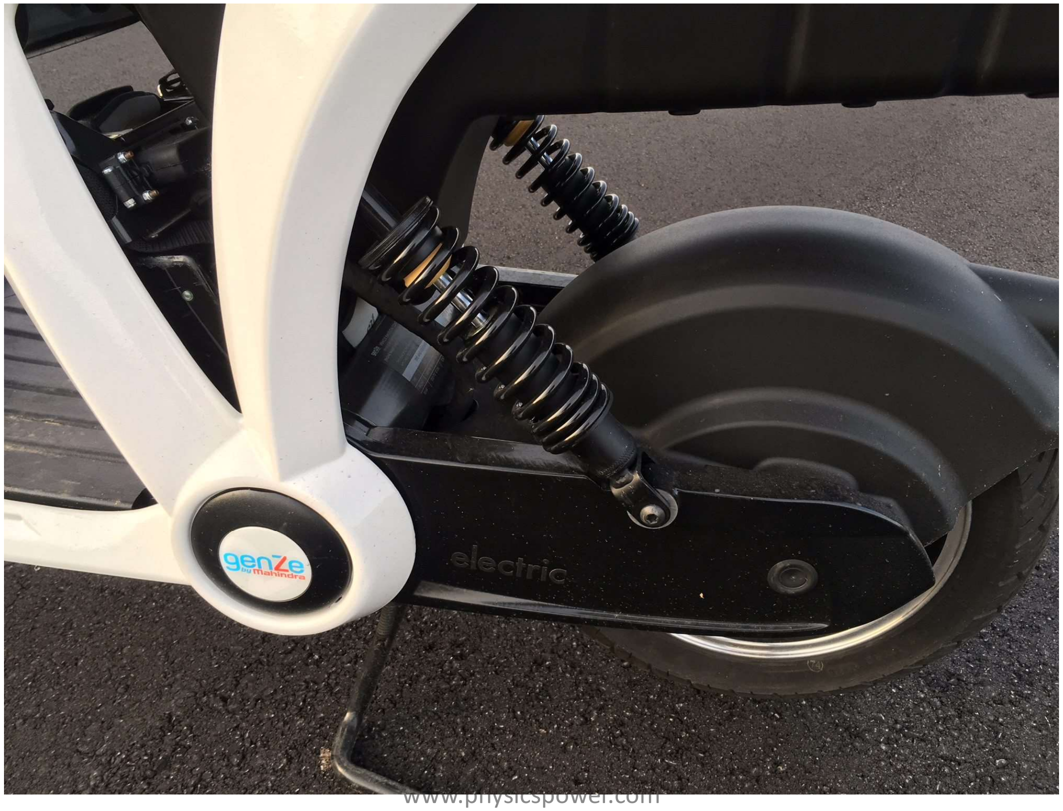
The product of force and time that produces a finite change in momentum of the body is called impulse.

$$\text{Impulse (J)} = \text{Force (F)} \times \text{time (t)}$$

$$\therefore \quad \text{Impulse (J)} = F \times t$$

APPLICATIONS OF IMPULSE

The vehicles like scooter, car, bus, truck etc., are provided with shock absorbers:



A cricket player lowers his hands while catching a cricket ball:

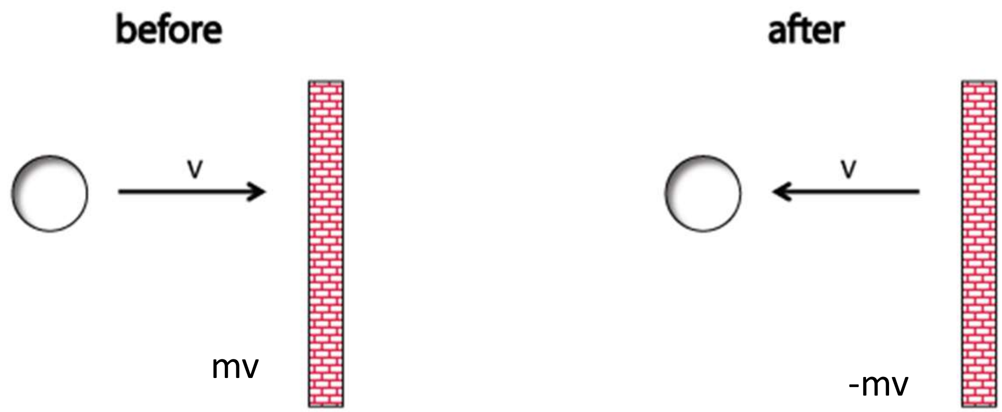
A fielder pulls his hands gradually with the moving ball while holding a catch.

Image source: www.brainly.in

When a person falls from a certain height on a cement floor:

China wares and glass wares are wrapped in paper or straw pieces before packing:

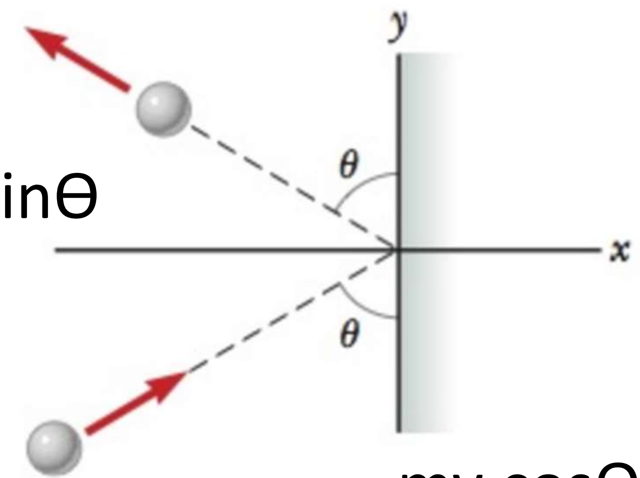
Change in momentum of a body in different cases:



Change in linear momentum $dp = p_f - p_i$

$= -mv - (mv) = -2mv$

Change in momentum of a body in different cases:



mv sinϴ

mv cosϴ

Change in linear momentum along x - axis

$$dp = p_f - p_i$$

$$= -mv \sin\theta - (mv \sin\theta) = -2\, mv \sin\theta$$

CONCERVATION
OF
LINEAR MOMENTUM

Law of conservation of linear momentum:

Under the absence of external force, the total linear momentum of an isolated system of particles is conserved i.e. total linear momentum of the system is constant.

Proof:

When one object exerts a force on other object,

the other object also exerts an equal & opposite force on the first object

Force exerted by Object A = Force exerted by Object B

$$m_1 \frac{(v_1 - u_1)}{t} = -m_2 \frac{(v_2 - u_2)}{t}$$

$$m_1 (v_1 - u_1) = -m_2 (v_2 - u_2)$$

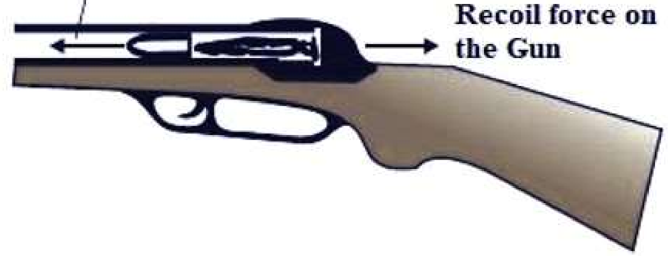
$$m_1v_1 - m_1u_1 = -m_2v_2 + m_2u_2$$

$$m_1v_1 + m_2v_2 = m_2u_2 + m_1u_1$$

∴ Final Momentum of 2 objects = Original Momentum of 2 objects

Thus, momentum is conserved

Practical application of the principle of conservation of linear momentum:



Recoiling of a gun:

After firing their total momentum = momentum of the gun + momentum of the bullet = MV + mv

But according to the conservation principle, momentum before and after must be equal. So, MV + mv = 0

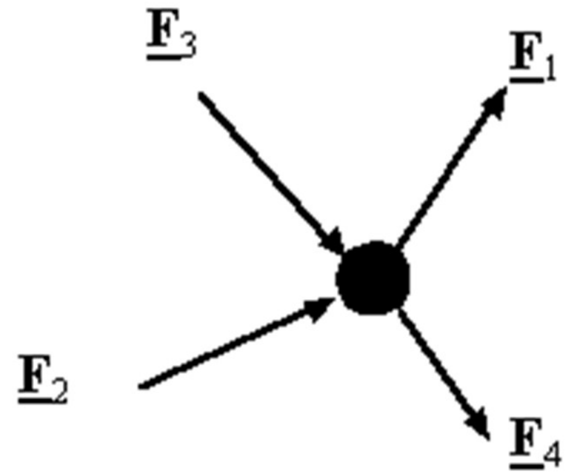
$$mv = -MV = M(-V)$$

Equilibrium of particle:

Sum of all forces acting on the particle is zero.

$$F_1 + F_2 + F_3 + F_4 = 0$$

$$\sum F = 0$$



COMMON FORCES
IN
MECHANICS

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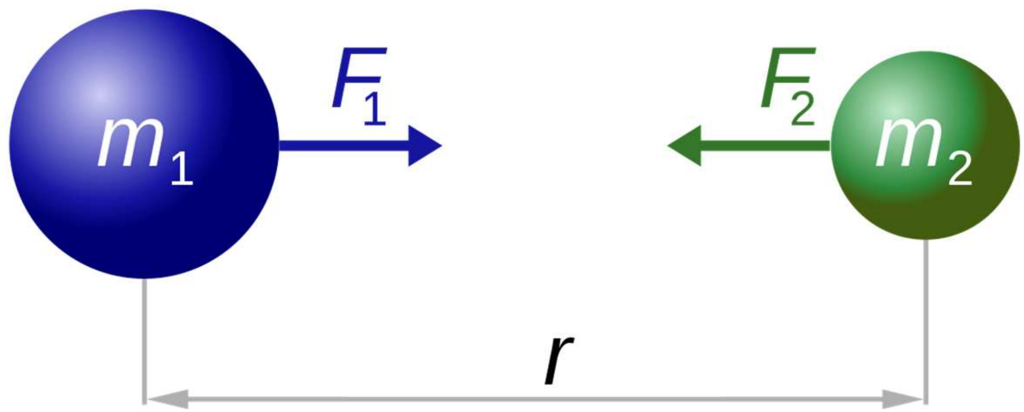
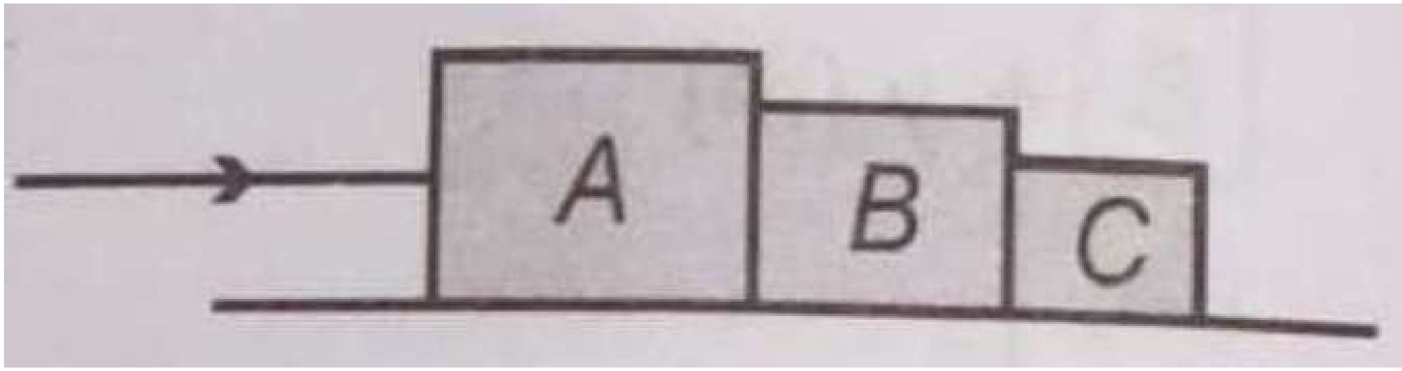
Gravitational forces



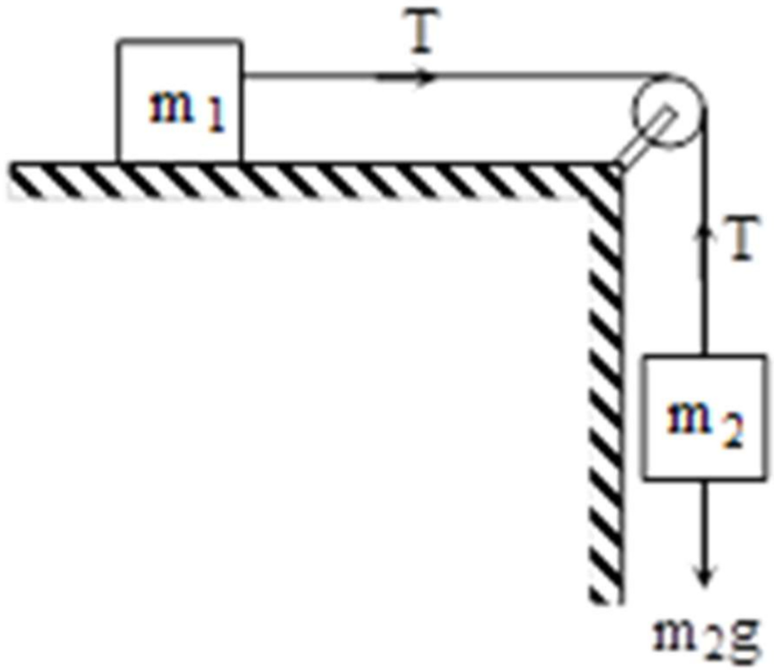
$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

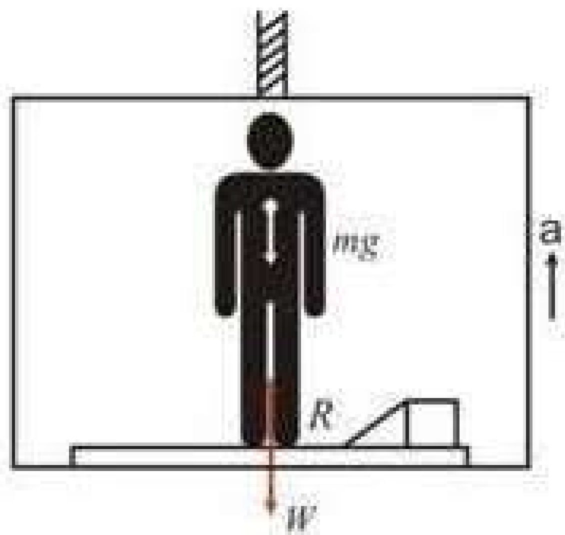
Contact forces:

Contact forces on a body will arise due to a contact with some other objects. It may be a solid or fluid.



Connected bodies:




mg
a
R
W

Application:

When a body of mass 'm' is taken in a lift with acceleration 'a'

While moving upwards apparent weight, $W_1 = m(g + a)$

$$W_1 = W\left(1 + \frac{a}{g}\right)$$

When lift is moving downwards with acceleration 'a' apparent weight, $W_1 = m(g - a)$

$$W_1 = W\left(1 - \frac{a}{g}\right)$$

FRICTION

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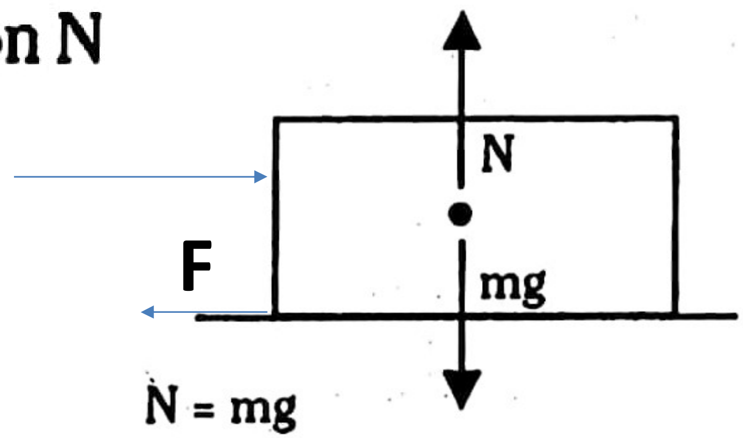
Friction:

Frictional force F ∝ Normal reaction N

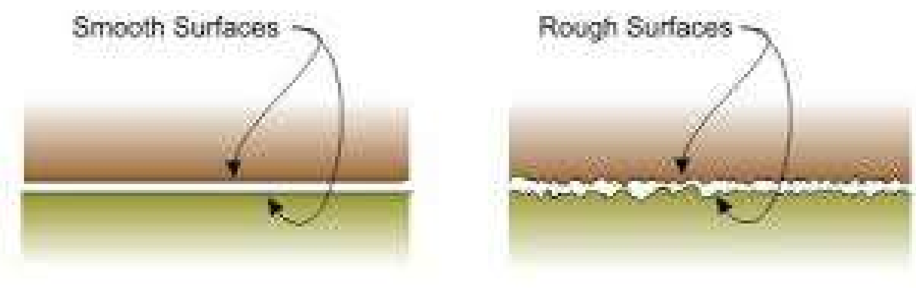
$$F \;\alpha\; N$$

$$F = \mu N$$



Causes of Friction:

Surface irregularities



Friction Force is affected by the smoothness of the surfaces

Friction is due to cohesive or adhesive force

Advantages of Friction:

- We are able to walk because of friction
- It is impossible for a car to move on a slippery road
- Breaking system of vehicles works with the help of friction
- Transmission of power to various parts of a machine through belts is possible by friction
- Friction between roads and tires provides the necessary external force to accelerate the car.

Disadvantages of Friction:

- In many cases we will try to reduce friction because it dissipates energy into heat.
- It causes wear and tear to machine parts
- Generates the heat which may causes damage to the parts of the machines

Methods of reducing Friction:

- Polishing
- Lubricants
- Ball bearings
- A thin cushion of air maintained between solid surface reduces friction.

Types of Friction:

1. Static friction
2. Kinetic friction
3. Rolling friction

Static Friction:

1. Static friction does not exist independently
2. The magnitude of static friction gradually increases with applied force to a maximum value called limiting static friction f_s
3. Static friction opposes the causes of motion
4. Static friction is independent of area of contact
5. Static friction is proportional to normal reaction

$$f_s \ \alpha \ N$$

$$f_s = \mu_s N$$

Kinetic Friction:

1. Kinetic friction is independent of velocity of the body
2. Kinetic friction is independent of area of contact
3. Kinetic friction is proportional to normal reaction

$$f_k \ \alpha \ N$$

$$f_k = \mu_k N$$

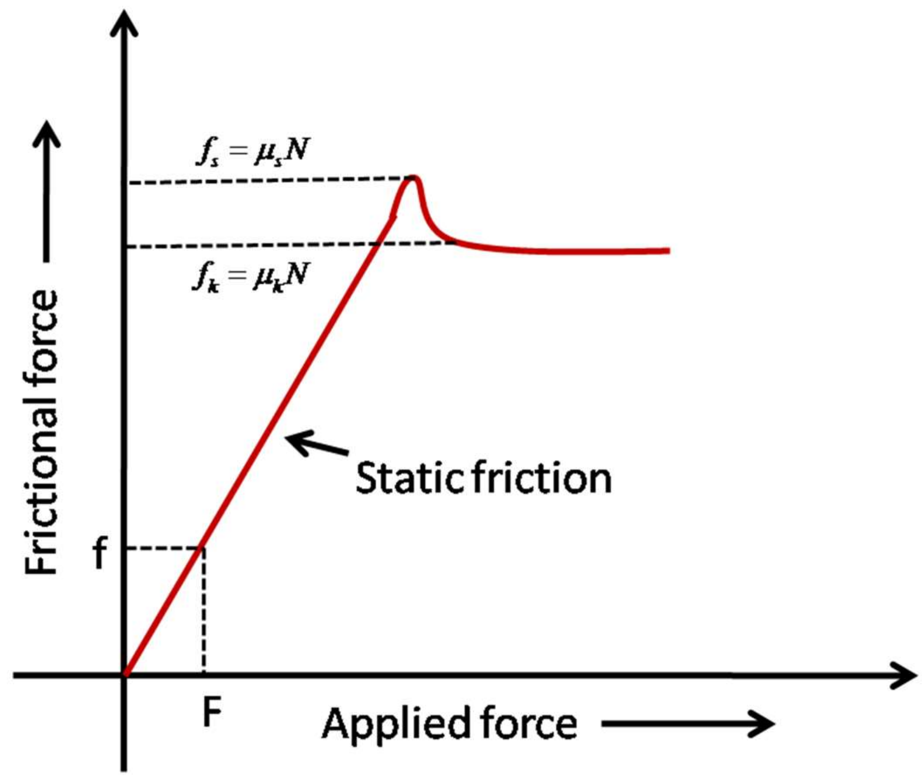


Image source: www.meritnation.com

Rolling Friction:

1. Rolling friction has least value for a given normal reaction when comparted with static friction or kinetic friction
2. Rolling friction will develop a point contact between the surface and rolling sphere.
3. Rolling friction depends on area of contact
4. Rolling friction is inversely proportional to radius of rolling body
5. Rolling friction is directly proportional to normal reaction

$$f_r \ \alpha \ N$$

$$f_r = \mu_r N$$

Angle of Friction:

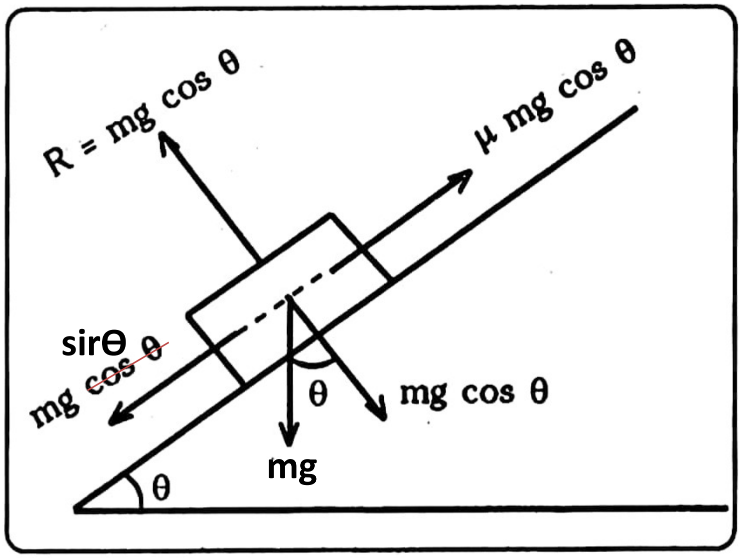
Force acting along the inclined plane in downward direction = mg sin θ.

This component is responsible for downward motion.

Force acting perpendicularly to the surfaces in contact in downward direction = mg cos θ

mg sin θ = Frictional force (f_k)

mg cos θ = Normal reaction (N.R.)



But coefficient friction $\mu_k = \frac{f_k}{N.R}$

But coefficient friction $\mu_k = \frac{f_k}{N.R}$

$$= \frac{mg \sin\theta}{mg \cos\theta} = \tan\theta$$

Here θ is called angle of repose

$$\therefore \mu_k = \tan\theta$$

CIRCULAR MOTION

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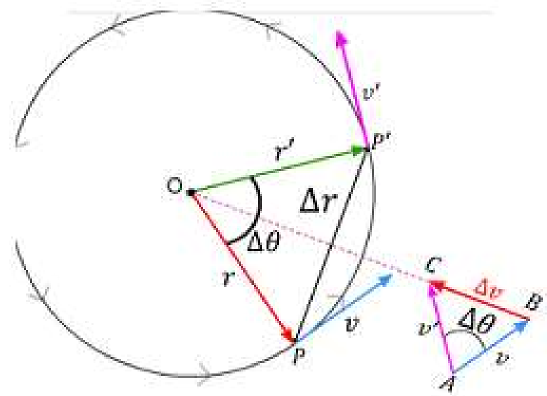
Circular motion:

Centripetal acceleration:



$$\frac{|\Delta v|}{v} = \frac{|\Delta r|}{r}, \quad r \text{ - Radius of the circle}$$

$$|\Delta v| = \frac{v}{r} |\Delta r|$$

$$\frac{|\Delta v|}{\Delta t} = \frac{v}{r} \frac{|\Delta r|}{\Delta t} \quad \Rightarrow \quad |a| = \frac{v}{r} \lim_{\Delta t \to 0} \frac{|\Delta r|}{\Delta t} \qquad \lim_{\Delta t \to 0} \frac{|\Delta r|}{\Delta t} = v$$

$$v = r\omega$$

$$a = \left(\frac{v}{r}\right) v \quad \Rightarrow \quad a = \frac{v^2}{r} \quad \Rightarrow \quad \boldsymbol{a} = \boldsymbol{\omega^2 r}$$

Centrifugal force:

$$F_c = ma_c \quad \text{and} \quad a_c = \frac{v^2}{r}$$

$$a = \omega^2 r$$

$$F_c = \frac{mv^2}{r}$$

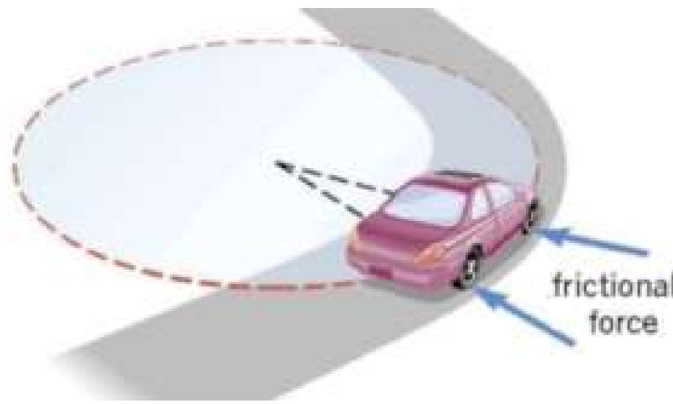
$$F_c = mr\omega^2$$

Motion of a vehicle at a turn (Un-banking road):

Maximum velocity at the turn:

$$Centrifugal\ force = \frac{mv^2}{R}$$

$$force\ of\ friction = \mu mg$$



$$\frac{mv^2}{R} = \mu mg$$

$$v = \sqrt{\mu g R} = v_{max}$$

Motion of a vehicle on a smooth banked road:

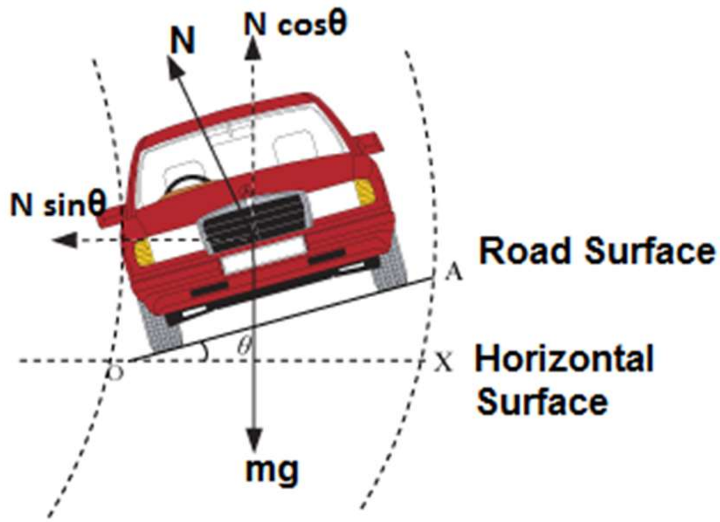
$$N\cos\theta = mg \quad ----(1)$$

$$N\sin\theta = \frac{mv^2}{r} ----(2)$$

Dividing equation (2) by equation (1)

$$\tan\theta = \frac{v^2}{rg}$$

$$or \quad v = \sqrt{rg\tan\theta}$$



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