Chapter = 03

DYNAMICS

DYNAMICS

Derivation and Meaning: - The word Dynamic is derived from the **Greek** word **Dynami** Meaning **"MOTION".**

Definition:- The branch of physics which deals with the study of motion by analyzing the cause of motion is known as dynamics.

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FORCE

Definition:- It is a physical quantity which moves or tends to move a body , stops or tends to stop a moving body. OR

The product of mass and acceleration is known as force.

Symbol:- It is denoted by "F".

Mathematical Form:- $F=ma$

Unit:- Its SI unit is newton (N).

Quantity:- It is a vector quantity.

Nature:- It is a derived quantity.

Examples:-

(i) With the help of force a fielder stops a fast moving ball.

(ii) With the help of force a horse pulls the cart.

(iii) With the help of force a goal keeper stops the ball.

(iv) With the help of force we push a stilled car etc.

TYPES OF FORCES

All the forces can be divided into two broad categories which are given below.

(1) Contact forces.

(2) Non- Contact forces.

(1) **CONTACT FORCES**: -

Definition:- The force which acts between the two objects only when there is a physical contact between them is known as contact force. OR

The force which produces when two interacting objects are physically contacting with each other is known as contacting force.

Examples:- (i) Tension in a rope.(ii) Force of friction (iii) Air resistance (iv) Normal force etc.

(1) NON- CONTANT FORCES : -

Definition:- A force which acts even when two bodies are not in physical contact is known

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as non-contact forces. OR
The force which produces when two interacting objects are not physically contacting with each other is known as contacting force

Examples: -
(i) Gravitational force.
(ii) Magnetic force.
(iii) Electric force etc.

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NEWTON'S LAWS OF MOTION

Purpose:- Newton's laws of shows the relation between force and acceleration.
Application:- To provide the basis for understanding the effect that forces have on an object.

Newton's First Law of Motion

Statement:- A body continues its state of rest or of uniform motion in a straight line provided no net force acts on it .OR
If the net (external) force acting on an object is zero , the object will maintain its stated of rest or of uniform motion (constant velocity). OR
In the absence of external force a rest body will be remains at rest and moving body will be move with uniform velocity in a straight line.
Other Name:- This law is called Law of Inertia.
Mathematical Form:- $F_{net} = 0$ then $\Delta V = 0$ or $a = 0$
Explanation:- The study of this law of motion can be divided into two parts which are given below.
(1) Bodies at rest:- The first part of the law states that " a body at rest will be remain at rest it no net force act on it ".
Examples: -
(i) A book lying on the table will be remain stationary and will not change their state by themselves unless someone moves them by applying a net force.
(2) **Bodies at motion**:- The second part of the law states that " a body in motion will continue to move in a straight line with uniform speed if no net force acts on it ".
Examples:-
(i) If we roll a ball it comes to rest after some time. But careful study of the moving ball shows that there are forces (like friction and air resistance) which opposes the motion of the ball. If we removes these forces ,then the ball will continue its uniform motion for ever.

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INERTIA

Definition:- It is the property of a body due to which it resists any change in its state of rest or motion. OR

Inertia is a natural tendency of an object to remain at rest or in motion at a constant velocity.

Explanation:- Greater the inertia of a body greater will be the force required to bring a change in its state of rest or of uniform motion. In fact mass is a measure of the inertia of a body.

Factor of Inertia:- The inertia of a body depends upon its mass. Greater the mass of the body greater will its inertia and vice versa.

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Unit:- The SI unit of inertia is Kilogram (kg)

Examples:-

(i) A truck has greater inertia than a car due to greater mass.

(ii) A steel ball has greater inertia than a rubber ball due to greater mass etc.

Note:- The mass of an object is a quantitative measure of inertia.

Why Newton's First Law of Motion Is called Law of inertia OR What is law of inertia?

Answer:- **Statement**:- Newton's First Law of Motion is called **Law of inertia**.

Reason:- Because it deals with the inertial properties of body.

Explanation:- If a car or bus suddenly starts moving , a person sitting in it would fall in the back –ward direction. It is because the lower part of the body of the person is in contact with the seat of the car or the bus and is carried forward by the motion of the car or the bus. But the upper free part of the body of the person remains at rest due to inertia and so the person falls in the backward direction. But if the moving car or the bus suddenly stops, the person falls forward.

NEWTON 'S SECOND LAW OF MOTION

Purpose:- Newton's second law of motion deals with situations when a net force is acting on a body.

Statement:- When a net force acts on a body it accelerates the body in the direction of the net force the acceleration is directly proportional to the net force and inversely proportional to the mass of the body. OR

The net force (F) on the body is equal to the product of the body's mass (m) and its acceleration (a). OR

A net force applied on the body produces an acceleration in the body. This acceleration is

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directly proportional to the magnitude of the net force and inversely proportional to the mass of the object.

Other Name:- This law is also **called Law of acceleration**.

Mathematical Form:- F = ma

Explanation:- If a force (F) produces an acceleration(a) in a body of mass (a) then from the above statement.

$$a \propto F \quad \text{.........................} \quad (i)$$

$$a \propto \frac{1}{m} \quad \text{.......................} \quad (ii)$$

By combining eq (i) and (ii) we get.

$$a \propto \frac{F}{m} \quad \text{.......................} \quad (iii)$$

By changing the sign of proportionality into the sign of equality then eq (iii) becomes.

$$a = \text{constant} \left(\frac{F}{m}\right)$$

$$a = K\frac{F}{m}$$

Constant = K = 1

$$a = 1 \times \frac{F}{m}$$

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

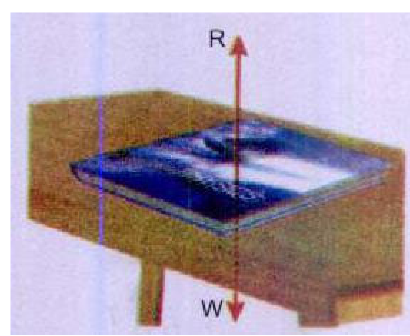
or F = ma .... (iv).

Equation (iv) represents the mathematical form of Newton's second law of motion.

Note:- Newton's second law of motion tells us that acceleration "a" will be largest when force "F" is large and mass "m" is small.

Examples:- When a fielder catches the ball then he move his hand in backward direction along the direction of motion of the ball, to reduce the impulsive force. So as a result the fielder can catch the ball easily and feels and no pain.

Newton's Third law of Motion



Statement:- To every action there is always an equal and opposite reaction. OR Action and reaction are always equal in magnitudes but opposite in direction.

Mathematical Form:- Action = Reaction

F = - F

Explanation:- It should be noted that action and reaction always occurs in pair. Action and reaction never neutralized each other because they always act on different bodies.

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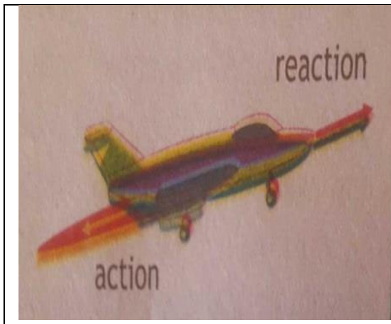
Examples:- (i)Consider a book lying on a table. The weight (W)of the book is acting on the table in the downward direction. This is the action. The reaction(R) of the table acts on the book in the upward direction as shown in figure .
(ii)The jet plane eject gases at high speed as an action and air as reaction apply force on the plane to make it move forward.
(iii) Walking on the ground surface.
(iv) Flying of birds etc.



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Result: -
(i) Forces always exerted in pairs.
Action and reaction forces can never balance each other.

Why action reaction cannot neutralize each other?

Answer: - **Statement**: - Action reaction cannot neutralize each other.
Reason:- Because the action and reaction act on different bodies.
Explanation:-As we know that action and reaction always occurs in pairs and that action is on one body while its reaction is on the other body. The action and reaction forces are equal in magnitude but opposite in direction and can never neutralize each other. They always act on different bodies.

Mass and Weight

Mass: -
Definition:- The quantity of matter in a body is known as mass.
Symbol:- It is denoted by "**m**".
Mathematical Form:- $m = \frac{\vec{F}}{\vec{a}}$
Unit:- Its SI unit is kilogram **(kg).**
Quantity:- It is a **scalar** quantity.
Nature:- It is a **derived** quantity.
Constant Quantity:- It is a **constant** quantity.
Measuring Device:- It is measured with the help of **beam balance**.
WEIGHT:-
Definition: - The downward force with which the earth pulls a body towards its center is known as weight.
Symbol:- It is denoted by $\vec{W}$.
Mathematical Form:- $\vec{W}$ = mg

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Unit:- Its SI unit is **newton** (N).
Quantity:- It is a **vector** quantity.
Nature:- It is **derived** quantity.
Variable Quantity:- It is a **variable** quantity.
Measuring Device:- It is measured with the help of **spring balance**.

What is the difference between mass and weight? pakcity.org

LINEAR MOMENTUM

Definition:- The **quantity of motion** in a body is known as linear momentum. OR
The product of **mass** and **velocity** is known as linear momentum.
Symbol:- It is denoted by **P**.
Mathematical Form:-

Linear Momentum = Mass x Velocity

$$P = mv$$

Unit:- Its SI unit is **kg m/s (kg ms^{-1}**).
Other unit:- Its other unit is newton meter(**Ns)**.
Quantity:- It is a **vector** quantity.
Nature:- It is a **derived** quantity.
Factors:- There are **two** factors of linear momentum which are given below.

(1)**Mass (m):- G**reater the **mass** of the body greater will be its **momentum** and vice versa.

$$\vec{P} \propto m$$

Examples:-
(i)The truck has more momentum than car moving with same speed.
(ii) The train has more momentum truck moving with same speed etc.
(2)Velocity (V):- Greater the **velocity** of the body greater will be its **momentum** and vice versa.

$$\vec{P} \propto \vec{V}$$

Examples:-
(i) A fast moving cricket ball has a higher momentum than an identical slow moving ball.
(ii) A fast moving car has higher momentum than an identical slow moving car etc.

ASSIGNMENT #3.3:- The fastest recorded speed for golf ball hit by a golfer is 75.8m/s (273 km/h). If mass of golf is 46g what is the magnitude of its magnitude?

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Solution:-

Given Data:-

Velocity of golf ball= V = 75.8 m/s

Mass of golf ball= m= 46g

= m = $\frac{46}{1000}$ kg

= m = 0.046 kg

Required Data:-

Momentum of golf ball = P = ?

Formula:- P = mV ………………… (1)

Calculation:- By putting values in equation (1) we

Result: - So as a result the magnitude of momentum of golf ball is 3.48 kg m/s.

FORCE AND MOMENTUM OR Show that $F = \frac{\Delta P}{\Delta t}$

The time rate of change of linear momentum of a body equal to the net force acting on the body. OR

When a force acts on a body, it produces an acceleration in the body and will be equal to the rate of change of momentum of the body.

Mathematical Form: - $F = \frac{\Delta P}{\Delta t}$

Proof:- Consider a force (F) produces an acceleration (a) in a body of mass (m). From Newton's 2nd law of motion.

$F = ma$ …………………….. (i)

We also know that $a = \frac{\Delta V}{\Delta t}$ …………………….. (ii)

As $\Delta V = V_f - V_i$ then equation (ii) becomes.

$a = \frac{V_f - V_i}{\Delta t}$ ………………… (iii)

Now by putting equation (iii) in equation (i) we get

$F = m \times \frac{V_f - V_i}{\Delta t} = \frac{mV_f - mV_i}{\Delta t}$ … ……….. (iv)

As $mV_f = P_f$ and $mV_i = P_i$ then equation (iv) becomes

$F = \frac{P_f - P_i}{\Delta t}$ ……………. (v)

As $P_f - P_i = \Delta P$ Then equation (v) becomes

$F = \frac{\Delta P}{\Delta t}$ ………………………… (vi)

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Equation (iv) represents the Newton's 2nd law of motion in term of momentum.
From equation (vi) the force can be define as " The time rate of change of momentum of a body is equal to net force acting on the body".

NOTE:- From the (vi) we can conclude that for sudden change in momentum force is large and vice versa.

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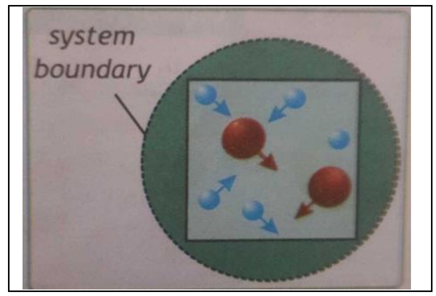
ISOLATED SYSTEM

Definition:- The system on which the external force is zero is known as isolated system.

Example:-

The molecules of a gas enclosed in a vessel can be considered as an isolated system of interacting bodies. Gas molecules interact with the walls of the container. All other external forces are considered to have a negligible effect on the motions of the molecules and container.



NEWTON'S LAWS AND CONSERVATION OF MOMENTUM

Statement:- The momentum of an isolated system of two or more than two interacting bodies remains constant. OR

If there is no external force applied to a system then the total momentum of that system remains constant. OR

The momentum of an isolated system remains constant.

Mathematical Form:- Initial momentum = Final momentum

$$P_i = P_f$$

Derivation:- As we know that

$$F = \frac{\Delta P}{\Delta t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

- In case of isolated system F = 0 then Eq (i) becomes

$$0 = \frac{\Delta P}{\Delta t} \quad \text{OR} \quad 0 \times \Delta t = \Delta P$$

$$0 = \Delta P \quad \ldots\ldots\ldots\ldots\ldots (ii)$$

As $\Delta P = P_f - P_i$ Then eq (ii) becomes.

$$0 = P_f - P_i \quad \text{OR} \quad P_f - P_i = 0$$

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$$P_f = P_i$$

Result:- If no net external force acts on a system of particle, the total momentum of the system cannot be change.

Examples:-

(i) Collision of two objects.
(ii) Firing of gun.
(iii) Explosion of bomb.
(iv) Collision of atoms.
(v) Propulsion of rocket etc.

CHANGE IN MOMENTUM AND COLLISIONS

Collision: - An event during which particle comes close to each other and interact by means of forces is known as collision.

Explanation:- Considered a system consisting two objects "A" and "B" of masses m_1 and m_2 moving with velocities u_1 *and* u_2 respectively , Such that after collisions their velocities changes to v_1 *and* v_2 .

Total Momentum of the system before collision:-

$$P_i = m_1u_i + m_2u_2$$

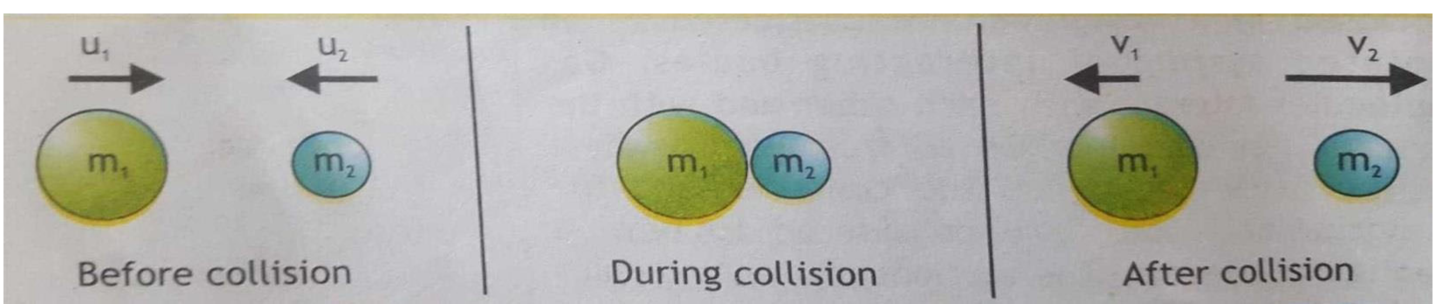
Total Momentum of the system after collision:-

$$P_f = m_1v_1 + m_2v_2$$

By law of conservation of momentum

$$P_i = P_f$$

Therefore $m_1u_i + m_2u_2 = m_1v_1 + m_2v_2$

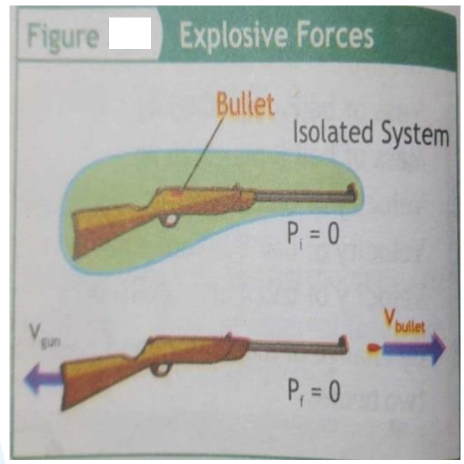


CHANGE OF MOMENTUM AND EXPLOSIVE FORCES

Explosion:- It is a type of an instant interaction in which particles of the system move apart from each other after a brief.

Explanation:- Explosion is the opposite of a collision. The explosive forces which could be from an expanding spring or from expanding hot gases, are internal forces. If the system is isolated, its total momentum during the explosion will be conserved by the law of conservation of momentum.

FIRING OF RIFLE



Consider an isolated system of bullet of mass "m" and rifle of mass "M" as shown in figure (A).

Before firing :- Both the gun and bullet are at rest so

Total momentum of the gun and bullet = P_i = 0

After firing : - When the gun is fired the bullet moves with Velocity V_b with forward momentum and the gun recoils backward with velocity V_g . In this way the total momentum is again zero.

Total momentum of the gun and bullet after firing = P_f = MV_g + mV_b

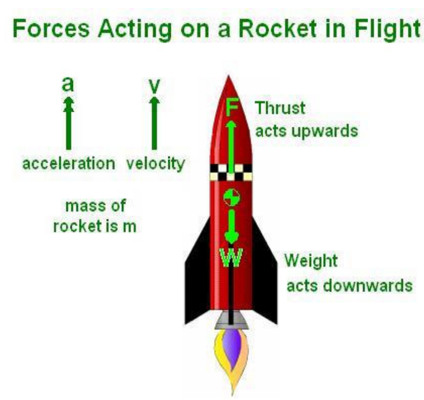
From law of conservation of momentum:-

$$P_f = P_i$$

$$MV_g + mV_b = 0$$

Due to the large mass of the rifle it recoils with much lower velocity as compared to the bullet.

ROCKET PROPULSION AND THRUST



A phenomenon similar to muzzle velocity occurs in rocket in propulsion. The rocket ejects gases from its tail at a high velocity, just as a rifle ejects bullet or cannon fires a shell from its barrel. A rocket 's mass is not constant because the fuel it contains is constantly decreasing. Thus giving acceleration to the rocket called thrust. Any space vehicle is maneuvered in empty space by firing its rocket in the direction opposite to that in which it needs to accelerate. When the rocket pushes on the gases in one

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direction, the gases push back on the rocket in the opposite direction.

FRICTION

Definition:- The force that opposes relative motion or attempted motion between systems in contact is known as friction. OR

The force which resists the motion of a body is known as friction. OR

The force which opposes the motion of an object while in contact with its surroundings is known as friction.

Symbol:- It is denoted by **" f "**.

Cause :- Roughness of a surface.

Unit:- Its SI unit is newton.

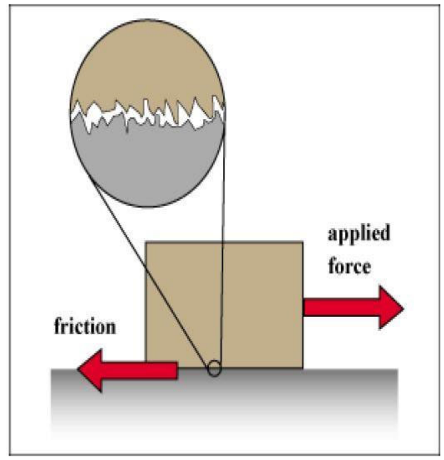
Nature:- It is a derived quantity.

Direction:- It is always opposite to the direction of motion.

Factors:-

(i) Normal force or compressing force.

(ii) Nature of surface in contact each other.



Microscopic Description of friction:- As we know that every surface is rough, even surfaces that appears to be highly polished can actually look quite rough when examined under a microscope. Some surfaces are more rough than others. Therefore when one surface slide over another, these irregularities bump into one another which gives rise to frictional force. Secondly at these contact points the molecules of the different bodies are closed enough to exert strong attractive intermolecular forces on each other thus opposing motion and result in friction.

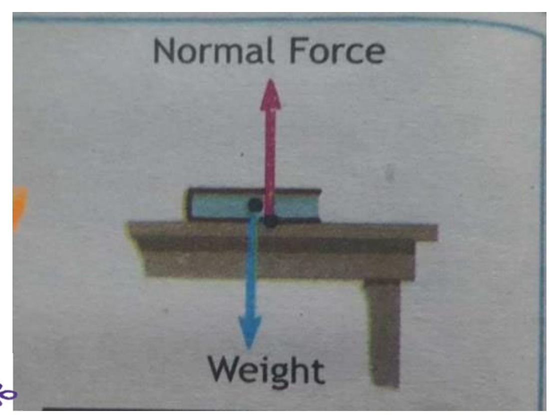
NORMAL FORCE

Definition:- A contact force perpendicular to the contact surface that prevents two objects from passing through one another is known as normal force. OR

It is a force which exist when two bodies are in contact and one pushes the other.

Other Name:- It is also called normal reaction.

Symbol:- It is denoted by **"F_N"**.



Explanation:-

(i) This force is always perpendicular to the surface.

(ii) Its SI unit is newton.

(iii) It is a derived quantity.

(iv) In geometry normal means perpendicular.

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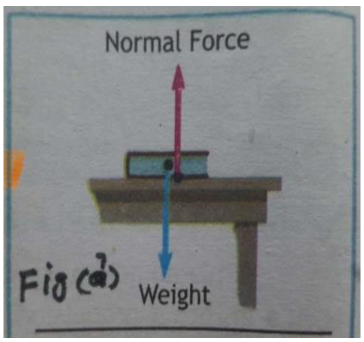
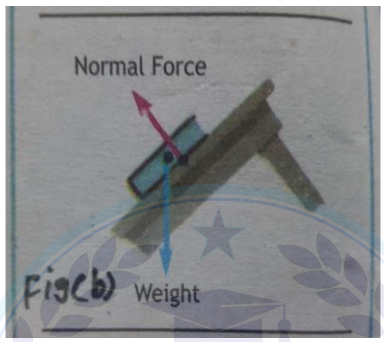
Examples:- Consider a book lying on a table. The weight (W) of the book is acting on the table in the downward direction. This is the action. The reaction(R) of the table acts on the book in the upward direction as shown in figure.

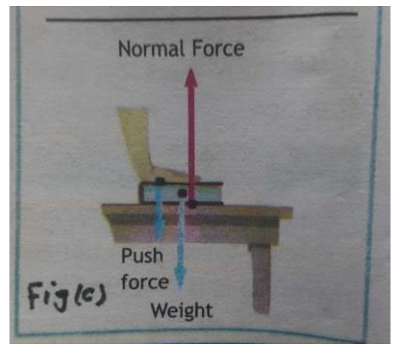
(i)If the surface of the table is horizontal then the $\vec{F_N} = \vec{W}$.

(ii) If the surface of the table is not horizontal then the $\vec{F_N} \neq \vec{W}$.

(iii) If there are other vertical forces acting on the book, then the $\vec{F_N} \neq \vec{W}$.







EFFECT OF NORMAL FORCE ON FRICTION

From experimental results we can conclude that " **The magnitude of friction is directly proportional to the magnitude of the normal force**".

Mathematically:-

$$\text{Friction} \propto \text{Normal force}$$

$$f \propto F_N$$

Types:- There are two types of friction which are given below.

(1) Static friction.

(2) Kinetic friction.

(1) STATIC FRICTION: -

Definition:- The frictional force that tends to prevent a stationary object form starting to move is called static friction. OR

The frictional force during the rest state of a body is known as static friction.

Symbol:- It is denoted by f_s .

Limiting friction:- The maximum value of static friction is known as limiting friction.

Example:- A book lying on the table. The force of friction between the book and the table is called static friction.

(2) KINETIC FRICTION:-

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Definition:- The frictional force that acts against during motion of an object in a direction opposite to the direction of motion is known as kinetic friction.
Symbol:- It is denoted by f_k **.**
Example:- A car moving on the road. The force of friction between the road and car tyre is called kinetic friction.

Kinetic friction is always less than static friction i-e $f_k < f_s$.

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DIFFERENCE BETWEEN STATIC AND KINETIC FRICTION

STATIC FRICTION	KINETIC FRICTION
It occurs when two objects are at rest.	It occurs when objects are in motion.
It is denoted by f_s.	It is denoted by f_k.
Its mathematical form is $f_s = \mu_s N$	Its mathematical form is $f_k = \mu_k N$
It increases as the applied force is increased.	It remains constant regardless of how fast the objects are moving.
It can be zero.	It cannot be zero.
Its magnitude will be more.	Its magnitude will be less.
Example:- Book lying on the table.	Example:- Man sliding down on snowy slope.

COEFFICIENT OF FRICTION

Definition:-The ratio between the force of limiting friction f_s and the normal reaction f_N is constant.
Symbol:- It is denoted by **μ**.
Mathematical Form:- $\mu = \frac{f_s}{f_N}$
Unit:- It is a unit less quantity.

EXPRESSION FOR COEFFICIENT OF STATIC FRICTION

From experimental results we can conclude that " **the magnitude of limiting static friction is directly proportional to the magnitude of the normal force**".
Mathematically:-

Limiting static Friction ∝ Normal force

$$f_{s,max} \propto F_N$$
$$f_{s,max} = constant\ (F_N)$$
$$f_{s,max} = \mu_s\ (F_N)$$

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$$\mu_s = \frac{f_{s,max}}{F_N} \text{ .... (i)}$$

Equation (i) is the required expression for the co-efficient of static expression.

EXPRESSION FOR COEFFICIENT OF KINETIC FRICTION

From experimental results we can conclude that "**The magnitude of kinetic friction is directly proportional to the magnitude of the normal force**".

Mathematically:-

Limiting static Friction ∝ Normal force

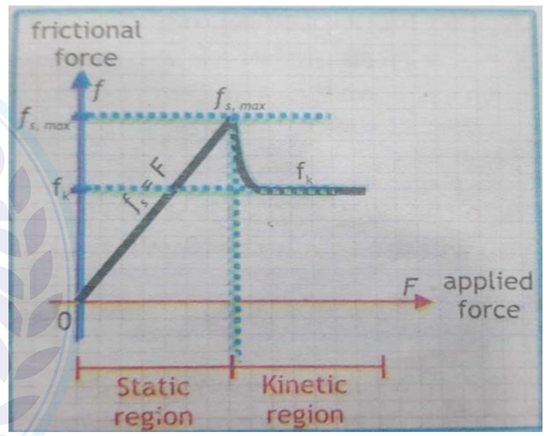
$$f_K \propto F_N$$

$$f_K = constant\ (F_N)$$

$$f_K = \mu_k\ (F_N)$$

$$\mu_k = \frac{f_k}{F_N} \text{ .... (i)}$$

Equation (i) is the required expression for the co-efficient of kinetic expression.



GRAPHICAL INTERPRETATION OF FRICTION: - The graph is drawn between applied force "F" and friction "f" it shows that by increasing the applied force static friction "f_s" also increases until it reaches a certain maximum value called limiting friction($f_{s,max}$)

At this point the object starts moving and frictional force rapidly decreases to a smaller kinetic friction f_k value which nearly remains constant.

APPROXIMATE VALUES OF COEFFICIENTS OF FRICTION		
Surfaces	**Coefficient of static friction μ_s**	**Coefficient of kinetic friction μ_k**
Glass on glass	0.94	0.4
Ice	0.1	0.02
Rubber on dry concrete	1.0	0.8
Steel on ice	0.1	0.05
Steel on steel	0.78	0.42
Wood on leather	0.6	0.3
Wood on wood	0.35	0.3

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ADVANTAGES OF FRICTION

(i)With the help of friction we can walk on the ground.
(ii) Friction holds the screw and nail in wood.
(iii) It helps in the lighting of a match stick.
(iv) With the help of friction a bird can fly.
(v) With the help of friction we can tie a knot.
(vi) With the help of friction we are able to write on a paper.
(vii) With the help of friction we can stop a moving car or bicycle.
(viii) With the help of friction we can climb on a tree or wall.
(ix) With the help of friction we can hold different parts of a body.
(x) With the help of friction vehicle can move on ground.

DISADVANTAGES OF FRICTION

(i) It produces wear and tear of tyres.
(ii)Energy is wasted to overcome friction in machinery.
(iii) It slow down the moving objects and causes heating of moving parts in machinery.
(iv) It limits the speed of high speed vehicles.
(v) It can reduce the life time of a machine.

ROLLING FRICTION:-

Definition:- The friction which arises due to the rolling of one body over another body is known as rolling friction. OR
When a body rolls over a surface the force of friction is known as rolling friction.

Example:- If we set a heavy spherical ball rolling it experiences an opposing force is called rolling friction.

Sliding Friction:-

Definition:- The friction which arises due to the sliding of one body over another body is known as sliding friction. OR
When a body slides over a surface the force of friction is known as sliding friction.

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Example:- If we set a heavy block slides it experiences an opposing force is called sliding friction.

TENSION

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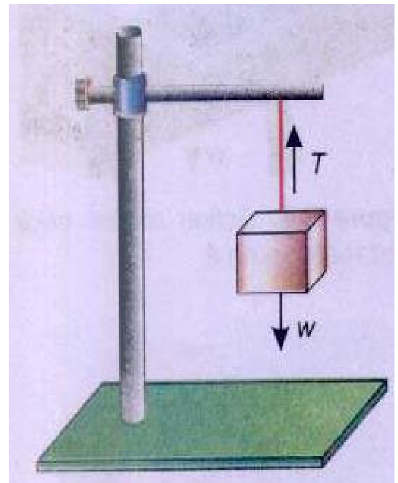
Definition:-The force acting along the string is known as tension. OR

The pulling force exerted by a stretched rope, string, cable or rod on an object to which it is attached is known as tension.



Symbol:- It is denoted by **T**.

Unit:- It s SI unit is **newton** (N).

Quantity:- It is a **vector** quantity.

Nature:- It is a **derived** quantity.

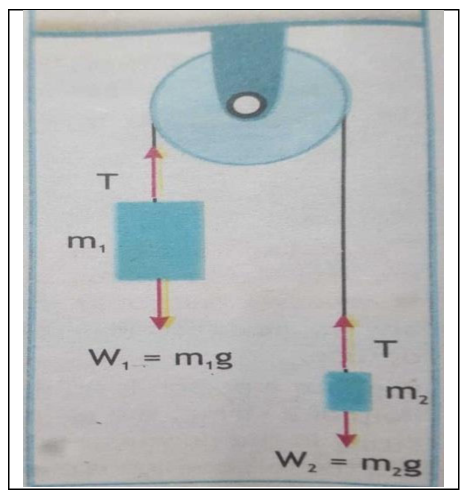
Explanation:- Consider a block supported by a string. The upper end of the string is fixed on a stand. Let **"W"** be the weight of the block. The block pulls the string downwards by its weight. This causes a tension **" T "** in the string. The tension **" T "** in the string is acting upwards at the block. As the block is at rest, therefore the weight of the block acting downwards must be balanced by the upwards tension " **T** " in the string.

Thus the tension " **T** " in the string must be equal and opposite to the weight **" W "**of the block as shown in figure.

Note:- As the object is at rest then the magnitude of tension is equal is equal to that of weight of the object as shown in figure.

ATWOOD MACHINE

Definition:- When two objects of unequal mass are hang vertically over a frictionless pulley of negligible mass the arrangement is called an Atwood's machine.



Explanation:- Consider the motion of two objects having masses "m_1" and "m_2" suspended by an inextensible string which passes over a frictionless pulley forming Atwood's machine.

Condition:- **$m_1 > m_2$** Then

(a) m_1 will be move downward under the action of gravity and **m_2** will move upward.

(b) Tension and acceleration **"a"** will be same for both bodies.

Net force on m_1:- From figure there two force acting on "m_1" which are given below

(i) Weight of body = $W_1 = m_1g$ (vertically downward).

(ii) Tension in string = T (acting vertically upward).

Net force on "m_1" is:-

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$F_1 = W_1 - T$ .... (1)

From Newton 2nd law of motion :- $F_1 = m_1a$ Then eq(1) becomes

$m_1a = m_1g - T$ OR $T = m_1g - m_1a$ .... (2)

Net force on "m_2":- From figure there two force acting on "m_2" which are given below.

(i) Weight of "m_2" = $W_2 = m_2g$.

(ii) Tension in string = T (acting vertically upward).

Net force on "m_2" is:-

$F_2 = T - W_2$ .... (3)

$F_2 = m_2a$

$m_2a = T - m_2g$ OR $T = m_2g + m_2a$ .... (4)

Calculation of acceleration (a):- Since both equation (2) and equation (4) to "T" we can write

$$m_1g - m_1a = m_2g + m_2a$$

$$m_1g - m_2g = m_1a + m_2a \quad \text{rearranging}$$

$$g(m_1 - m_2) = a(m_1 + m_2) \quad \text{Take common}$$

$$g\frac{(m1 - m2)}{(m1 + m2)} = a\frac{(m1 + m2)}{(m1 + m2)} \quad \text{Divide both sides by } (m_1 + m_2)$$

$$g\frac{(m1 - m2)}{(m1 + m2)} = a\frac{\cancel{(m1 + m2)}}{\cancel{(m1 + m2)}}$$

$$g\frac{(m1 - m2)}{(m1 + m2)} = a \quad \text{OR} \quad a = g\frac{(m1 - m2)}{(m1 + m2)}$$

$$a = g\frac{(m1 - m2)}{(m1 + m2)} \quad \text{.................... (5)}$$

Equation (5) represents the acceleration of connected bodies.

ELEVATOR S AND ATWOOD'S MACHINE

The supporting cable in elevators passes up over a pulley and then back down to a heavy, movable counterweight as shown in figure. Gravitational force acting downward on the counter weight create tension in the cable. The cable then exerts an upward force on the elevator cage. Most of the weight of the elevator and passengers balanced by the counter weight. Only small additional forces from the elevator motors are needed to rise and lower the elevator and its counter weight. Although the elevator and counter weight move in different directions, they are connected by a cable, so they accelerate at the same rate. Elevators are only one of many examples of machines that have large masses connected by cable that runs over a pulley.

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Calculation of tension (T)

To find the value of "T" we can put the equation (5) in equation (4)

$$T = m_2g + m_2\left(g\,\frac{(m1 - m2)}{(m1 + m2)} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

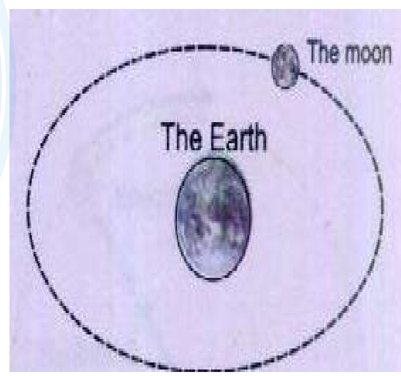
$$T = m_2g\left(1 + \frac{(m1 - m2)}{(m1 + m2)} \right) \qquad \text{take } m_2\,g \text{ common}$$

$$T = m_2g\left(\frac{(m_1 + m_2) + (m_1 - m_2)}{(m_1 + m_2)} \right) = m_2g\left(\frac{m_1 + m_2 + m_1 - m_2}{m_1 + m_2} \right)$$

$$T = \frac{m2g\ (m_1 + m_1)}{m_1 + m_2} = \frac{m_2g \times 2m_1}{m_1 + m_2} = \frac{m_2g \times 2m_1}{m_1 + m_2} = \frac{2m_1m_2}{m_1 + m_2}g$$

$$T = \frac{2m_1\ m_2}{m_1 + m_2}g$$

UNIFORM CIRCULAR MOTION



Definition:- The motion of a body along a circular with uniform speed is known as uniform circular motion.

Cause:- Centripetal force

Examples:-

(i) Motion of moon around the earth.

(ii) Motion of earth around the sun.

(iii) Motion of electron around the nucleus etc.

CENTRIPETAL ACCELERATION

Definition:- The acceleration which is produced in a body due to centripetal force is known as centripetal acceleration. OR

Symbol:- It is denoted by a_c.

Mathematical Form:- $a_c = \frac{v^2}{r}$

Unit:- Its SI unit is **m/s²** .

Quantity:- It is a vector quantity.

Nature:- It is a derived quantity.

Direction:- It is always directed towards the center of the circle.

Figure:-

Examples:-

(i) Motion earth around the sun.

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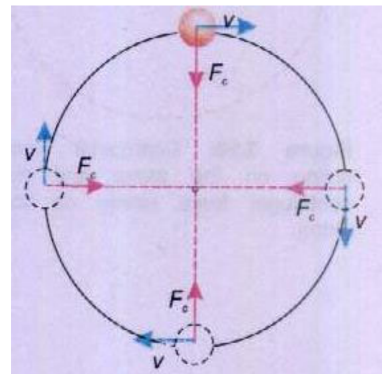
(ii) The motion of moon around the earth .
(iii) The motion of electron around the nucleus etc.

CENTRIPETAL FORCE

Definition:- The force which keeps a body to move on a circular path is known as centripetal force. OR
The force which compels a body to move a circular path is known as centripetal force. OR
The force needed to move a body around a circular path is known as centripetal force.



Other Name:- It is also called **Centre seeking force**.
Symbol:- It is denoted by F_c .
Mathematical Form:- $F_c = -\frac{m v^2}{r}$
Unit:- Its SI unit is newton.
Quantity: - It a **vector** quantity.
Nature: - It is **derived** quantity.
Direction: - It is always directed towards the **center** of the circle as shown in figure.
Examples:-
(i) The moon revolves around the Earth due to centripetal force.
(ii) The earth revolves around the Sun due to centripetal force etc.

CENTRIFUGAL FORCE

Definition:- The force which is equal in magnitude to the centripetal force but opposite in direction is known as centrifugal force.
Other Name:- It is also called **reaction force**.
Symbol:- It is denoted by F_r .
Mathematical Form:- $F_r = \frac{m v^2}{r}$
Unit:- Its SI unit is newton.
Quantity: - It a **vector** quantity.
Nature: - It is **derived** quantity.
Direction: - Its direction is always away from the center of the circle.

APPLICATIONS OF CENTRIPETAL FORCE

(A)Banking of Road:- pakcity.org
Definition:- Banking of roads means that the outer edge of a road is raised.
Explanation:- When a car moves along a curve track , centripetal force is required. In the absence of this force, the car will skid off the road. The force of friction between the tyre

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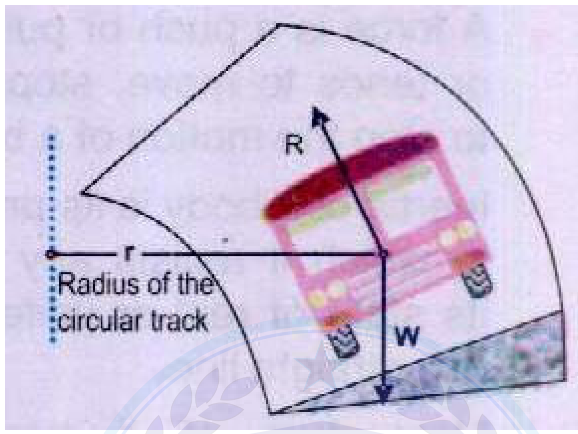
and the road provides this centripetal force and keeps the car moving on the curved path. However if the tires are worn out or the road is slippery due to some rain , snow or oil spill ,the friction will not be enough to provide necessary centripetal force.

For extra protection level of the outer edge of a round track is kept slightly higher than that of the inner edge known as banking of road. In this case the normal component of the vehicle weight increase the friction to provide the necessary centripetal force for safe turning around the circular track.



(B) Centrifuge:-

Definition:- It is a device which is used for the separation of liquids of unequal densities.

Principle: - Centripetal force.

Working: - As we known that substances suspended in a liquid can be separated by spinning a sample of liquid very quickly around an axle. Any smaller denser particles found in the liquid travel in a straight line inside the test tube, obeying Newton's first law of motion. The liquid in the test tube applies a centripetal on these particle to keep them moving in a circle. After running the centrifuge at high speed for a period of time, the particles becomes clumped together at the bottom of the test tube, which can be collected and the sample is analysed.

Use:- It is used to separate different isotopes of a given mixture.

(i) Separator:-

Definition:- It is a centrifugal device that separates milk into milk into cream and skimmed milk. pakcity.org

Principle:- Centripetal force

Working:- In this machine milk is whirled rapidly. Since milk is a mixture of light particles and heavy particles. When it is rotated the light particles gather near the axis of rotation, Whereas the heavy particles go away and hence cream can easily be separated from milk.

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(ii) Washing Machine Dryer:-

Definition:- It is a kind of centrifuge .

Construction:- It consists of a long cylinder with small holes on its walls.

Principle:- Centripetal force .

Working:- When wet clothes are placed in this cylinder, which is then rotated rapidly about its axis . Water moves outward to the wall of the cylinder and is drained out through the holes. In this way clothes becomes dry quickly.

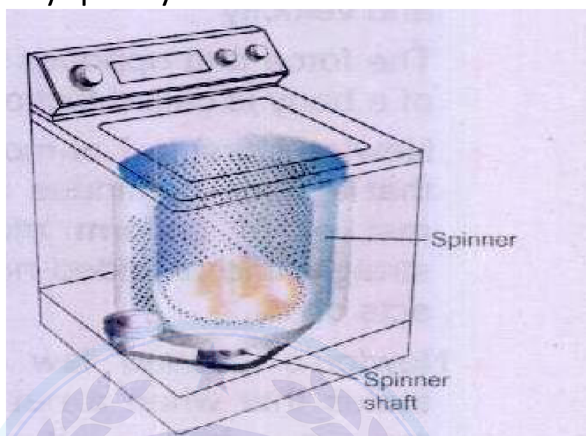

Figure : Dryer of washing machines has perforated wall.

CONCEPTUAL QUESTIONS

Question #1: Why does dust fly off, when a hanging carpet is beaten with a stick?

Answer: - **Statement**: - The dust fly off, when a hanging carpet is beaten with a stick.

Reason: - It is because of **"Inertia".**

Explanation: - As we know that the dust particles with in the hanging carpet are in state of rest. When the carpet is beaten with stick, it suddenly starts motion but the dust wants to be at rest due to **"inertia".**

Conclusion:-As conclusion we find that the dust particles fly off from the carpet when a hanging carpet is beaten with a stick.

Question #02: If your hands are wet and no towel is handy, you can remove some of the excess water by shaking them. Why does this work?

Answer: -**Statement**: - If your hands are wet and no towel is handy, we can remove some of the excess water by shaking them.

Reason: - It is because of "Inertia".

Explanation: - As we know that inertia is property of a body due to which it resist any change in its state of rest or of uniform motion. When we shake our hands, the hands come into state of motion, while the water drops are at rest and wants to remains at rest due to inertia.

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Conclusion: - As conclusion we find that to remove some of the excess water from our hand by shaking.

Question # 03: Why a balloon filled with air move forward, when its air is released?

Answer: - **Statement:** - A balloon filled with air move forward, when its air is released.

Reason: - It is because of

Action = Reaction

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

Explanation: - As we know that from Newton 3rd law of motion action and reaction always equal in magnitude but opposite in direction.

In case of balloon when

i. Air escapes from balloon it exerts force on external air in backward direction which is action.
ii. The external air exerts force on balloon in forward direction which is reaction.

Conclusion: - As conclusion we find that a balloon filled with air move forward, when its air is released.

Question #04: Why does a hose pipe tend to move, backward when the fireman directs a powerful stream of water towards fire?

Answer: -**Statement**: - A hose pipe tends to move, backward when the fireman directs a powerful stream of water towards fire.

Reason: - It is because of

Action = Reaction

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

Explanation: - As we know that from Newton 3rd law of motion "Action and reaction always equal in magnitude but opposite in direction.

In case of hose pipe:-When the fireman directs a powerful stream of water towards the fire then.

(i)The rushing water exert force of action on the hose pipe in the forward direction.

(ii)The water pushes the hose pipe in the backward direction which is reaction.

Conclusion:- As conclusion we find that the hose pipe tends to move backward direction when the fireman directs a powerful stream of water towards fire.

Question # 5: Your car is stuck is wet mud. Some students on their way to class see your predicament and help out by sitting on the trunk of your car to increase its traction. Why does this help?

Answer: -Statement: - When a car is stuck is wet mud. The students sit on the trunk of your car to increase its traction (friction).

Reason: - It is because of $f \propto F_N$

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Explanation: - As we know that

$$f = \mu F_N \text{ --------------(1)}$$

From equation (1) it is cleared that greater the magnitude of the normal force greater will be the force of friction and vice versa.

Now when the students sit on the trunk of the car stuck in the wet mud, it actually increases weight of car which increases normal force.

Conclusion: - So as a result the car comes out from the wet mud easily.

Question # 6: How does friction help you walk? Is it kinetic friction or static friction?

Answer: - **Statement**:- The friction help our walk. And this friction is static friction.

Reason: - It is because to stick foot on ground.

Explanation: - As we know that the force of friction is a contact force. It exists between our shoes and the earth surface. Because of this force we are able to walk on the ground. We would be unable to walk if there was no frication the soles of our shoes and the ground. When we push the ground backward and as a reaction the ground push us forward. The force of friction between sole and ground provides the necessary grip which pushes us forward.

Conclusion:- As conclusion we find that we are able to walk on the ground.

Question # 7: The parking brake on a car causes the rear wheels to lock up. What would be the likely consequence of applying the parking brake in a car that is in rapid motion?

Answer:- **Statement**: - The parking brake on a car causes the rear wheels to lock up. The likely consequence of applying the parking brake (Hand brake) in a car that is in rapid motion. The rear wheels will be lockup and the front wheels are in motion.

Reason: - It is because of inertia.

Explanation: - During fast driving on the road if the parking brake is applied, the rear wheel will be lock up. But the front wheels are in motion. Due to inertia these wheels try to maintain their motion. As the rear wheel of the car locks then it will rotate at its position instead of moving forward. The like consequences the car will go out of control of the driver and can cause an accident.

Conclusion:- As conclusion we find that the car will skid in this situation the car will go out of control of the driver and can cause an accident.

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Question # 8: Why is the surface of a conveyor belt made rough?

Answer: Statement: - The surface of a conveyor belt made rough.

Reason: - It is because to increase the force of friction.

Explanation: - As we know that the force of friction is a contact force. Its value depends upon the degree of roughness of the surface. Greater the degree of roughness of the surface greater will be the force of friction and vice versa.

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Conclusion: - As conclusion we find that the surface of the belt is made rough to increase the force of friction between the belt and the materials on the belt. So the things lying on the belt remains safe from falling down.

Question # 9: Why does a boatman tie his boat to a pillar before allowing the passengers to step on the river bank?

Answer: Statement:- A boatman ties his boat to a pillar before allowing the passengers to step on the river bank.

Reason: - It is because of

Action = Reaction

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

Explanation: - As we know that From Newton 3rd law of motion, Action and reaction always equal in magnitude but opposite in direction. When the passenger jump from the boat :-

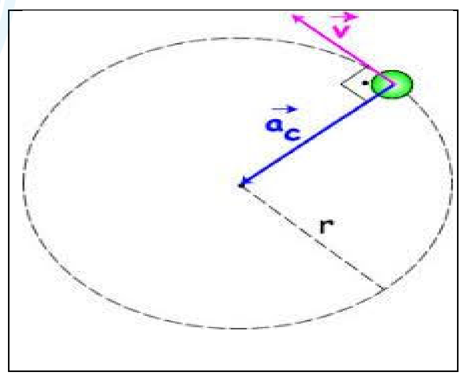
(i)They apply some force on the boat with their feet in the back ward direction which is action.

(ii)The reaction force of the boat is in opposite direction.

Conclusion: - As conclusion we find that the boatman ties his boat with a pillar to stay the boat in static form.

Question # 10: In uniform circular motion, is the velocity constant? Is the acceleration constant? Explain**.**

Answer: - **Statement**:- In uniform circular motion, the velocity does not remains constant but the acceleration is remains constant throughout the motion.



Reason: - It is b**ecause** during circular motion the directions of velocity changes continuously from point to point.

Explanation: - As we know that in uniform circular motion the magnitude of velocity remains constant at every point of the circle. Only its direction always changes because of centripetal force which is always directed toward the center of the circle. This centripetal force produces centripetal acceleration in the body which is also directed towards the center. This acceleration remains constant throughout the motion, because of uniform circular motion. As shown in figure .

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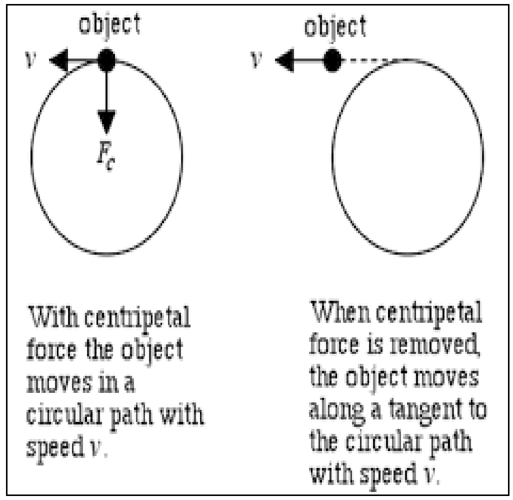
Question #11:-You tie a brick to the end of a rope and whirl the brick around you in a horizontal circle. Describe the path of the brick after you suddenly let go of the rope.



Answer: -Statement: -When we tie a brick to the end of a rope and whirl the brick in a horizontal circle of radius "r". The path of the brick after we let go the rope suddenly it moves away along the tangent to the circle.

Reason: - It is due to centrifugal force.

Explanation: - As we know that the tension in the rope provides the required centripetal force to the brick to perform circular path. Now if we let go the rope suddenly the brick moves away along the tangent to the circle due to centrifugal force as shown in figure.

Note: - Both centripetal and centrifugal forces are equal in magnitudes but in directions.

Question # 12: Why is the posted speed for a turn lower than the speed limit on most highways?

Answer:- Statement:- The posted speed for a turn lower than the speed limit on most highways.

Reason:-

Explanation: - As we know that

$$F_c = \frac{mV^2}{r} \text{ ----------------- } (1)$$

From equation (1) it is cleared that higher the speed of the body, greater amount of centripetal force is required to move along a circular path. At higher speed it is not possible for the fractional force to provide the required centripetal force for the body to take a turn. As a result the body will skid away due to insufficient centripetal force provided by the friction between the tyres and road.

So in order to avoid such risky situation the driver should keep the speed of the body lower while taking a turn.

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NUMERICAL QUESTIONS

Problem # (01): 1580 Kg car is traveling with a speed of 15.0 m/s . What is the magnitude of the horizontal net force that is required to bring the car to a halt in a distance of 50.0 m?

Ans:-**Solution**:-

Given data:-

Mass of car = m = 1580 kg

Initial velocity of the car = V_i = 15.0 m/s

Final velocity of the car = V_f = 0 m/s

Distance = S = 50.0m

Required Data:-

Force = F = ?

Formula:- As we know that

F = ma .... (i)

(a)First we find the value of "a":- From 3rd equation of motion

$$2as = V_f^2 - V_i^2 = a \times 2 \times 50.0 = (o)^2 - (15.0)^2$$

$$a \times 100 = 0 - 225 = a\times 100 = -225 \quad \text{OR} \quad \frac{a \times 100}{100} = \frac{-225}{100}$$

$$\frac{a \times 100}{100} = \frac{-225}{100} \quad \text{OR} \quad a = -2.25\ m/s^2$$

Calculation:- By putting values in equation (i) we get

$$F = 1580 \times -2.25 = -3555N = -3.555 \times 10^3 N$$

Note:- The negative sign shows that the force is retarding.

Result:- So as a result the required force to bring the car to a halt in a distance of 50.0m is - 3555N = -3.555 x10^{3}N.

(2)A bullet of mass 10g is fired with a rifle . The bullet takes 0.003s to move through barrel and leaves with velocity of 300 m/s. What is the force exerted on the bullet by the rifle?

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Ans: Solution:-

Given Data:-

Mass of bullet = m = 10g = $\frac{10}{100}$ kg = 0.01kg

Time taken = t = 0.003sec

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Initial velocity = V_i = 0m/s
Final velocity = V_f = 300 m/s
Required data:-
Force = F = ?
Formula:- As we know that

F = ma .... (1)

(i)First we find the value of "a":- From 1st equation of motion

$$V_f = V_i + at \quad \text{OR} \quad a = \frac{V_f - V_i}{t} = \frac{300-0}{0.003} = \frac{300}{0.003} = 100000 \text{ m/s}$$

Calculation:- By putting values in equation (1) we get

F = ma = 0.01 x 100000 = 1000 N.

Result:- So as a result the force exerted on the bullet by the rifle is 1000 N.

Pb#03:-A 2200 kg vehicle traveling at 94 km/h (26 m/s) can be stopped in 21s by gently applying the brakes . It can be stopped in 3.8 s if the driver slams on the brakes. What average force is exerted on the vehicle in both of these stops?

Answer:-**Solution:-**
Given data:-
Mass of vehicle = m = 2200 kg
Initial Velocity of vehicle = V_i = 94 km/ h = 26 m/s
Time taken in 1st case =t_1 = 21 sec
Time taken in 2nd case =t_2 = 3.8 sec
Final velocity = V_f = 0 m/s

$$V_f = V_i + at \quad \text{OR} \quad a = \frac{V_f - V_i}{t}$$

Required data:-
(i) The force exerted on vehicle in 1st case = F_1 = ?
(ii) The force exerted on vehicle in 2nd case = F_2 = ?
Formula: - As we know that

F = ma .... (1)

(i) For F_1 :- Equation (1) becomes

$$F_1 = ma_1 = m\left(\frac{V_f - V_i}{t_1}\right) \text{ .... (2)}$$

Calculation:- By putting values in (2) we get

$$F_1 = m\left(\frac{V_f - V_i}{t_1}\right) = 2200\left(\frac{0-26}{21}\right) = \frac{2200 \times -26}{21} = \frac{-27200}{21} = -2723.80 \text{ N} = -2.723 \times 10^3 \text{ N}$$

(ii) For F_2 :- Equation (1) becomes

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$$F_2 = ma_2 = m\left(\frac{V_f - V_i}{t_2}\right) \text{ .... (3)}$$

Calculation:- By putting values in (3) we get

$$F_2 = m\left(\frac{V_f - V_i}{t_2}\right) = 2200 \times \frac{0-26}{3.8} = \frac{2200\ X -26}{3.8} \frac{-27200}{3.8} = -15052.6 \text{ N} = -1.5052 \times 10^4 \text{ N}$$

Pb # 04:-You want to move a 500N crate across level floor. To start the crate moving you have to pull with a 230 N horizontal force. One the crate breaks loose and starts to move, you can keep it moving at constant velocity with only 200 N. What are the co-efficient of static and kinetic friction?

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Answer:-Solution:-

Given data:-

Weight of crate = Normal force = F_N = **500N.**

Static friction = f_s **=** 230 N.

Kinetic friction = f_k= 200 N

Required data:-

(i) Co-efficient of static friction = μ_s **= ?**

(ii) Co-efficient of kinetic friction = μ_k **= ?**

(i) For Co-efficient of static friction = μ_s **:-**

Formula:- As we know that $\mu_s = \frac{f_s}{F_N}$ .... (1)

Calculation:- By putting values in equation (1) we get

$$\mu_s = \frac{f_s}{F_N} = \frac{230}{500} = 0.46$$

(ii)For Co-efficient of kinetic friction = μ_k **:-**

Formula:- As we know that $\mu_k = \frac{f_k}{F_N}$ .... (2)

Calculation:- By putting values in equation (2) we get

$$\mu_k = \frac{f_k}{F_N} = \frac{200}{500} = 0.40$$

Pb# 05:- Two bodies of masses 3kg and 5kg are tied to string which is passed over a pulley. If the pulley has no friction, find the acceleration of the bodies of the bodies and tension in the string.

Answer:- Solution:-

Given data:-

Mass of 1st body = m_1= 5 kg

Mass of 2nd body = m_2 = 3kg

Gravitational acceleration = g = 10 m/s^2.

Required data: -

(i) Acceleration of the connected bodies to the string = a = ?

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(ii) Tension in the string = T = ?

(i) For Acceleration of the connected bodies to the string = a: -

Formula:- As we know that

$$a = \frac{m_1 - m_2}{m_1 + m_2} \times g \quad \text{.............................. (1)}$$

Calculation:- By putting values in equation (1) we get

$$a = \frac{5-3}{5+3} \times 10 = \frac{2}{8} \times 10 = \frac{2 \times 10}{8} = \frac{20}{8} = 2.5 \text{ m/s}^2 .$$

(ii)For Tension in the string = T :-

Formula:- As we know that

$$T = \frac{2m_1 m_2}{m_1 + m_2} \times g \quad \text{..................... (2)}$$

Calculation:- By putting values in equation (2) we get

$$T = \frac{2 \times 5 \times 3 \times 10}{5+3} = \frac{300}{8} = 37.5 \text{ N}$$

Pb # 06: Determine the magnitude of the centripetal force exerted by the rim of a car's wheel on a 45.0kg tire. The tire has a 0.480 m radius and is rotating at a speed of 30.0 m/s.

Answer:- Solution:-

Given data:-

Mass of car wheel = m = 45.0 kg

Radius of car wheel = 0.480 m

Speed of car Wheel = V = 30.0 m/s

Required data:-

Centripetal Force = F_c = ?

Formula:- $F_c = \frac{mv^2}{r}$ .... (i)

Calculation:- By putting values in equation (i) we get

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$$F_c = \frac{45.0 \times (30)^2}{0.480} = \frac{40500}{0.480} = 84375 \text{ N} = 8.43 \times 10^4 \text{ N}$$

Pb# 07:-A motorcyclist is moving along a circular wooden track of a circus (death Well) of radius 5m at a speed of 10 m/s. If the total mass of motorcycle and the rider is 150 kg find the magnitude of the centripetal force acting on him?

Answer:- Solution:-

Given data:-

Radius = r = 5m

Speed = V = 10m/s

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Mass = m = 150 kg

Required data:-

Centripetal Force = F_c = ?

Formula:- $F_c = \frac{mv^2}{r}$

Calculation:- By putting values in equation (i) we get

$$F_c = \frac{150 \times (10)^2}{5} = \frac{150 \times 100}{5} = \frac{15000}{5} = 3000 \text{ N} = 3 \times 10^3 \text{ N}$$

Result: - The centripetal force on motorcyclist is 3000= 3 x 10^3 N.

Pb#08: A car of mass 1000 kg is running on a circular motor way interchange near swabi with velocity of 80 m/s the radius of the circular motor way interchange is 800 m. How much centripetal force is required?

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Answer:- Solution:-

Given data:-

Mass = m = 1000 kg

Velocity = V = 80m/s

Radius = r = 800 m

Required data:-

Centripetal Force = F_c = ?

Formula:- $F_c = \frac{mv^2}{r}$ .... (i)

Calculation:- By putting values in equation (i) we get.

$$F_c = \frac{1000 \times (80)^2}{800} = \frac{1000 \times 6400}{800} = 1000 \times 8 = 8000 \text{ N} = 8 \times 10^3\ N$$

Result:- The centripetal force on motorcyclist is 8000 N = 8 x $10^3\ N$.

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