UNIT-3

DYNAMICS

FORCE

Force is that agent which produces motion or tends to produce motion or stops motion or tends to stop motion.

OR

Force may also be defined as it is an agent that changes or tends to change a body's state of rest or of uniform motion in a straight line.

OR

The rate of change in the momentum of a body is called Force.
Its SI unit is Newton (N)
One Newton (1 N) is the amount of force needed to accelerate a I kilogram mass at the rate of I meter per second squared (m/s^2)

LINEAR MOMENTUM

DEFINITION

The linear momentum of an object of mass **m** moving with a velocity **v** is defined as **the product of mass of a body and its velocity is called momentum**. It is a vector quantity.

FORMULA

Let	m	=	mass of a body
	v	=	linear velocity
and	P	=	linear momentum

Now by definition, we can write

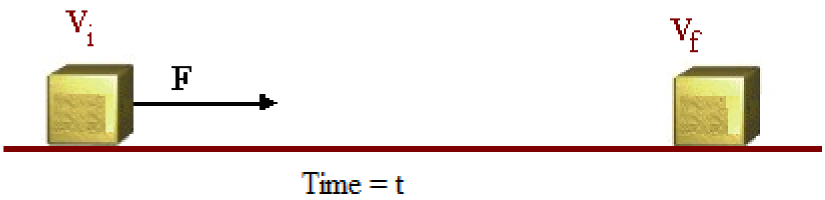
$$P = mv$$

UNIT

The unit of momentum is **Kg m/s**
(**N s**) Newton sec is the unit of momentum in the SI system

NEWTONS SECOND LAW AND LINEAR MOMENTUM

Consider a mass "m" moving with velocity v_i and force "F" changes its velocity "v_f" in time "t".



According to Newton's second law of motion, the net force acting on an accelerating body is given by

$$F = ma \text{ ------------------- (i)}$$

The acceleration of the body of mass m is given by

$$a = \frac{V_f - V_i}{t} \text{ -------------(ii)}$$

Substituting the expression of acceleration from equation (ii) in equation (i)

$$F = m\left(\frac{v_f - v_i}{t}\right)$$

$$F = \left(\frac{mv_f - mv_i}{t}\right)$$

$$F = \left(\frac{P_f - P_i}{t}\right)$$

$$F = \left(\frac{\Delta P}{t}\right)$$

$$F = \left(\frac{\text{Change in momentum}}{\text{time interval}}\right)$$

Net force = rate of change of momentum

IMPULSE

Impulse is defined as, ***"The sudden force acting on an object for a short interval of time"***. It is denoted by "J".

FORMULA

Impulse = Force (final time – initial time)
Impulse = Force x Δt
$J = F \times \Delta t$

UNIT

The SI unit of impulse is N s

SAFETY DEVICES:

The equation (F x Δt) is important when it comes to considering a number of safety features in our lives. If you are moving, you have momentum. To stop moving, a force must be applied. According to the equation (F x Δt) if you take longer time to stop, smaller force will be used to slow you down.

Observe a car to identify the safety measures taken to reduce the risk of injuries in road accidents. The car bumpers and grills are designed to provide extra time to reduce speed before any collision.

You can find some crumple zones or bumpers on the front and back sides. Seat belts are provided to keep the passengers from moving suddenly. There are extra cushions and airbags as well. These measures provide extra time to change the momentum of the passenger inside it. This means that force acting on the passenger is less to prevent the risk of fatal injuries.

REASONING QUESTION

Given that momentum is a physical quantity, explain why it has two equivalent forms of units, and how these forms relate to each other.

ANS: momentum is defined as the product of mass of a body and its velocity

$$P = mv$$
$$P = (Kg)\ (m/s)$$
$$P = (Kg)\ (m/s)$$

From Newton's second law of motion

$$F = m\,a$$
$$F = (Kg)\ (m/s^2)$$

Momentum can also be expressed as **force × time**

$$\text{momentum} = force\ x\ time$$
$$P = (Kg)\left(\frac{m}{s^2}\right) x\ s$$
$$P = N\ s$$

This shows the **two equivalent forms of units for momentum** :

1. kg·m/s **(mass × velocity)**
2. N·s **(force × time)**

Both forms are equivalent because:

1 N·s=1 kg·m/s

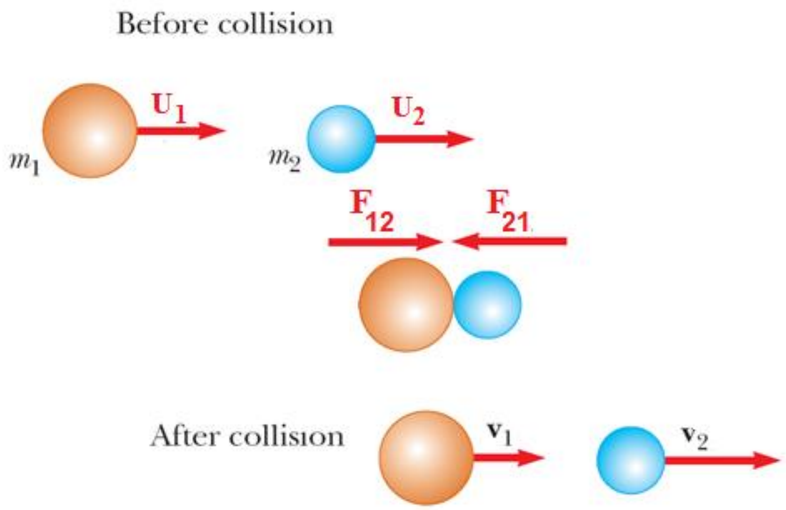
LAW OF CONSERVATION OF MOMENTUM

STATEMENT

In an isolated system of two interacting bodies, The total momentum of the system remains constant.

PROOF

Consider an isolated system of two bodies of masses m_1 and m_2 moving with initial velocities u_1 and u_2 respectively. after collision their velocities becomes V_1 and V_2.



When two bodies collide with each other, they come in contact for a time interval **t**. During this interval let the average force exerted by body m_1 on body m_2 be F_{12}

Change in momentum of 'm_2' after collision = $\mathbf{m_2v_2 - m_2u_2}$

Rate of change of momentum of body A = $\frac{m_2\, v_2 - m_2\, u_2}{t}$

According to Newton's second law of motion;

Net Force acting on the object = The time rate of change of momentum

Therefore,

$$\mathbf{F_{12}} = \frac{m_1v_1 - m_2v_1}{t}$$

Similarly for body 'm_1' we can write

$$F_{21} = \frac{m_1v_1 - m_1u_1}{t}$$

According Newton's third law of motion these forces will be equal but opposite.

$$F_{12} = -F_{21}$$

$$\frac{m_2v_2 - m_2u_2}{t} = -\left(\frac{m_1v_1 - m_1u_1}{t}\right)$$

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

$$\therefore \quad m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

$$\left(\begin{matrix}\text{Total momentum}\\ \text{before collision}\end{matrix}\right) = \left(\begin{matrix}\text{Total momentum}\\ \text{after collision}\end{matrix}\right)$$

This result is known as the **conservation of momentum.**

NEWTON'S FIRST LAW OF MOTION

In the first law of motion, Newton states that,

If the body is at rest, it will remain at rest. If the body is moving, it will continue to move forever at the same velocity (same speed and direction) unless it is acted upon by an external force

EXPLANATION

This law consists of two parts i.e. "if a body is at rest it will remain at rest until it is acted upon by an external force."

FOR EXAMPLE

A book lying on a table or a table lying in a room, they will not change its position until an external force acts on it.

The other part of the law is "if a body is in uniform motion in a straight line it will continue its state until it is acted upon by an external force."

For example

When we roll a ball on a surface it will come to rest due to friction and air resistance if these forces do not oppose the motion of the ball if will continue in uniform motion.

From the above discussion, we conclude two very important concepts.

1. **The definition of force i.e. it is a force that can change the position of force or it is the force that can stop the ball.**

2. **<u>THE INERTIA OF A BODY</u>**

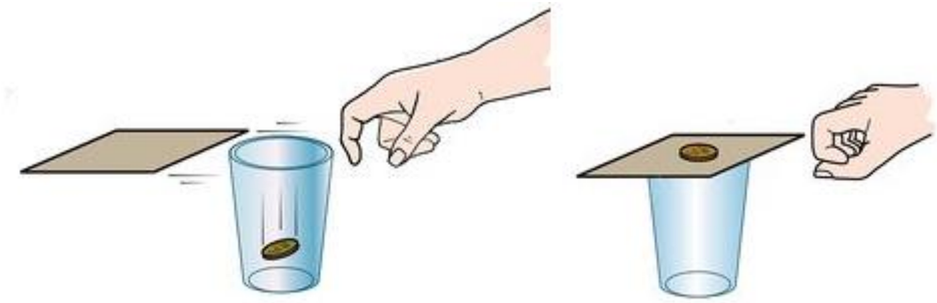
Inertia is the property of an object due to which it tends to continue its state of rest or motion. Inertia is resistance to change the state.

In other words, "Inertia is the tendency of an object to resist a change in its state". Therefore the first law of motion is also called the "Law of Inertia".

<u>EXAMPLE</u>

A person riding a bicycle along a level road does not come to rest immediately, he stops pedaling. The bicycle continues to move forward due to inertia. However the road's friction and air resistance act against its motion and bring it to rest after some time.

A small coin is put on a card and placed over the mouth of a glass. When the card is flicked away with the finger horizontally, the coin drops neatly into the glass due to inertia.



<u>NEWTON'S SECOND LAW</u>

This law provides the most fundamental equation of mechanics and stated as follows:

<u>STATEMENT</u>

When a net force acts on an object, it will cause the object to accelerate in the direction of the force. The amount of acceleration of an object is directly proportional to the net force and inversely proportional to its mass

$$a\ \alpha\ \frac{F}{m}$$

MATHEMATICAL FORM

Let **m** = mass of a body

F = Net force acting on the body

a = acceleration produced.

Now by definition

$$F = m a$$

EXPLANATION

The second law gives the quantitative definition of force and thus provides a means to calculate it

1- ***When m = constant*** ***then*** $a \propto F$ ***………………(i)***

i.e., the greater the force applied on a fixed mass the larger will be the acceleration produced.

2- ***When F = constant*** ***then*** $a \propto \frac{1}{m}$ ***……………(ii)***

i.e., the greater the mass of a body for a constant force to be applied the less will be the acceleration.

On combining equation (i) and (ii), we get

$$a \propto \frac{F}{m}$$

$$a = k\frac{F}{m} \ldots\ldots\ldots\ldots \quad (iii)$$

Where, **k = constant of proportionality**

1 Newton force is defined as the mass of 1kg object produces the acceleration of $1m/s^2$

$$1 = k \times \frac{1}{1}$$

$$1 = K$$

∴ by putting the value of k=1 in equation (iii), we get

$$F = ma$$

UNIT OF FORCE

The SI unit of force is Newton.
The unit of force is as follows

$$F = m\ a$$

Putting m = 1 kg and a= 1 m/s^2, F becomes 1 newton.
So,

1 Newton = 1kg x 1 m/s^2

So, the SI unit of force is $kg.m/s^2$, represented by N (Newton).

NEWTON

One Newton Force is defined as follows

"One Newton is that amount of force which produces an acceleration of one meter per square second in a mass of one kilogram."

$$1N = 1\ kg.\ 1\ m/s^2$$

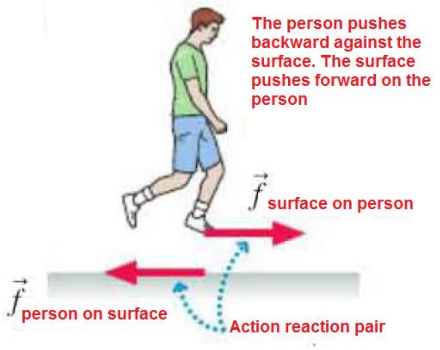
NEWTON'S THIRD LAW

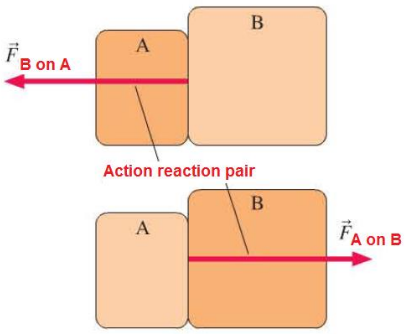
STATEMENT

If two objects interact, the force F_{AB} exerted by object A on object B is equal in magnitude but opposite in direction to the force F_{BA} exerted by object B on object A

OR

"The forces that two interacting bodies exert on each other are always equal in magnitude and opposite in direction.".



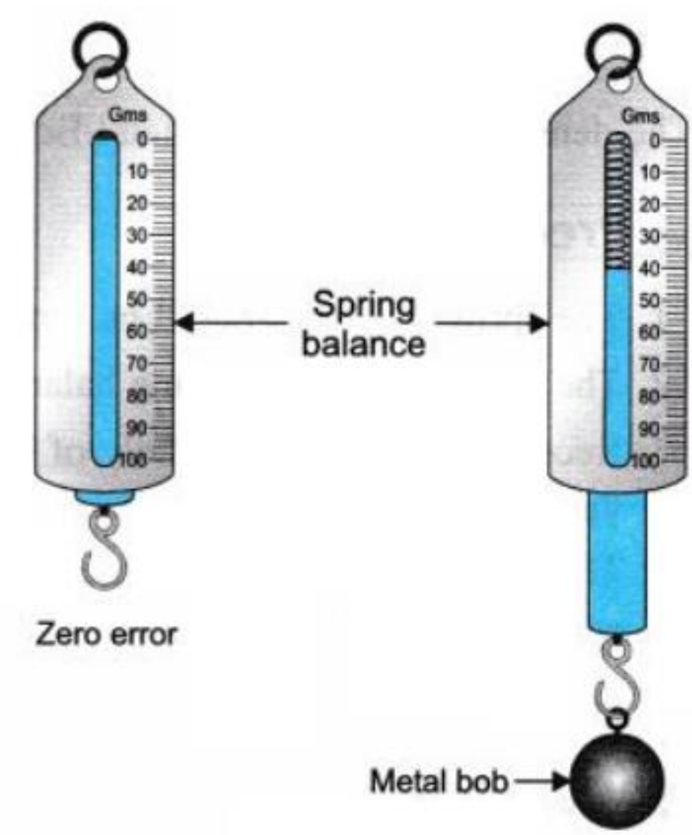


MASS

The mass of a body is the quantity of matter it contains. It is a scalar quantity.

WEIGHT

The weight of a body is the force with which the earth attracts it. It is the force of gravity on it. Weight is a vector quantity

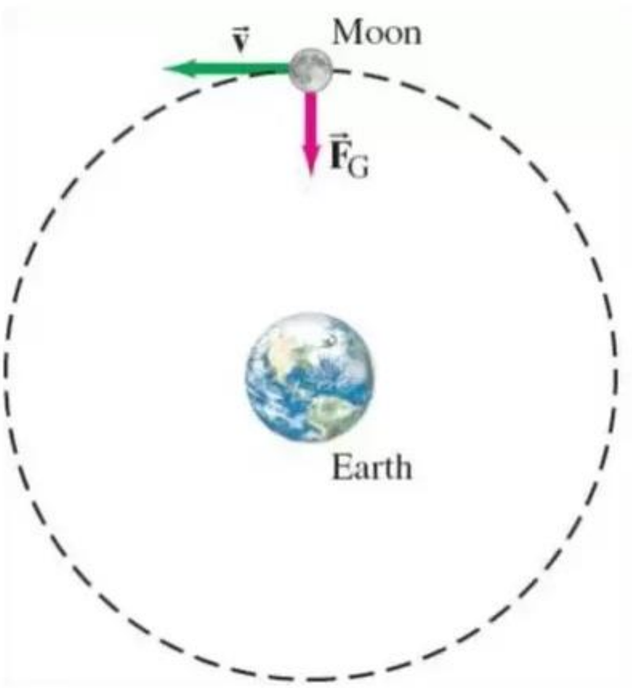


DIFFERENCE BETWEEN MASS AND WEIGHT

MASS		WEIGHT	
1	The quantity of matter in a body is called Mass.	1	Weight is the force with which Earth attracts a body towards its centre.
2	Mass is the measure of inertia.	2	It measures the gravitational force between the earth and the body.
3	$m = F/a$	3	$W = mg$.
4	Mass has no direction.	4	Weight is always directed towards the centre of the Earth.
5	The mass of a body remains constant everywhere.	5	The weight of a body does not remain constant. It is different at different attitudes of earth. g = Acceleration due to gravity. r_e = Radius of earth.
6	Mass can be determined by ordinary balance.	6	A spring balance can determine weight.
7	Mass remains constant at centre of the earth.	7	The weight of a body becomes zero at the centre of the earth.
8	Mass is a scalar quantity	8	Weight is a vector quantity.

UNIFORM CIRCULAR MOTION

If a body covers equal distance in equal interval of time in a circular path, then the body is said to be have uniform circular motion.

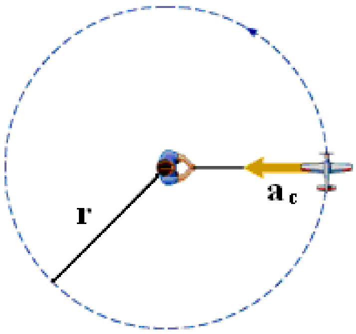


CENTRIPETAL ACCELERATION

DEFINITION:

The acceleration produced due to the changing direction of velocity of a body moving in a circular path with constant speed is called centripetal acceleration.

It is a vector quantity always directed toward the center of circular path.



uniform circular motion

FORMULA

$$\text{centripetal acceleration} = \frac{(\text{speed})^2}{\text{radius}}$$

$$a_c = \frac{v^2}{r}$$

UNITS:

The units of centripetal acceleration are the same as those of an acceleration i.e. m/s^2

CENTRIPETAL FORCE

The force which keep the body moving is a circular path is called centripetal force .It is represented by Fc.

FORMULA:

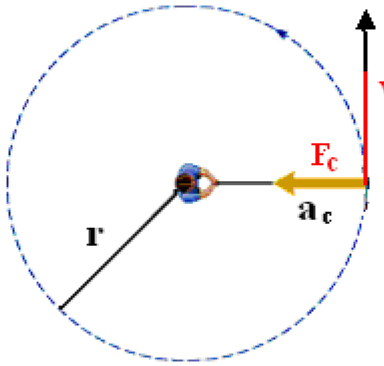
Consider a body of mass ‘m’ moving in a circle of radius ‘r’ with uniform speed . The direction of velocity is changing continuously towards the center of the circle . The force responsible for the change in direction of the velocity in the circle .

By Newton’s second Law.

$$F_c = m\,a_c$$

$$F_c = m\left(\frac{v^2}{r}\right) \qquad \left[a_c = \frac{v^2}{r}\right]$$

$$F_c = \frac{m\,v^2}{r}$$



uniform circular motion

CENTRIFUGAL FORCE

The force that keeps the body moving away from a circular path or resists the body's movement in a circular path is called centrifugal force.

APPLICATION OF CENTRIFUGE

BANKING OF ROAD:

Raising the outer edge of a road over its inner edge through a certain angle is known as the banking of the road.

NECESSITY OF BANKING OF THE ROAD:

i. ***When a vehicle moves along a horizontal curved road, necessary centripetal force is supplied by the force of friction between the wheels of the vehicle and the surface of the road.***
ii. ***Frictional force is not enough and unreliable every time as it changes when the road becomes oily or wet in the rainy season.***
iii. ***To increase the centripetal force the road should be made rough. But it will cause wear and tear of the tires of the wheel.***
iv. ***Thus, due to a lack of centripetal force vehicle tends to skid.***
v. ***When the road is banked, the horizontal component of the normal reaction provides the necessary centripetal force required for the circular motion of the vehicle.***
vi. ***Thus, to provide the necessary centripetal force at the curved road, banking of the road is necessary.***

CREAM SEPARATOR

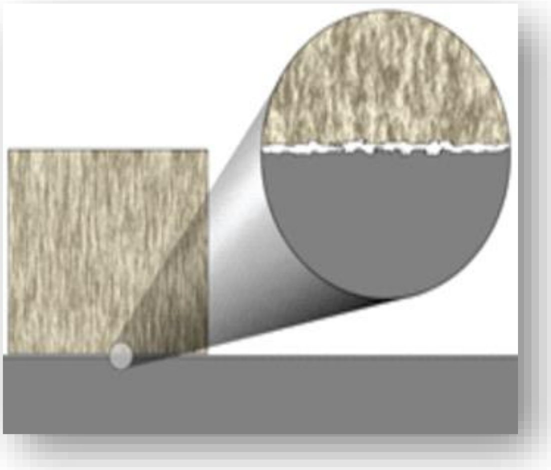
The milk plants in the country are using high-speed spinners to separate cream from milk. The skimmed milk is heavier whereas the cream is lighter. When the milk is spun at high speed the heavy particles are pushed towards the walls of the spinner. These particles push the lighter particles of cream to the center where it is collected through a tube

DRYER

Now a days built-in dryer is available in most of washing machines. It spins the wet clothes hence the water droplets are thrown away from the perforated walls of the dryer and clothes get dry instantly

FRICTION

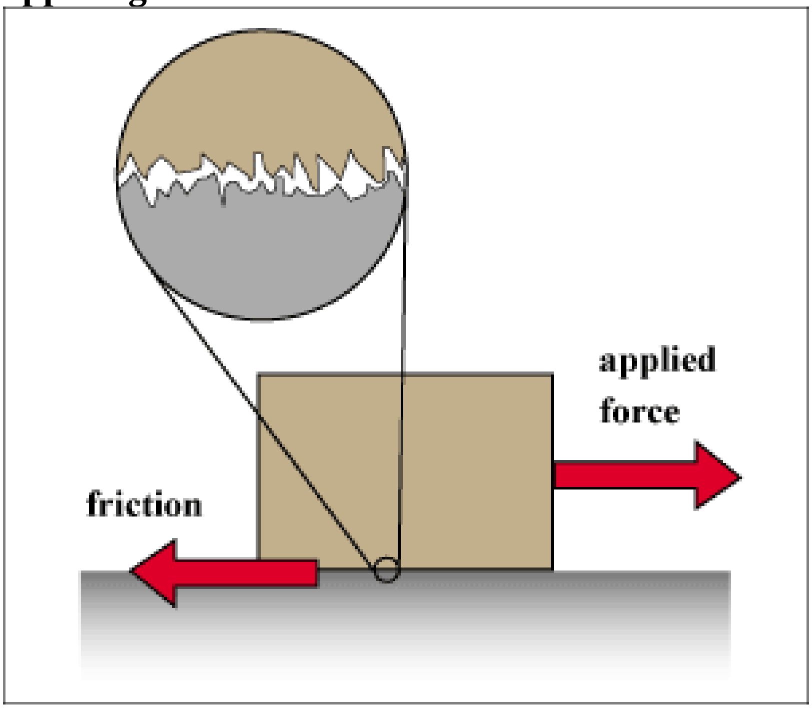
Friction is a contact force caused by the roughness or deformation of the materials in contact. The frictional force between a wooden block and a cemented floor is caused by the roughness of both surfaces



Frictional forces are always parallel to the plane of contact between two surfaces and opposite to the direction of the applied.

CAUSES OF FRICTION

Ordinary surfaces have projections and depressions. When the surfaces of two bodies are in physical contact, the gross interlocking of projections and depressions takes place, opposing the relative motion.

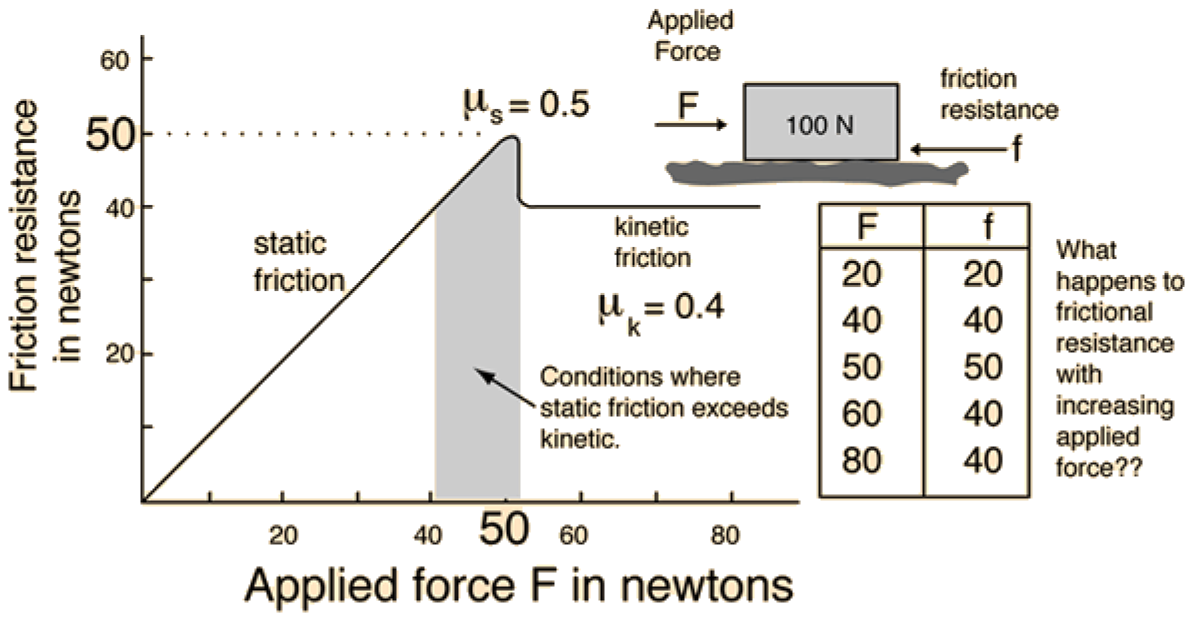


EXPLANATION

Consider a wooden block placed on a horizontal surface. One cord end is attached to the block, and the other is connected to a spring balance.

If we apply force "F" on the block horizontally we observe that initially, it will not move, while if we increase the applied force from its frictional force, the block will move. This gives an idea that the frictional increases with the increase of applied. It is a so-called self-

adjusting force. But if the body is on the verge of motion then frictional force is maximum and is called limiting friction (f).
In the above case, the applied force is equal to the force of friction. If we increase the applied force from the limiting friction, the block will slide on the surface. In this case, the applied force is greater than the frictional force.
We can better explain the whole procedure by the following table and a graph.



F	f
20	20
40	40
50	50
60	40
80	40

It is observed that the fractional force (limiting) is directly proportional to the Normal Reaction (R) of the surface which is opposite to the weight of the block.

Mathematically

It can increase to a certain value known as limiting force (F_s). It is proportional to normal force R.

$$F \ \alpha \ R$$

$$f = (\text{constant})\ R$$

Where μ = constant of proportionality and is called the coefficient of friction b/w the two surfaces.

$$f = \mu R \ \ldots\ldots.(i)$$

$$\mu = \frac{f}{R}$$

When a body is placed on a surface its weight w acts downward then according to Newton's third law of motion R = W, here w = mg by putting the value R = mg in eq.

$$f = \mu \, m \, g$$

STATIC FRICTION

It is the force acting on an object at rest that resists its ability to start moving. The maximum static friction is known as "limiting friction"

KINETIC FRICTION

It is the force that resists the motion of a moving object. It is interesting to know that in almost all situations, static friction is greater than kinetic friction.

SLIDING FRICTION

When one body slides over the other body the friction between two surfaces is said to be sliding friction.

ROLLING FRICTION

When a body moves on wheels the friction is said to be rolling friction. Rolling friction is much lesser than sliding friction.

In case of rolling friction the contact area between two surfaces is lesser than the contact area in case of sliding bodies. Therefore ball bearings are used in vehicles that they reduce the contact area as compared to the contact area of axel and bush.

ADVANTAGES OF FRICTION

1. **Without friction between the feet and the ground it will not be possible to walk.**
2. **The tyres of a motor car and bicycles are made rough to increase friction.**
3. **In the absence of friction, the brakes of a motor car cannot work.**
4. **It is the friction between the belt and pulley that helps in the rotation.**
5. **The proper forces of friction of friction are maintained between the joints of the body due to this we could run and do other rapid movements.**

DISADVANTAGES OF FRICTION

1. **Wear and tear of the machinery is due to excessive friction.**
2. **A large amount of Power is wasted in overcoming the friction and the efficiency of the machine decreases considerably.**
3. **Excessive friction between the rotating or sliding over another parts of a machine produces enough heat and causes damage to the machinery.**

METHODS OF REDUCING FRICTION

1. **The various parts of the machines which are moving over one another are properly lubricated.**
2. **In machines the sliding of various parts is usually replaced by rolling and this is done by using ball bearings.**
3. **Where sliding is unavoidable a thick layer of greasing material is used between the sliding surfaces.**
4. **The front of the fast-moving objects eg, cars, aero planes are made oblong to minimize air friction.**