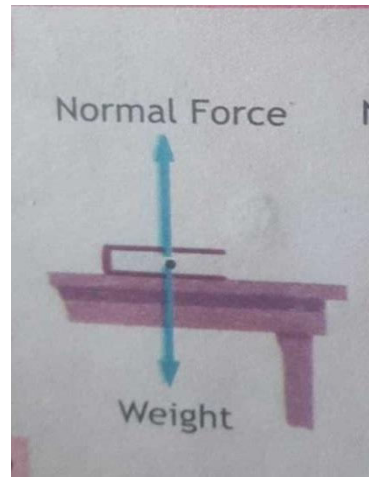
Chapter = 04

TURNING EFFECT OF FORCES

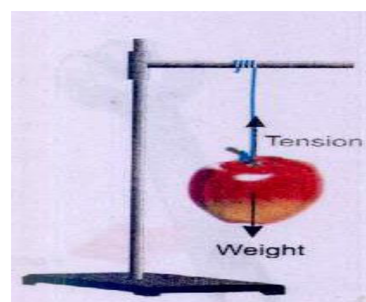
FORCE DIAGRANS



Definition:- A diagrams showing all the forces acting on a body using arrows , considering body as a point mass is known as force diagrams.
Other Name:- It is also called free body diagrams.
Purpose:- To study the effects of forces acting on any object.
Explanation:- As we know that the force is a vector quantity and it can be represented by an arrow. Force diagrams are very useful conceptual tools for physics students because they help examine the forces acting on an object. In force diagrams the object on which forces are shown is reduced to a dot (point) at its center and the forces acting on an object are represented by arrows pointing away from it.
Examples:- (1) A book lying on the table. Its force diagram is shown in figure.

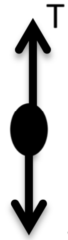
T (Normal force)

W (weight)



(ii) An apple is suspended by a string as shown in figure.
Force diagram is:-

T (Tension)



W (weight)

SOME GOLDEN POINTS:-
(1) Point of action of force:- The point at which the force is applied.
(2)Line of action of force:- The direction through which the force is applied.

PARALLEL FORCES

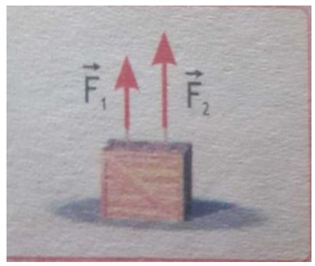
Definition:- Two forces are said to be parallel if the angle between them is 0^0 or 180^0 are known as parallel forces. OR
Those forces whose lines of action are parallel to each other but point of action are different are known as parallel forces.

Examples:-
(i) To lift a box with double support.
(ii) An apple is suspended by a string.
(iii) A book lying on the table etc.

Types of Parallel forces:- There are two types of parallel forces which are given
(1) Like Parallel forces.
(2) Un-like Parallel forces.

(1) Like Parallel forces:-

Definition:-Those Parallel forces which are same in direction are known as like Parallel forces .



Examples:-
(i) When we lift a box with a double support we are applying like parallel forces from each support , the force form one support may be greater than the other.
(ii) Consider a bag with apples in it. The weight of the bag is due to all the apples in it. Since the weight of every apple in the bag is the force of gravity acting on it vertically downwards, Therefore weights of apples are the parallel forces. All these forces are acting in the same direction. Such forces are known as like Parallel forces.
(iii) Consider two forces are acting on a rod as shown in figure. These force forces are not equal but parallel and act in the same direction.

Resultant of Like Parallel forces ($\overrightarrow{R}$):-

$$\vec{R} = \vec{L} + \vec{K}$$

Un-like Parallel forces:-

Definition:- Those Parallel forces which are opposite in direction are known as un-like Parallel forces.

Angle Range:- The angle between the between two un-like parallel forces is 180^0.

Resultant of two Like Parallel forces ($\overrightarrow{R}$):-

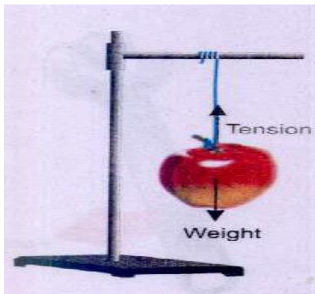
$$\vec{F} = \vec{F_1} - \vec{F_2}$$

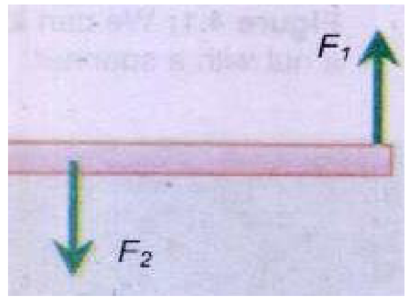
Examples:-
(i) An apple is suspended by a string as shown in figure. The string is stretched due to the weight of the apple. The forces acting on it are , Weight of the apple acting vertically

downwards and tension in the string pulling it vertically upwards. The two forces are parallel but opposite to each other. These forces are known as Un-like parallel forces.

(ii) When we apply force with our both hands on steering wheel of a car to turn it the force from one hand may be greater than the other as shown in figure.

(iii) Consider two forces ($\overrightarrow{F_1}$) and ($\overrightarrow{F_2}$) are acting on a rod as shown in figure. These force forces are not equal but parallel and act in the opposite direction.





<u>ADDITION OF FORCES</u>:-

<u>Definition</u>:- It is a process of obtaining a single force which produces the same effect as produced by a number of forces acting together. OR

The combination of two or more than two forces to get a single force is known as addition of forces.

<u>Mathematical Form</u>:- $\boldsymbol{F_R} = \mathrm{F}_1 + \boldsymbol{F_2} + \boldsymbol{F_3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + \boldsymbol{F_n}$

Factors:- The magnitude of resultant force depends upon:-

(i) The magnitudes of the given forces.

(ii) The angle between the forces.

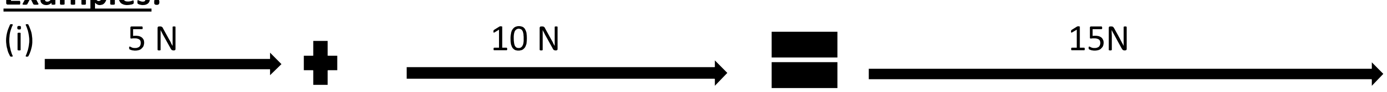
<u>Addition of parallel forces</u>:-

(a) <u>For like parallel forces</u>:- In this case

Resultant force = Sum of forces

$$\mathbf{F_R = F_1 + F_2}$$

<u>Examples</u>:-

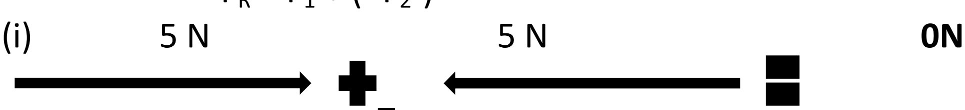


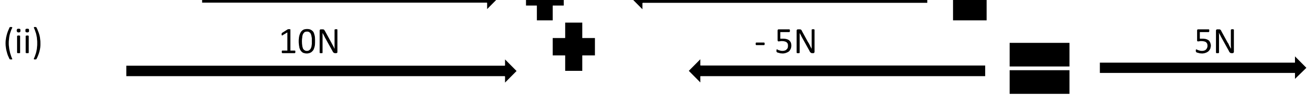
(b) <u>For Un - like parallel forces</u>:- In this case

Resultant force = Subtraction of magnitudes of forces

$$F_R = F_1 + (-F_2)$$

<u>Examples</u>:- (i)

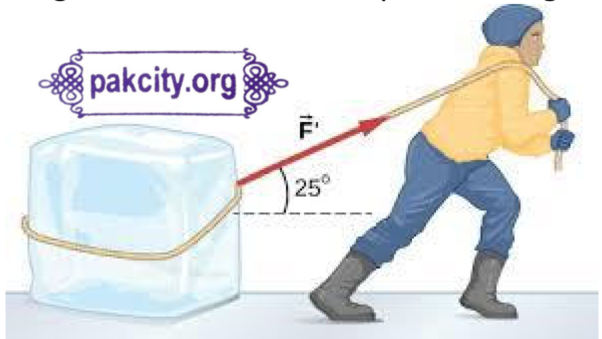




Non Parallel Forces

Definition:- Those forces which are acting on a body at an angle other than **" 0^0" or " 180^0"** are known as non-parallel forces.

Example:- A boy pulling a stone with the help of a string as shown in figure.



ADDITION OF NON- PARALLEL FORCES

Non - parallel can be added with the help of "Head to tail rule".

HEAT TO TAIL RULE:-

Statement:- It is a graphical method which is used to find the resultant of two or more forces (vectors) .

Explanation:-

(i) Draw the representative lines of vectors.

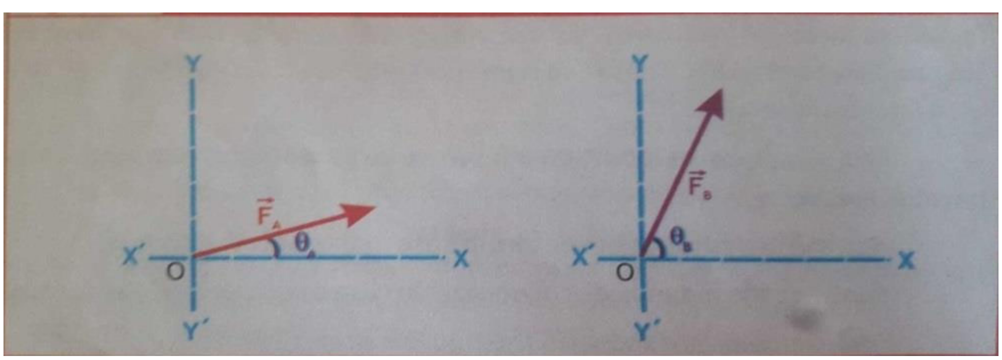
(ii) Join the tail of 2nd with the head of 1st vector.

(iii) Join the tail of 1st vector of with the head of 2nd vector.

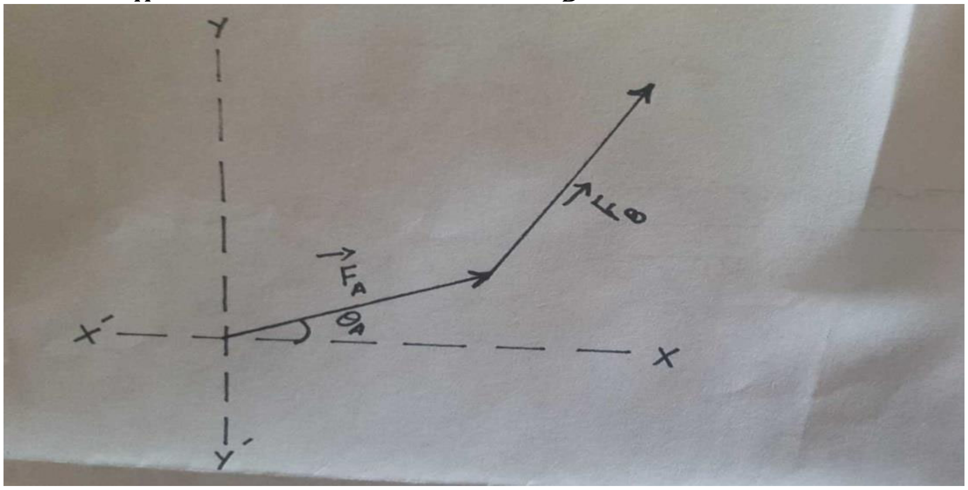
(iv) This line gives the magnitude of resultant vector.

Example:- Consider two persons pulling a cart such that their force vectors are drawn to same scale. Draw $\overrightarrow{F_A}$ making an angle "θ_A" with the X-axis and $\overrightarrow{F_B}$ making an angle "θ_B" with the x-axis .

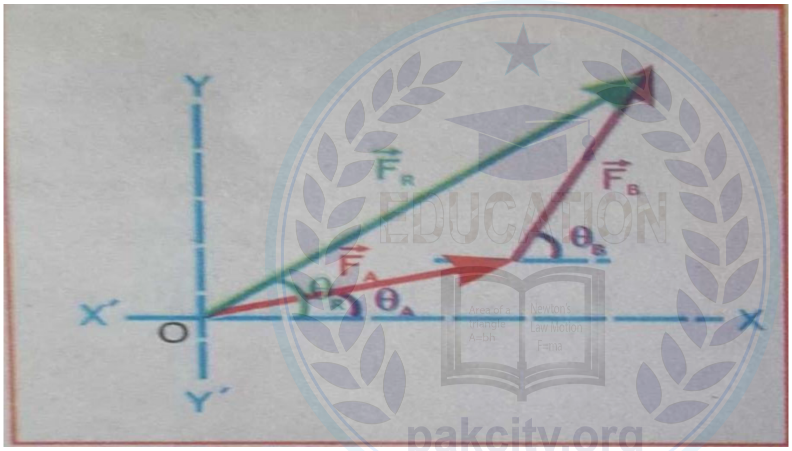
STEPS:- **(i)** Draw the representative lines of vectors $\overrightarrow{F_A}$ **and** $\overrightarrow{F_B}$ according to selected scale.



(ii) Join the vector $\overrightarrow{F_A}$ with the head of vector $\overrightarrow{F_B}$.



(iii) This line gives the magnitude of the resultant force ($\overrightarrow{F_R}$).



(iv) <u>Magnitude $\overrightarrow{F_R}$</u> :- $\overrightarrow{F_R} = \overrightarrow{F_A} + \overrightarrow{F_B}$

RESOLUTION OF FORCES

<u>Definition</u>:- The process of splitting a force vector into its components is known as resolution of forces.

<u>Explanation</u>:-

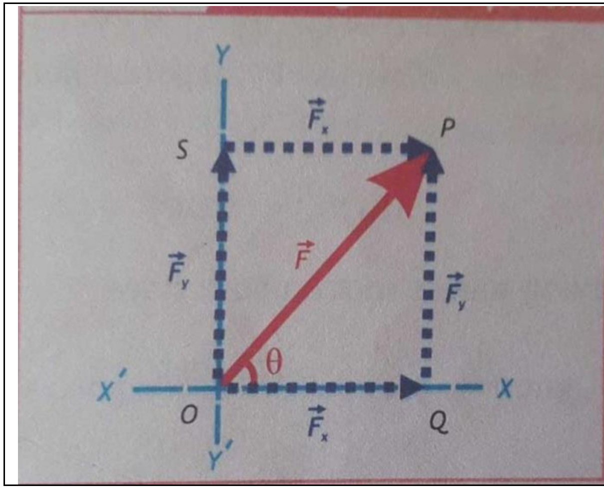
(i) It is the reverse processes of addition of vectors.

(ii) In this process a single vector can be converted into two or more components.

(iii) The force vectors so obtained are called rectangular components.

<u>Rectangular Components</u>:- Those components of a force (vector) which are mutually perpendicular to each other are known as rectangular components.

<u>Mathematically</u>:- $F = F_x + F_y$



Explanation:- Consider a force "F" in the Cartesian coordinate system represented by the line OP making an angle "θ" as shown in figure.

To find the rectangular Components:- Now to resolve the force "F" into its components.

Steps:-

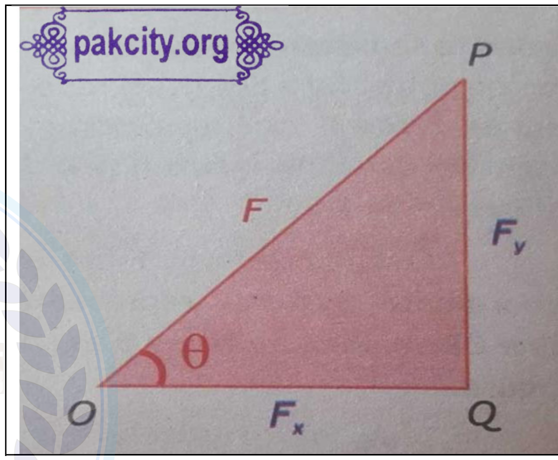
(i) Draw perpendicular from point "P" on the X-axis and Y-axis which meets the axis at points "Q" and "S" respectively.

(ii) Put arrow heads from the direction of "O" towards "Q" and "S".

(iii) OQ = SP= F_x (Horizontal Components).

(iv) OS = QP = F_y (Vertical Component).

(v) Angle between C and F_y is 90^0 .



Components represented in term of force:-

(a) **For horizontal Components (F_x):-** From figure ΔOPQ

$$\text{Cos } \theta = \frac{Base}{Hyp} = \frac{OQ}{OP} = \frac{F_x}{F}$$

$$\text{Cos } \theta = \frac{F_x}{F} \quad \text{OR} \quad F \text{ Cos } \theta = F_x$$

$$F_x = F \text{ Cos } \theta$$

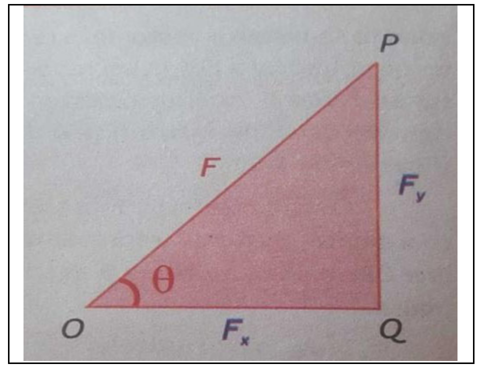
(b) For Vertical Component (F_y):-

$$\text{Sin } \theta = \frac{Perp}{Hyp} = \frac{QP}{Op} = \frac{F_y}{F}$$

$$\text{OR} \quad \text{Sin}\theta = \frac{F_y}{F} \quad \text{OR} \quad F \sin\theta = F_y$$

$$F_y = F \sin\theta$$

(c) <u>For magnitude of resultant force</u> ($\vec{F}$):- From triangle "ΔOPQ ".



By using Pythagoras theorem:

(Hypotenuse)^2 = (Base)^2 + (Perpendicular)^2

OR (OP)^2 = (OQ)^2 + (PQ)^2

OR $\sqrt{(OP)2} = \sqrt{(OQ)2 + (PQ)2}$

$OP = \sqrt{(OQ)2 + (PQ)2}$

OR $F = \sqrt{F_x^2 + F_y^2}$ .... (3)

Equation (3) represents the magnitude of the resultant force.

<u>Direction of resultant force</u>:- In "ΔOPQ " :-

$$\tan\theta = \frac{Perpendicular}{Base} = \frac{PQ}{OQ}$$

OR $\tan\theta = \frac{F_y}{F_x}$ OR $\theta = tan^{-1}\frac{F_y}{F_x}$ .... (4)

Equation (4) represents the direction of the resultant force.

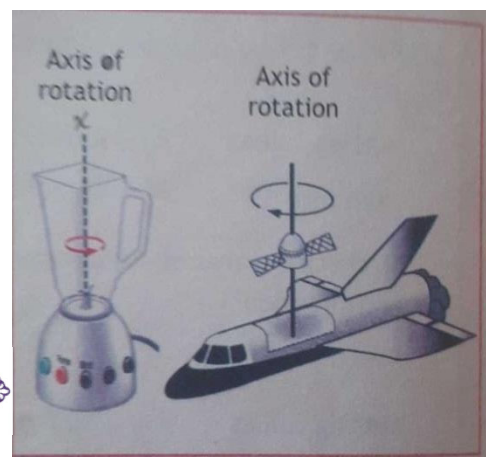
ANGLE VALUES			
θ	sin θ	cos θ	tan θ
0^0	0.000	1.000	0.000
30^0	0.866	0.500	0.577
45^0	0.707	0.707	1.000
60^0	0.866	0.500	1.732
90^0	1.000	0.000	infinite

ROTATIONAL MOTION

<u>Definition:-</u> The rotation of a body about a fixed point is known as rotational motion. **<u>Examples</u>**:-

(i) The motion of hands of clock.

(ii) The motion of tyre of a car etc.



<u>Rigid Body</u>:-

<u>Definition</u>:- Rigid objects are objects of fixed form that do not distort or deform (change shape) as they move .

A rigid body is the one that is not deformed by force or forces acting on it.

<u>Examples</u>:- (i) A book. (ii) A car etc.

<u>Extended Object OR body</u>:-

<u>Definition</u>:- An object which occupies non-zero space .

<u>Examples</u>:- (i) Book (ii) car (iii) Rod etc.

<u>Uniform OR Homogenous body</u>:-

Definition:- A body having uniform density.
Examples:- A homogenous sphere , Cube , Disk etc.
Axis of rotation:-
Definition:-It is a line about which rotation take place.

CENTER OF MASS

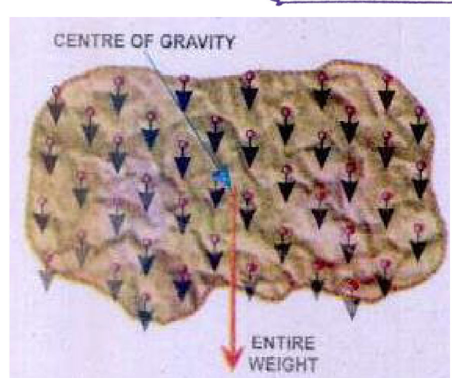
Definition:- The point about which mass is equally distributed in all direction is known as center of mass. OR

Centre of mass of a system is such a point where an applied force causes the system to move without rotation.

Abbreviation:- It is abbreviated by **" C.M ".**
Explanation: - As we know that an extended rigid body is made of large number of small interconnected particles. The masses of all the particles together make the mass of the body. There is a specific point around which the whole mass of a body is equally distributed in all directions.
Characteristics of center of mass: -
(i) It is the point at which we can imagine all the mass of an object to be concentrated.
(ii) The force applied at this point will only produce linear acceleration.
(iii) It is used to describe the overall motion of an extended body.
(iv) If the net is zero then the **"C.M"** will be move with uniform velocity.

CENTER OF GRAVITY

Definition:- The point where the whole weight of the body appears to act is known as center of gravity.
Abbreviation:- It is abbreviated by **" C.G ".**
Explanation: - As we know that an extended rigid body is made of large number of small interconnected particles. Earth attracts each of these of particle downwards towards its center. The pull of the earth acting on a particle is equal to its weight. The weight of all the particles together make the weight of the body. There is a specific point where the whole of the body appears to act as shown in figure.



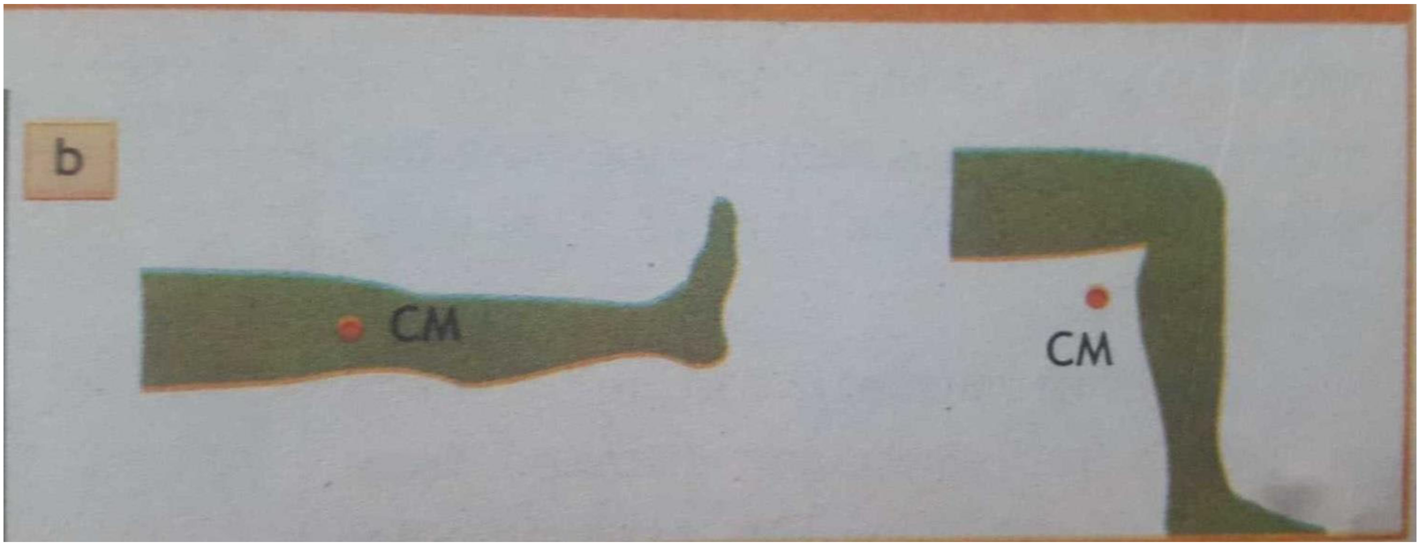
CENTER OF MASS (GRAVITY) OF SOME OBJECTS	
NAME OF BODY	POSITION OF CETER OF GRAVITY
1 Sphere	1 Center of the sphere
2 Uniform rod	2 Center of rod
3 Circular plate	3 Center of plate
4 Plate square rectangular or parallelogram in shape	4 Intersection of diagonals
5 Triangular plate	5 Intersection of medians
6 Cylinder	6 Mid – point of axis

Note:- The CM/CG may or may not lie inside the mass , sometimes the CM/CG is outside the distribution of mass.

(1):- Example:- Banana in the figure a has center of gravity outside the mass distribution.

Note:- Center of mass may change its location depending upon the orientation of the object. If parts of an object change position relative to each other the location of CM / CG will change.

<u>Example</u>:- Leg shown in figure. When the leg is stretched the mass is inside the body, but when the leg is bent the change in mass distribution changes CM/CG and is shifted outside the body.



DIFFERENCE BETWEEN CENTER OF MASS AND CENTER OF GRAVITY:-

Center of mass	Center of gravity
It is the point about which mass is equally distributed in all direction.	It is the point where the weight of the body appears to act.
It is abbreviated by " **C.M** ".	It is abbreviated by " **C.G** ".
It does not depends upon the gravitational field.	It depends upon the gravitational field.

NOTE: The force applied at :-

(i) Center of mass produce translational motion.

(ii) Point other than center of mass produce turning effect (Rotation).

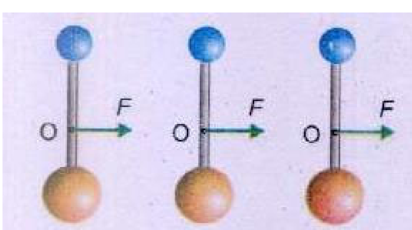


Figure : A force applied at COM moves the system without rotation.

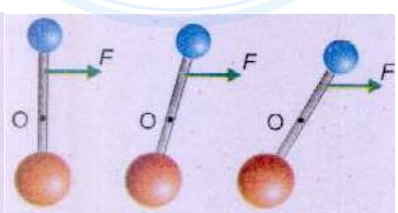


Figure : The system moves as well as rotates when a force is applied away from COM.

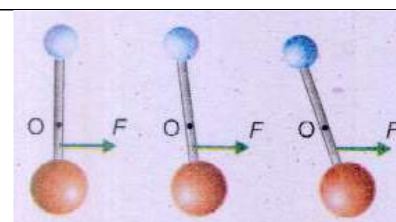


Figure : The system moves as well as rotates when a force is applied away from COM.

DETERMINATION OF C.M / C.G FOR IRRE-GULAR OBJECTS

We can find the out the C.M / C.G of an irregular objects with the help of plumb line.

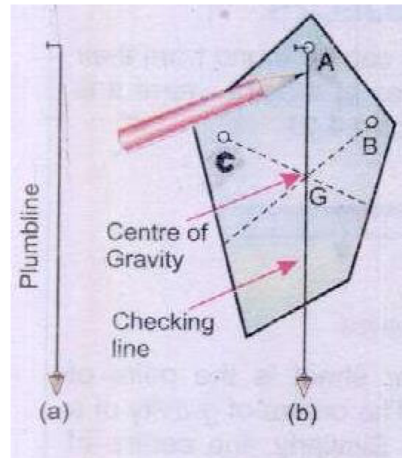
Plumb Line:- A card with a weight attached used to produce a vertical line.

Explanation:-

(i) Take an irregular piece of card board.

(ii) Make holes **"A" , "B"** and **"C"** near its edges.

(iii) Fix the nail on the wall.



(iv) Support the cardboard on the nail through one of the hole let it be **"A",** So that the card board can swing freely about **"A".**

(v) The card board will come to rest with its **"C.M"** just vertically below the nail.

(vi) Vertical line from **"A"** can be located using the plumb line hung from the nail.

(vii) Mark the line on the cardboard behind the plumb line.

(viii) Repeat it by support the cardboard from the hole **"B".**

(ix) The line from the **"B"** will interact at point **"G".**

(x) Similarly draw another line from the hole **"C".**

(xi) Note that these lines also passes through the **"G".**

(xii) It will found that all the vertical lines from holes **"A" , "B" and "C"** have a common point **"G".**

(xiii) This common point **"G"** is the center of gravity of the cardboard.

TORQUE

Meaning:- It is a **Greek** word which means "**To Twist**" .

Definition: - The turning effect produced in a body about a fixed point due to applied force is known as torque. OR

The turning effect of force in a body is known as torque. OR

The cross product of applied force and moment arm is known as torque. OR

The vector product of applied force and moment arm is known as torque.

Other Name:- It is also called **Moment of force**.

Symbol:- It is denoted by " $\vec{\tau}$".

Mathematical Form:- Torque = Force x Moment arm

$$\vec{\tau} = \vec{F} \times \vec{d}$$

$$\vec{\tau} = F\, d \sin\theta \quad \text{.........................} \ (1)$$

Unit: - Its SI unit is Nm (Newton meter).

Quantity:- It is a vector quantity.

Nature:- It is a derived quantity.

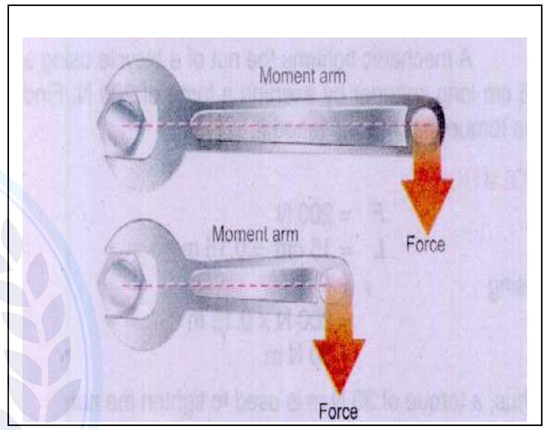
Moment Arm: - It is the perpendicular distance the axis of rotation and the line of action of the force.

Factors of torque: - From equation (1) cleared that the torque has three factors which are given below.

Factors of torque: - From equation (1) cleared that the torque has three factors which are given below.

(i) Applied force (F):- Greater the applied force greater will be the torque produced and vice versa i-e $\vec{\tau} \propto \vec{F}$

(ii) Moment arm (d):- Greater the moment arm greater will be the torque produced and vice versa i-e $\vec{\tau} \propto \vec{d}$.



Example:- It is easy to tighten a nut using a spanner longer arm than a spanner of shorter arm because of more torque.

(iii) Value of angle (θ): - The value of torque depends upon the value of angle between the force and moment arm which can be explained in the following cases.

Case (a):- It force and moment arm is parallel to each other i-e $\theta = 0^0$ then from equation (1)

$$\vec{\tau} = F\, d \sin\theta = F\, d \sin(0^0)$$

Sin $(0^0) = 0$

OR $\vec{\tau} = 0$ Nm

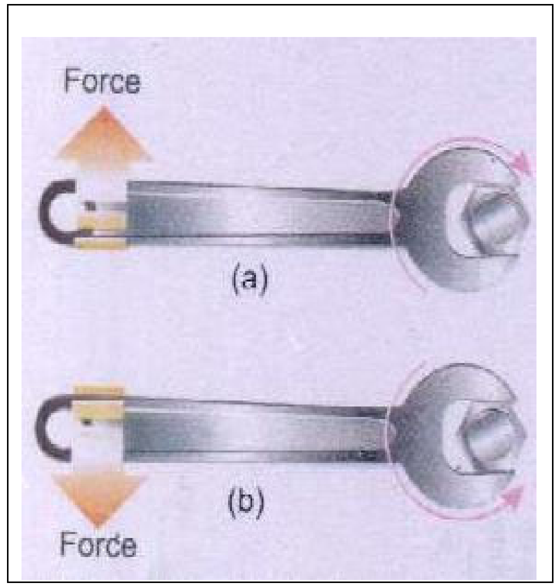
Case (b):- It force and moment arm is parallel to each other i-e $\theta = 90^0$ then from equation (1)

Sin $(90^0) = 1$

$$\vec{\tau} = F\, d \sin\theta = F\, d \sin(90^0)$$

$$\vec{\tau} = F\, d \sin(90^0) = Fd$$

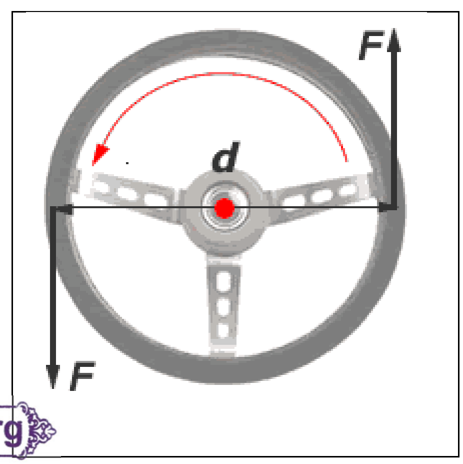
Types OR Senses of torque: - There are two types of torque which are given below.
(i) Clock wise torque.
(ii) Anti clock wise torque.



(i) **Clock wise torque**:- If the force is capable of rotating the body in clockwise direction the torque is known as Clock wise torque.
(ii) **Anti clock wise torque**:- If the force is capable of rotating the body in clockwise direction the torque is known as Clock wise torque.
Note:- Conventionally Clockwise torque is taken as negative whereas anticlockwise torque is taken as positive.
Examples of torque: -
(i) A door is opened or closed due to torque.
(ii) Tightening of a nut with a wrench (spanner) etc.

COUPLE

Definition:- Two equal and opposite parallel forces acting along different lines on a body constitute a couple. OR
A pair of two un-like parallel forces having same magnitude but not along the same line is known as couple. Effect of couple:- It does not produce any translation, but only rotation.
Explanation:-
(i) It is a pure moment.
(ii) It is a special case of moments.
(iii) The resultant force of a force is zero but resultant of a couple is not zero.
(iv) The shortest distance between two couple forces is called couple arm.
Unit:- Its SI unit is **N.m** (newton meter).
Example:- When a driver turns a vehicle, he applies forces that produce a torque. This torque turns the steering wheel. These forces act on opposite sides of steering wheel as shown in figure and are equal in magnitude but opposite in direction. These two forces form a couple.



Other Examples:-
(i) Winding up the spring of a toy car.

(ii) Double arm spanner.
(iii) Opening and closing the cap of bottle etc.

EQUILIBRIUM

Definition:- The state of a body in which it is at rest or moving with uniform velocity under the action of several forces is known as equilibrium. OR
The state of a body in which its acceleration is zero is known as equilibrium. OR
A body is said to in equilibrium if it is in rest or moving with uniform velocity. OR
The state of a body in which under the action of several forces acting together there is no change in translational motion as well as rotational motion is known as equilibrium.

Examples:-
(i) A book lying on the table.
(ii) A car moving with uniform velocity on the road.
(iii) A lamp hanging from the ceiling.
(iv) A paratrooper coming down with uniform velocity etc.

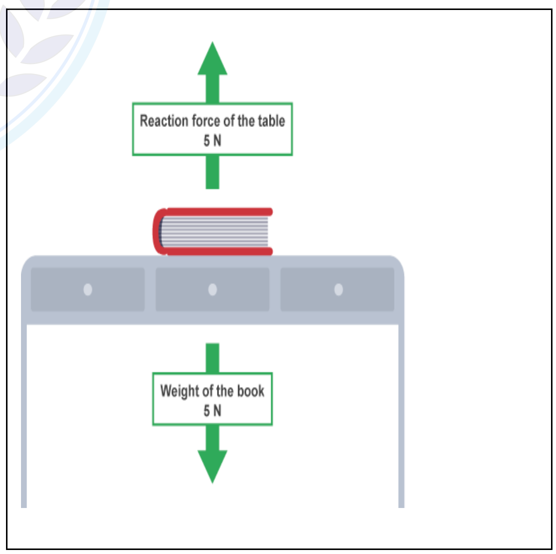
Conditions of equilibrium:- For a body to be in a state of equilibrium two conditions are to be fulfilled which are given below.

(1) First Condition of Equilibrium:-
Definition:- The sum of all forces acting on a body must be zero.
Other Name:- This condition is also called force condition.
Mathematical Form:-
$F_{net} = F_1 + F_2 + F_3 + F_4 + \ldots\ldots\ldots\ldots\ldots\ldots F_n = 0$

OR $\sum \overrightarrow{F_{net}} = 0$

The symbol is a Greek word called sigma which is used for summation (i-e Sum).

Examples:-
(i) A book lying on the table. The book exerts a force " **"W "** equal to its weight downwards and the table applies an upward force **"R".** These two forces are equal in magnitude but opposite in direction. So as a result they cancel the effect of each other. So the net force becomes Zero and thus the book is in equilibrium.



From figure:- Weight of book = Reaction force of the table

$$\vec{W} = \vec{R} \quad \text{OR} \quad \vec{W} - \vec{R} = 0 \quad \text{OR} \quad 5 - 5 = 0$$

Result: - $\sum \vec{F} = \sum(5-5) = 0$

(ii). Motion of paratrooper.
(iii). A static car.
(iv). Motion of a bus with uniform velocity.
(v). Picture hanging on the wall etc.

Note:- First condition of equilibrium only explains the translation equilibrium i-e a body is in state of rest or moving with uniform velocity.

Second Condition of equilibrium:-

Definition:- The of all torques acting on a body must be zero.

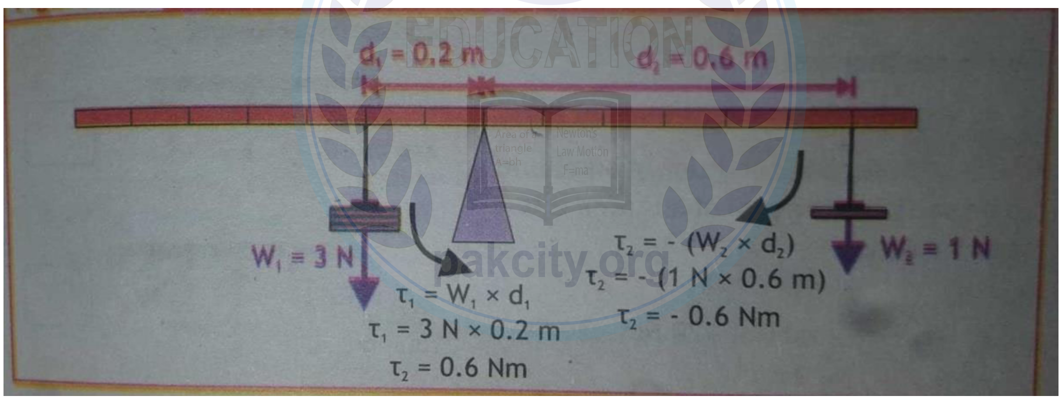
Other Name:- This condition is also called torque condition.

Mathematical Form:- $\vec{\tau}_{net} = \vec{\tau}_{1+}\ \vec{\tau}_2 \ldots\ldots\ldots\ldots\ldots\ldots \vec{\tau}_n$

$$\sum \vec{\tau}_{net} = 0$$

Examples:-

Example:- If we suspend weight of 3N at 0.2 from the pivot it exert the same torque as 1N weight at 0.6m from the fulcrum. A uniform stick will be balance on the pivot as shown in figure.



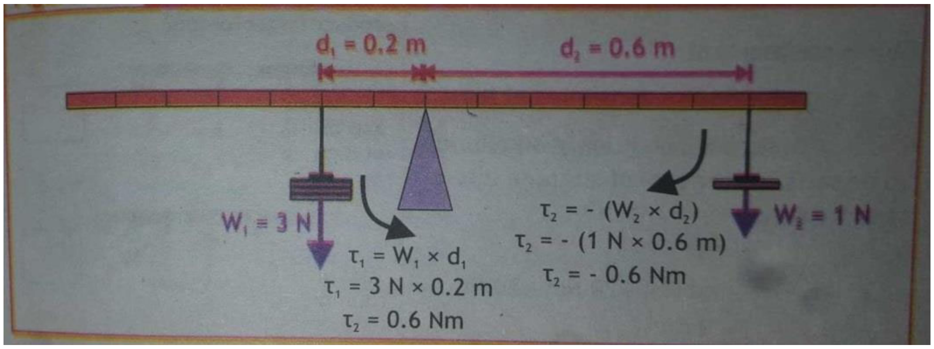
PRINCIPLE OF MOMENT

Definition:- For an object in equilibrium the sum of clockwise torque (moments) taken about the pivot must be equal to the sum of anti-clockwise moments taken about the same pivot. OR

A body is balanced it the sum of clockwise moments acting on the is equal to the sum of anticlockwise moments acting on it.

Mathematical Form:- Clockwise moments = Anticlockwise moments

<u>Example</u>:- If we suspend weight of 3N at 0.2 from the pivot it exert the same torque as 1N weight at 0.6m from the fulcrum. A uniform stick will be balance on the pivot as shown in figure.



<u>Types of equilibrium</u>:- There are two types equilibrium which are given below.

(A) Static Equilibrium.

(B) Dynamic Equilibrium.

<u>(A) Static Equilibrium</u>:-

<u>Definition</u>:- If a body at rest it is said that it is in static equilibrium. OR

When a body is at rest under the action of several forces acting together and several torques acting the body is said to be in static equilibrium.

<u>Examples</u>:-

(i) A book lying on a table.

(ii)A bulb hanging from a ceiling.

(iii) A picture on a wall etc.

(B) <u>Dynamic Equilibrium</u>:-

<u>Definition</u>:- A body is in dynamic equilibrium when moving with constant (uniform) velocity. OR

When a body is moving at uniform velocity under the action of several forces acting together the body is said to be in dynamic equilibrium.

<u>Examples</u>:-

(i) A paratrooper falling down uniform velocity.

(ii) Rotation of compact dick with constant angular velocity etc.

<u>Types of Dynamic equilibrium</u>:- There are two types dynamic equilibrium which are given below.

(1) Dynamic Translational Equilibrium.

(2) Dynamic Rotational Equilibrium

(1) <u>Dynamic Translational Equilibrium</u>:-

<u>Definition</u>:-When a body is moving with uniform linear velocity the body is said to be in dynamic translational equilibrium.

Example:-

(i) A paratrooper falling down with constant linear velocity.

(ii) A car moving with uniform linear velocity on a straight road etc.

(2) Dynamic Rotational Equilibrium:-

Definition:- When a body is moving with uniform angular velocity the body is said to be in dynamic rotational equilibrium.

Example:-

(i) Rotation of compact dick with constant angular velocity.

(ii) Rotation of car wheel about its axis with constant angular velocity etc.

STABILITY

Definition:- The stability of an object refers to the object to return to its original position when the force that changed its orientations is removed. OR

Stability is a measure of how hard it to displace an object or system from equilibrium. OR

The stability of an object is the measure of a body ability to maintain its original position.

Explanation:- As we know that the condition of equilibrium does not specify whether an object is stable or not. The stable objects does not topple easily. The position of the center of mass of a body affects whether or not it topples over easily. This is importance in the design of such things as tall vehicles (which tends to overturn when rounding a corner), racing cars, reading lamps, even drinking glasses.

Factors or Increasing Stability:-

An objects stability is improved by :-

(i) Lowering the center of mass (Center of gravity) or

(ii) Increasing the area of support (Base area) or

(iii) By both

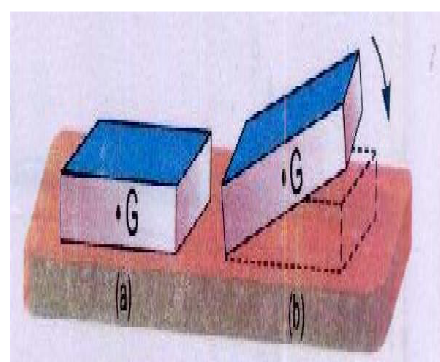
STATES OF EQUILIBRIUM:-

There are three states of equilibrium which are given below.

(1) Stable Equilibrium.

(2) Un-Stable equilibrium.

(3) Neutral Equilibrium.



(1) Stable Equilibrium:-

Definition:- A body is in stable equilibrium if when slightly displaced and then released it returns to its previous position.

OR

A body is said to be in stable equilibrium if after a slight tilt it returns to its previous position.

Example:- A book lying on the table.

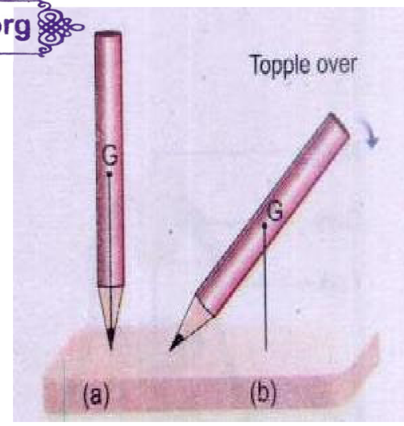
Effect on the height of center of gravity:- As we know that when a body is in stable equilibrium its center of gravity is lowest position. When is tilted its center of gravity rises. It returns to its stable state by lowering its center of gravity. A body remains in stable equilibrium as long as the center of gravity acts through the base of the body.

(2) Un-Stable equilibrium:-

Definition:- A body is in Un-Stable equilibrium if it moves further away from its previous position when slightly displaced and released. OR

If a body does not return to its previous position when sets free after a slightest tilt is said to be un- stable equilibrium.

Example:- A pencil balanced at its tip.



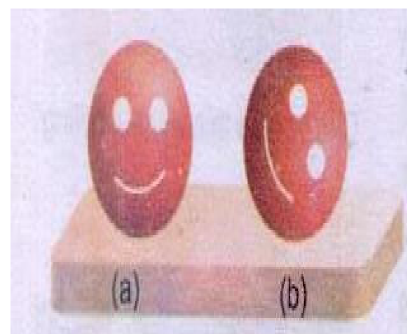
Effect on the height of center of gravity:- As we know that the center of gravity of the body is at its highest position in the state of un-stable equilibrium. As the body topples over about its base (tip) its center of gravity moves towards its lower position and does not return to its previous position.

(3) Neutral Equilibrium:-

Definition:- A body is in neutral equilibrium if it stays in its new position when displaced. OR

If a body remains in its new position when disturbed from its previous position it is said to be in a state of neutral equilibrium.

Example:- A ball is placed on the horizontal surface.



Effect on the height of center of gravity:- As we know that in neutral equilibrium all the new states in which a body is moved are the stable states and the body remains in its new state. In neutral equilibrium the center of gravity of the body remains at the same height irrespective to its new position.

CONCEPTUAL QUESTIONS

Question # 01: **Can the rectangular component of the vector be greater than the vector itself? Explain.**

Answer: Statement: No, it is not possible that the rectangular component of the vector be greater than the vector itself.

Reason:- It is because of

$$|A| = \sqrt{A_x^2 + A_y^2} \text{ ------------------ } (1)$$

Explanation:- From eq (1)

$$A^2 = \left(\sqrt{A_x^2 + A_y^2}\right)$$

$$A^2 = \left(\sqrt{A_x^2 + A_y^2}\right)$$

$$A^2 = A_x^2 + A_y^2$$

This implies that

- $A^2 > A_x^2$ or $A > A_x$
- $A^2 > A_y^2$ or $A > A_y$

Conclusion:- As conclusion we find that the magnitude of the rectangular component of a vector may be equal to vector's magnitude but can never be greater.

Question # 02: **Explain why door handles are not put near hinges?**

Answer: - Statement:- The door handles are not put near hinges.

Reason:- It is because $\tau \propto d$

Explanation: - As we know that

$$\tau = F\,d \text{ ------------ } (1)$$

From eq (1) it is cleared that the torque depends upon applied force and moment arm.

(i) Greater the moment arm greater will be the torque produced and the door will be open easily.

(ii)If the door handles are put near hinges then moment arm becomes smaller and the torque also becomes smaller.

Conclusion:- As conclusion we find that in this case it is more difficult to close or open a door.

Question # 3: **Can a small force ever exert a greater torque than a larger force? Explain.**

Answer: - Statement: - Yes, a small force ever exerts a greater torque than a larger force.

Reason: - It is because of $\tau \propto d$

Explanation: - As we know that

$$\tau = F\,d \text{ ------------ } (1)$$

From equation (1) it is cleared that the torque depends upon the applied force and moment arm. Greater the moment arm greater will be the torque produced and vice versa. So as a result a small force with a longer moment arm will be exert more torque than a larger force with a smaller moment arm.

Conclusion:- As conclusion we find that a small force ever exerts a greater torque than a larger force.

Question # 04: **Why it is better to use a long spanner rather than a short on to loosen a rusty nut?**

Answer: - Statement: - It is better to use a long spanner rather than a short on to loosen a rusty nut.

Reason: - It is because of $\tau \propto d$

Explanation: - As we know that

τ = F d ------------ (1)

From equation (1) it is cleared that the torque depends upon the applied force and moment arm. Greater the moment arm greater will be the torque produced and the rusty nut loose easily.

Conclusion:- As conclusion we find that It is better to use a long spanner rather than a short on to loosen a rusty nut.

Question # 05: **The gravitational force acting on a satellite is always directed towards the center of the earth. Does this force exert torque on satellite?**

Answer: - Statement:-The gravitational force acting on a satellite is always directed towards the center of the earth. This force exerts zero torque on satellite.

Reason: - It is because of $\theta = 0^{o}$ between F and d .

Explanation: - As we know that

$\boldsymbol{\tau}$ = F d sin θ .... **(4)**

As $\theta = 0^{o}$ between "F" and "d" then equation (4) becomes

τ = F d sin (0) sin (0) = 0

τ = F d (0)

τ = 0

Result: - As a result we conclude that the net torque on the satellite is zero.

Question # 06: **Can we have situations in which an object is not in equilibrium, even though the net force on it is zero? Give two examples.**

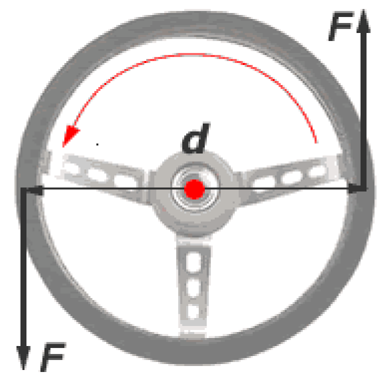
Answer: - Statement: - Yes we have situations in which an object is not in equilibrium but the net force on it is zero.

Reason: - For complete equilibrium.

i) $\sum F = 0$ ii) $\sum T = 0$

Explanation: - As we know that

If $\sum F = 0$ and $\sum T \neq 0$ then the object will be rotate and will not be in state of complete equilibrium.



Examples:-

(i)Steering wheel of a car: - When we rotate the steering wheel of a car with the help of two equal but opposite forces as shown in figure.

From figure $\sum F = 0$ and $\sum T \neq 0$

Result: - So as result we can conclude that we have situations in which an object is not in equilibrium but the net force on it is zero.

Other Examples:-

(i) Bicycle Pedals
(ii) Opening and closing the cap of a bottles.
(iii) Turning of water tap.
(iv) Double hand spanner etc.

Question # 07: Why do tightrope walkers carry a long narrow rod?

Answer: - Statement: - The tightrope walkers carry a long narrow rod.

Reason: - It is because to maintain the stability OR To get balanced condition.

Explanation: - As we know that

From second condition of equilibrium:-

Clock wise torque = Anti clock wise torque

(i)The tightrope walker leans towards the right and produce clockwise torque, then he move the rod in such a way to produce anti clock wise torque.

(ii)Both torques will cancel the effect of each other because they are equal in magnitudes but opposite in direction.

Conclusion: - As a result we can conclude the tightrope walker carry a long-rod to get stability to prevent him-self from falling the rope.

Question # 08: **Why does a wearing high-heeled shoe sometimes cause lower back pain?**

Answer: - Statement: - The wearing high-heeled shoe sometimes causes lower back pain.

Reason: - It is because of disturbance of center of gravity.

Explanation:- As we know that By wearing “high-heeled” shoes push the body in the forward direction. So the center of gravity of the body is disturbed i-e is push forward due to which instability increases. In order to maintain stability the body (person) must move the center of mass by back again, usually by leaning the shoulder back ward.

Result:- As a result we can conclude that by wearing high-heeled shoe sometimes causes lower back pain.

Question # 9:**Why is it more difficult to lean backwards? Explain.**

Answer: - Statement: - It is more difficult to lean backwards.

Reason: - It is because of disturbance of centre of gravity.

Explanation: - As we know that During leaning backward the centre of gravity of the body is disturbed from its normal position due to which instability increases and it becomes very difficult for the body to maintain its state of equilibrium.

Other Reason:- (i) Due to human anatomy.

(ii).Due to instability and due to lower centre of gravity.

Conclusion:- As a result we can conclude that It is more difficult to lean backwards.

Question # 10**: Can a single force applied to a body change both its translational and rotational motion? Explain.**

Answer: - Statement: - Yes a single force applied to a body change both its translational and rotational motion.

Reason: - It is because of the applied force at

i. Centre of mass produce translational motion.
ii. Point other than centre of mass produce turning effect (Rotation).

Explanation:- As we know that if a body is free to move, any force on that object will change its translational motion. If that force is not applied to the centre of mass, it will change rotational motion as well.

Example:- Hold a pencil upright in your hand. Right now both motions are zero, assuming you are not moving. Now flick the top of the pencil and watch it spin and fly out of your hand. You can see that both translational and rotational motions were changed by a single force.

Conclusion:- As a result we can conclude that a single force applied to a body change both its translational and rotational motion.

Question # 11:**Two forces produce the same torque. Does it follow that they have the same magnitude? Explain. Describe the path of the brick after you suddenly let go of the rope.**

Answer: - Statement: - Two forces produce the same torque. Then it does not follow that they have the same magnitude.

Reason: - It is because the torque depend upon

i) Applied force
ii) Moment arm

Explanation: - As we know that

$$\tau = F\ d \sin\theta \text{ -------------- } \mathbf{(1)}$$

Examples: -

Case I: - if $F_1 = 20$ N and $d_1 = 2$ m then

$$\tau_1 = F_1 \times d_1$$
$$\tau_1 = 20 \times 2$$

τ_1 = 40 Nm

Case I: - if F_2 = 8 N and d_2 = 5m then

$\tau_2 = F_2 \times d_2$

$\tau_2 = 8 \times 5$

τ_2 = 40 Nm

Result: - As a result we can conclude that we get the same torque for two different forces by adjusting the values of moment arms.

(b)If the rope is suddenly let go off, the brick move away along tangent to the circular path as shown in figure.

NUMERICAL QUESTIONS

(1)To open a door force is 15N is applied at 30^0 to the horizontal, find the horizontal and vertical component of force.

Answer:- **Solution**:-

Given data:-

Force = F = 15 N

Angle = θ = 30^0

Required data:-

(i) horizontal component of force = F_x = ?

(ii) vertical component of force = F_y = ?

(i) **For F_x** :-

Formula :- $F_x = F \cos\theta$ .... (1)

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

$F_x = F \cos\theta = 15 \times \cos 30^0 = 10 \times 0.866 = 12.99$ N = 13 N.

(ii) **For F_y :-**

Formula:- $F_y = F \sin\theta$ .... (2)

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

$F_y = F \sin\theta = 15 \times \sin 30^0 = 15 \times 0.5 = 7.5$ N

Result:- So as a result **(i)** F_x = 13 N **(ii)** F_y = 7.5 N.

(2) Bolt on a car engine needs to be tightened with a torque of 40 Nm. You use a 25 cm long wrench and pull on the end of the wrench perpendicularly. How much force do you have to exert?

Answer:- **Solution**:-

Given Data:- Torque = τ = 40 Nm

Moment arm = r=25 cm = $\frac{25}{100}m$ =0.25m

Angle = θ= 90^0

Required data:- Force = F = ?

Formula:- τ = F x r = F r Sin θ

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

40 = F x 0.25 x Sin 90^0 = F x 0.25 x 1 = F x 0.25

40 = F x 0.25 OR F = $\frac{40}{0.25}$ = 160 N

Result:- So the net force is 160 N.

Q.03:-Sana, who's mass is 43 kg, sits 1.8 m from the center of a seesaw. Faiz, who's mass is 52 kg, wants to balance Sana. How far from the center of the seesaw should Faiz sit?

Ans:- Solution:-

Given Data:-

Mass of Sana = m_1= 43 kg

Sana's moment arm = d_1= 1.8m

Mass of Faiz = m_2= 52kg

Required Data:-

Faiz's moment arm = d_2= ?

Formula:- From principle of moment

Torque of Sana = Torque of Faiz

$$\tau_s = \tau_F$$

$$F_1 \text{ x } d_1 = F_2 \text{ x } d_2$$

$$m_1\text{g x } d_1 = m_2\text{g x } d_2$$

$$\frac{m_1 g \times d_1}{m_2 g} = d_2 \quad \text{OR} \quad d_2 = \frac{m_1 g \times d_1}{m_2 g} \quad \text{................ (1)}$$

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

$$d_2 = \frac{43 \times 10 \times 1.8}{52 \times 10} = \frac{774}{520} = 1.488 \text{ m}$$

Result:- So as a result the Faiz's moment arm = d_2= 1.488m

Q # 04:Two kids of weighing 300 N and 350 N sitting at the ends of 6 m long seesaw. The seesaw is pivoted at its center. Where would a third kid sit so that the see-saw is in equilibrium in the horizontal position? The weight of the third kid is 250 N. (Ignore the weight of see-saw).

Ans:-**Solution:-**

Given Data:-

Weight of first kid = W_1= 300 N

Weight of second kid = W_2= 350 N

Weight of third kid = W_3= 250 N
Length of see-saw = L = 6m
Moment arm of first kid = d_1= 3m
Moment arm of second kid= d_2= 3m
Required Data:- Moment arm of third kid= d_3= ?
Condition:- The 3rd child will be sit on the side of 1st kid to maintain the stability of the sea-saw because $W_2 > W_1$.

Formula:- From 2nd condition equilibrium

Clock wise torque = Anti-clock wise torque

$$d_2 \text{ x } W_2 = d_1 \times W_1 + d_3 \times W_3$$

$$\frac{d_2 \times W_2 - d_1 \times W_2}{W_3} = d_3$$

$$d_3 = \frac{d_2 \times W_2 - d_1 \times W_2}{W_3} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

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

$$d_3 = \frac{3 \times 350 - 3 \times 300}{250} = \frac{1050 - 900}{250} = \frac{150}{250} = 0.6 \text{ m}$$

Result:- So as a result the Moment arm of third kid= d_3= 0.6m.

Q#05:Two children push on opposite sides of a door during play. Both push horizontally and perpendicular to the door. One child pushes with a force of 20 N at a distance of 0.60 m from the hinges, and the second child pushes at a distance of 0.50m. What force must the second child exert to keep the door from moving? Assume friction is negligible.

Answer:- Solution:-
Given Data:- Force exerted by first child = F_1 = 20 N
Moment arm of F_1 = d_1 = 0.60 m
Moment arm of F_2 = d_2 = 0.50m
Required Data:-
Force exerted by second child = F_2 = ?
Formula:- From 2nd condition of **eq**uilibrium

Torque of F_1 = Torque of F_2

$$\tau_1 = \tau_2$$

$$F_1 \text{ x } d_1 = F_2 \text{ x } d_2 \quad \text{OR} \quad \frac{F_1 \times d_1}{d_2} = F_2$$

OR $$F_2 = \frac{F_1 \times d_1}{d_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

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

$$F_2 = \frac{20 \times 0.60}{0.50} = \frac{12}{0.50} = 24\text{ N}$$

Result:- So as a result the force exerted the 2nd child = F_2 = 24 N

Q # 06:-A construction crane lifts building material of mass 1500 kg by moving its crane arm; calculate moment of force when moment arm is 20 m. After lifting the crane arm, which reduces moment arm to 12m calculate moment.

Given Data:-

Mass of material = m = 1500 kg

Weight of material = W = mg = 1500 x10 = 15000 N

Moment arm = d_1 = 20 m

Moment arm = d_2 = 12m

Required Data:-

(i) Moment of force = τ_1 = ?

(ii) Moment of force = τ_2= ?

Formula:- $\tau =$ **Fd ………………… (1)**

(i) For Moment of force = τ_1 :- Equation (1) becomes

τ_1 = Fd_1 …………………… (2)

Calculation:- By putting values in equation (2)

τ_1 = Fd_1 = 14700 x 20 = 294000 N.m = 2.94 x 10^5 N.m

(i) For Moment of force = τ_2 :- Equation (1) becomes

τ_2 = Fd_2 …………………… (2)

Calculation:- By putting values in equation (3)

τ_2 = Fd_2 = 14700 x 12 = 176400 N.m = 1.76 x 10^5 N.m

Result:-

(i) τ_1 = 294000 N.m = 2.94 x 10^5 N.m .

(ii) τ_2 = 176400 N.m = 1.76 x 10^5 N.m.