UNIT 04

Turning Effects of Force

Q.1. Define like and unlike parallel forces. Explain with an example. 09104001

Ans: Like Parallel Forces:

If the parallel forces are acting in the same direction, then they are called like parallel forces.

Unlike Parallel Forces:

If the parallel forces are acting in the opposite direction, then they are called like parallel forces.

Example:

Consider three forces F_1, F_2, and F_3 acting on a rigid body at different points, as shown in Fig. 4.1. Here, the forces F_1 and F_2 are like parallel forces because they act in the same direction. In contrast, F_2 and F_3 are unlike parallel forces because they act in opposite directions.

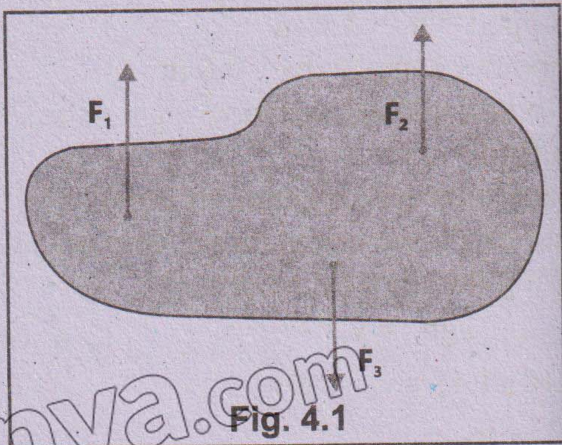


Fig. 4.1

Q.2. Define Resultant force. Explain how resultant force is found out by heat-to-tail rule with example. 09104002

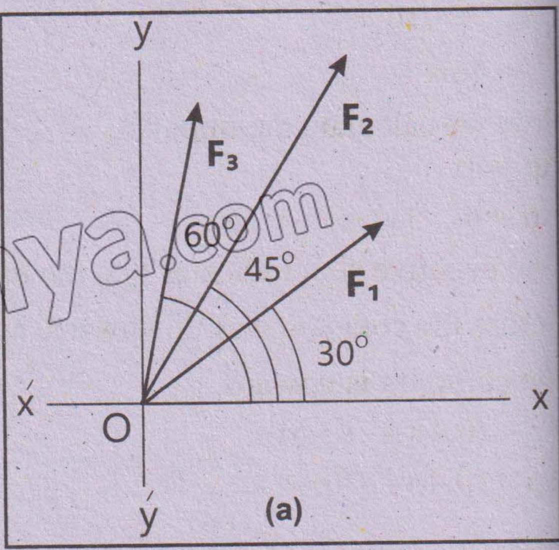
Ans: Resultant Force: A resultant force is a single force that has the same effect as the combined effect of all the forces to be added.

Head to tail rule:

The head-to-tail rule is a method used to add two or more Vectors, like forces. To apply this rule, place the tail of the second vector at the head of the first vector. If there are more than two vectors, continue placing the tail of each next vector at the head of the previous vector. After arranging all the vectors in this way, the resultant vector is drawn from the tail of the first vector to the head of the last vector. This resultant represents the total effect of all the vectors that are added.

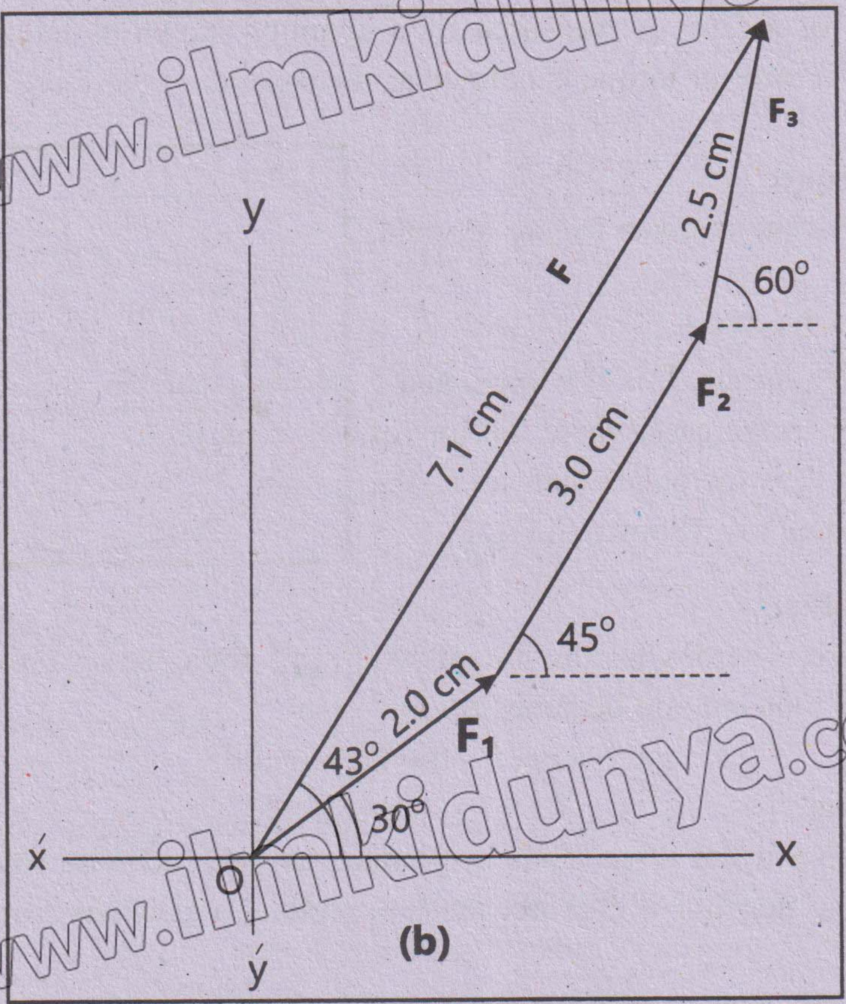
Example 4.1

Let us add three force vectors F_1, F_2 and F_3 having magnitudes of 200 N, 300 N and 250 N acting at angles of $30^0, 45^0, 60^0$ with $x - axis$.(Shown in Fig.) By selecting a suitable scale $100\,N = 1\,cm$, we can draw the force vectors as shown in Fig.(a). To add these vectors, we apply head-to-tail rule as shown in Fig.(b).



(a)

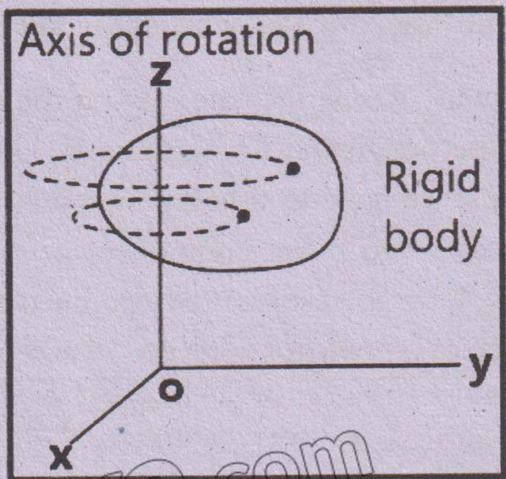
Measured length of resultant force is 7.1 cm. according to selected scale, magnitude of the resultant force F is 710 N and direction is at an angle 43^0 with $x-axis$. (Shown in Fig.)



Q.3. What is meant by rigid body and axis of rotation? 09104003

Ans: Rigid body:

If the distance between two points of the body remains the same under the action of a force, it is called a rigid body. A rigid body is the one that has no deformation by applying force.



Axis of rotation:

During rotation, all the particles of the rigid body rotate along fixed circles. The straight line joining the centers of these circles is called the axis of rotation in this case, it is OZ.

Q.4. What is meant by line of action of force and moment arm? 09104004

Ans: Line of action of force:

The line along which the force acts is called the line of action of the force.

Moment Arm:

The perpendicular distance from the axis of rotation to the line of action of the force is known as the moment arm. A larger moment arm results in a greater turning effect.

Q.5. Define moment of force. Prove its mathematical relation. **09104005**

Ans: Moment of Force (Torque):

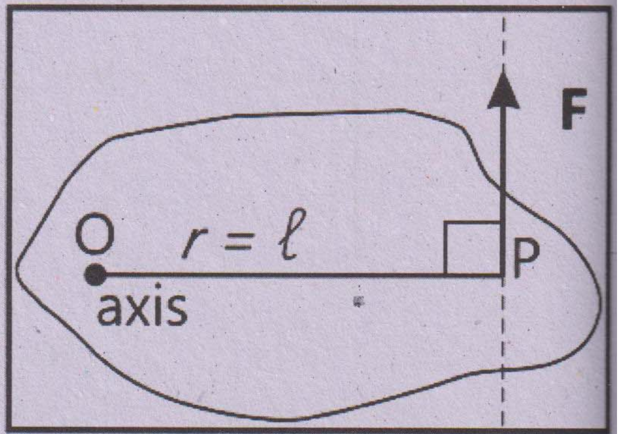
The turning effect of a force is measured by a quantity known as moment of force or torque. Moment of a force or torque is defined as the product of the force and the moment arm.

Calculation of Torque:

The magnitude of torque is given by the formula:

$$\tau = F \times l$$

Where τ (tau) is the torque, F is the force, and l is the moment arm. In the case where the line of action of a force F is perpendicular to r, the moment arm is equal to r. (Shown in Fig.)



Zero Torque Condition:

The torque of a force is zero when the line of action of a force passes through the axis of rotation, because its moment arm becomes zero.

$$\tau = F \times r = F \times 0 = 0 \quad \text{as } r = 0$$

Direction of Torque:

The torque is positive if the force tends to produce an anticlockwise rotation about the axis, and it is taken as negative if the force tends to produce a clockwise rotation.

Unit of Torque:

The SI unit of torque is newton meter (N·m).

Handling Non-Perpendicular Forces:

In many cases, the line joining the axis of rotation and point P where the force **F** acts, is not perpendicular to the force **F**. Therefore, OP will not be the moment arm for **F**. In such cases, we have to find a component of force **F** that is perpendicular to OP= l (Fig.4.2), or we can find r, the component of l that is perpendicular to the line of action of force **F** (Fig.4.3). To resolve this, we need to know how to find the rectangular components of a force or any vector, a process known as the resolution of forces.

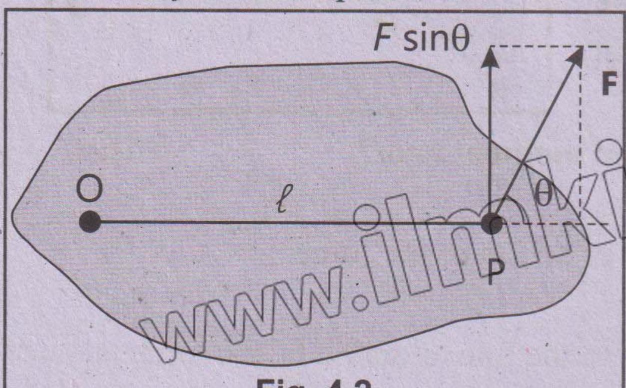


Fig. 4.2

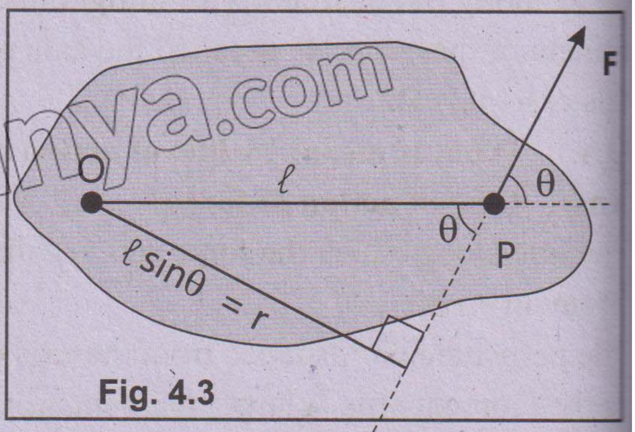


Fig. 4.3

Q.6. Define and explain couple. 09104006

Ans: Couple: When two equal and opposite parallel forces act at two different points of the same body, they form a couple.

Explanation:

The two forces are equal in magnitude but opposite in direction. Because they are applied at different points, they produce a turning effect (torque) on the object.

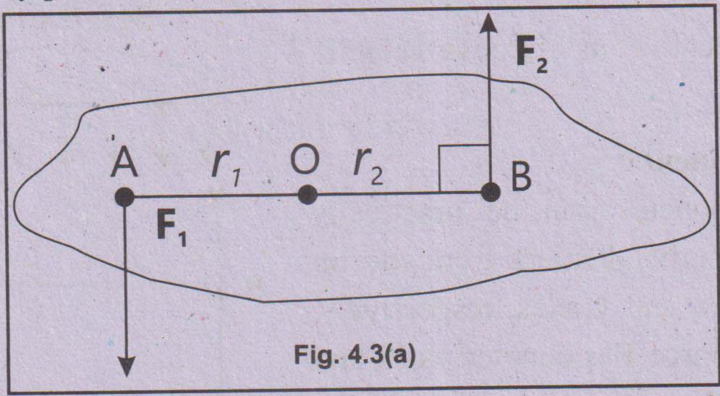


Fig. 4.3(a)

Examples from Daily Life:

- Opening or closing a water tap
- Turning a key in a lock
- Opening the lid of a jar
- Turning the steering wheel of a motor car

Q.7. Explain the concept of resolution of vectors/ forces. How can a force be resolved into perpendicular/ rectangular components? 09104007

Ans: Resolution of Vectors/ forces:

By the head-to-tail rule, two or more vectors can be added to give a resultant vector. The reverse process is also possible: *a given vector can be divided into two or more parts called* ***components***. If these components are added, their resultant equals the original vector. *Dividing a force into its components is known as the* ***resolution of a force***.

Perpendicular/ Rectangular Components:

Usually, a force is resolved into two perpendicular components, known as rectangular components. These components represent the force's effective values in the horizontal (x-axis) and vertical (y-axis) directions.

Process of Resolution:

Let us resolve a force **F** into its perpendicular components. A force **F** acting on a body at an angle θ with the x-axis is shown in Fig. 4.4a. Imagine a beam of light is placed above the vector **F**. As the light falls perpendicularly to the x-axis, it will cast a shadow of vector F onto the x-axis. We call this shadow the x-component of vector **F**.

Component:

A component of a vector is its effective value in a given direction.

Determining Components:

The x and y components can be practically drawn by dropping perpendiculars from the tip of vector **F** onto the x and y axes, respectively. The x-component of force **F** is denoted as $\mathbf{F_x}$ and the y-component as $\mathbf{F_y}$. The magnitudes of the perpendicular components can be found from the right-angled triangle OAC in Fig. 4.4b:

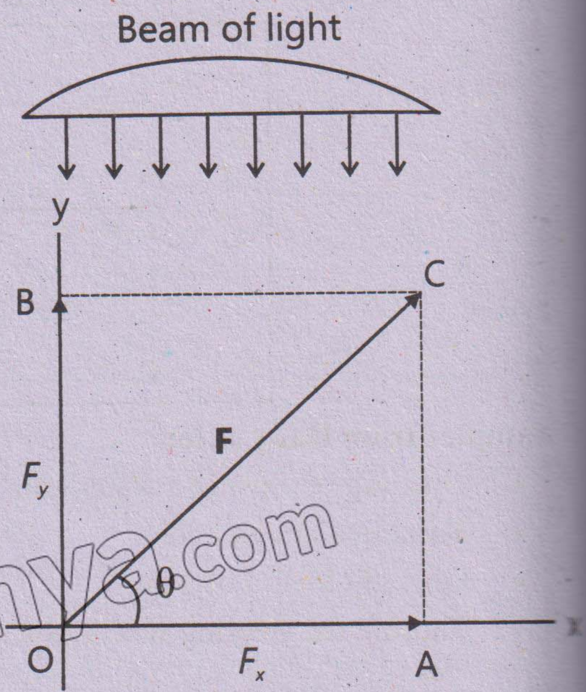


Fig. 4.4 (a)

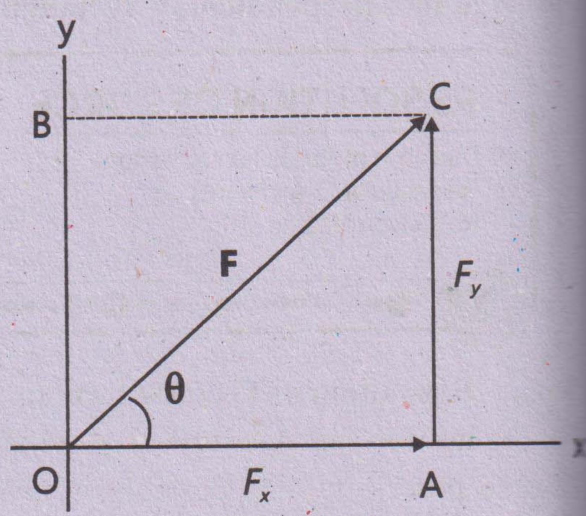


Fig. 4.4 (b)

X-Component (F_x)

In the given ΔOAC:

$$\frac{Base}{Hyponenuse} = \cos\theta$$

$$\frac{OA}{OC} = \cos\theta$$

$$\frac{F_x}{F} = \cos\theta$$

$$\text{or} \quad F_x = F\cos\theta \quad \ldots\ldots\ldots\ldots(4.2)$$

F_x is called horizontal component.

Y-Component (F_y)

In the given ΔOAC:

$$\frac{Perpendicular}{Hyponenuse} = \sin\theta$$

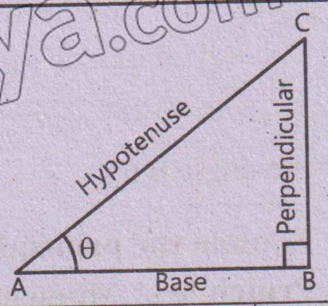
$$\frac{AC}{OC} = \sin\theta$$

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

F_y is called horizontal component.

For Your Information!

Trigonometric Ratios



Trigonometric is a branch of mathematics that deals with the properties of a right angled triangle. A right angled triangle ABC is shown in the figure. Angle A is denoted by θ (theta) called the angle of the right angled triangle. The side AB is called the base, the side BC is called the perpendicular and the side AC is called as hypotenuse. The ratio of any two sides is given the names as below:

$$\frac{\text{Perpendicular}}{\text{Hypotenuse}} = \frac{BC}{AC} = \text{sine } \theta$$

$$\frac{\text{Base}}{\text{Hypotenuse}} = \frac{AB}{AC} = \text{cosine } \theta$$

$$\frac{\text{Perpendicular}}{\text{Base}} = \frac{BC}{AB} = \text{tangent } \theta$$

For simplicity, sine θ, cosine θ and tangent θ are written as sin θ, cos θ and tan θ respectively. Values of these ratios for some frequently used angles are given in the table.

θ	sinθ	cosθ	tanθ
0°	0	1.0	0
30°	$\frac{1}{2}$ = 0.5	$\frac{\sqrt{3}}{2}$ = 0.866	$\frac{1}{\sqrt{3}}$ = 0.577
45°	$\frac{1}{\sqrt{2}}$ = 0.707	$\frac{1}{\sqrt{2}}$ = 0.707	1.0
60°	$\frac{\sqrt{3}}{2}$ = 0.866	$\frac{1}{2}$ = 0.5	$\sqrt{3}$ = 0.866
90°	1.0	0	∞ Unlimited

Q.8. Explain how to determine the magnitude and direction of a force from its perpendicular components.

09104008

Ans: The magnitude and direction of a force can be found if its perpendicular components are known. Consider a right-angled triangle OAC (Fig. 4.4b), where F_x and F_y are the perpendicular components of the force F.

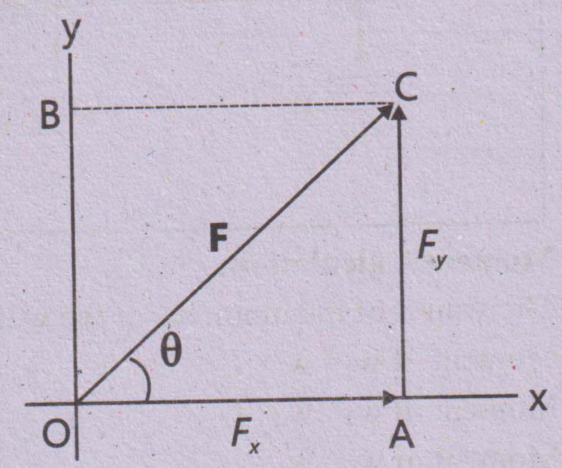


Fig. 4.4 (b)

Magnitude of the Force:

Applying the Pythagorean theorem to the right-angled triangle:

$(hyp)^2 = (Base)^2 + (Prep)^2$

$(OC)^2 = (OA)^2 + (AC)^2$

In terms of the components of force:

$$F^2 = F_x^2 + F_y^2$$

Therefore, the magnitude F of the force is: $F = \sqrt{F_x^2 + F_y^2}$

Direction of the Force:

The direction θ of the force F is given by the relationship between its components F_x and F_y:

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

$$\tan\theta = \frac{F_y}{F_x}$$

Hence, the angle θ is: $\theta = \tan^{-1}(\frac{F_y}{F_x})$

Q.9. Explain the principle of moments and explain it with an example. 09104009

Ans: Principle of Moments:

The principle of moments states that when a body is in balanced position, the sum of clockwise moments about any point equals the sum of anticlockwise moments about that point.

Example:

Balance a metre rule on a wedge at its center of gravity (CG) such that the meter rule stays horizontal. Then suspend two weights, w_1 and w_2, on one side of the metre rule at distances l_1 and l_2 from the center of gravity. Place a third weight, w_3, on the other side at a distance l_3 from the center. The weights w_1 and w_2 will tend to rotate the metre rule anticlockwise about the center of gravity (CG). The weight w_3 will tend to rotate it clockwise.

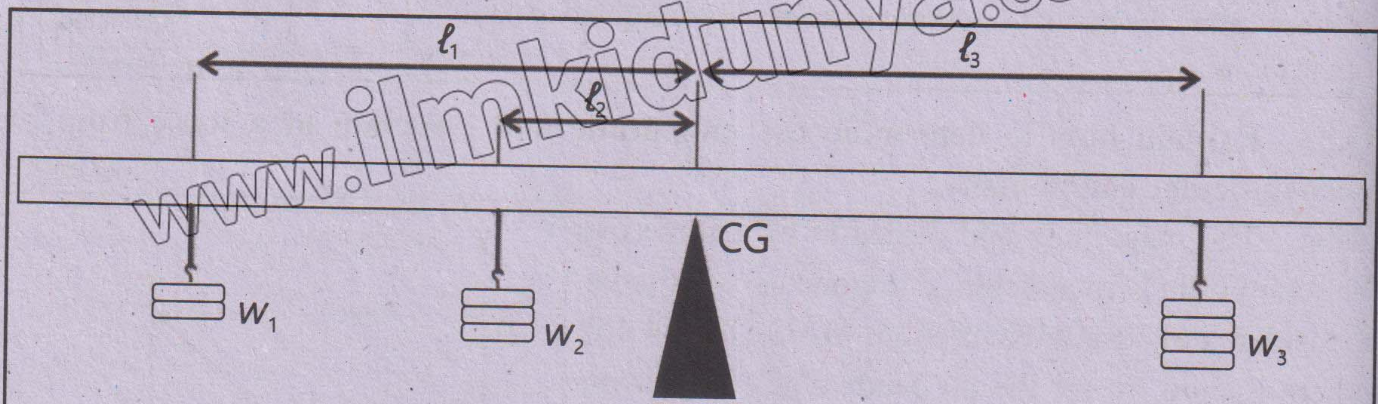


Fig. 4.5

Moment Calculation:

The values of the moments of the weights are:

Moment of $w_1 = w_1 \times l_1$

Moment of $w_2 = w_2 \times l_2$

Moment of $w_3 = w_3 \times l_3$

When the metre rule is balanced:

Total anticlockwise moments = Total clockwise moments

$$w_1 \times l_1 + w_2 \times l_2 = w_3 \times l_3$$

Q.10. Explain the concept of the center of gravity of an object and describe how to find the center of gravity of an irregular-shaped plane lamina. 09104010

Ans: Centre of gravity: *"Centre of gravity is that point where total weight of the body appears to be acting"* If a body is supported at its center of gravity, it remains balanced without rotating.

An object is composed of a large number of small particles, and each of these particles experiences a gravitational force directed towards the center of the Earth. Since the object is small compared to the Earth, the value of gravitational acceleration 'g' can be considered uniform for all the particles. As a result, each particle experiences the same force mg, where (m) is the mass of the particle.

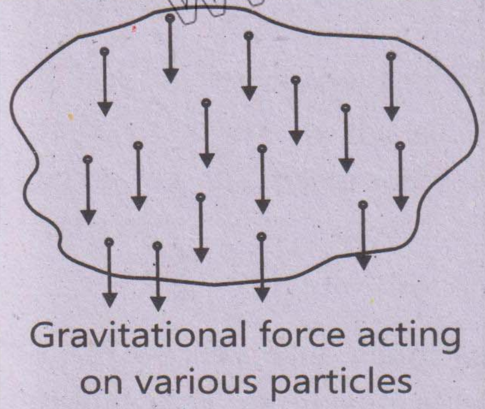


Fig. 4.6(a)

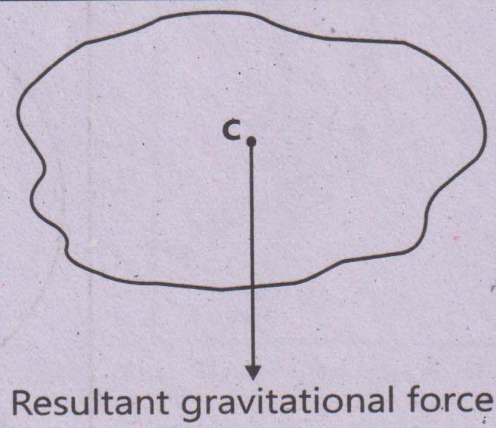


Fig. 4.6(b)

Since all these forces are parallel and act in the same direction, their resultant force will be the sum of all these individual forces, i.e.,

$$\text{Resultant force} = \sum mg = \sum F = W$$

This sum of gravitational forces is equal to the total weight of the object $w = \sum mg$, where $M = \sum m$ is the total mass of the object.

Center of Gravity of an Irregular-Shaped Plane Lamina:

For an irregular-shaped plane lamina, the center of gravity can be found by suspending it freely from different points. Every time the lamina is suspended, its center of gravity lies along the vertical line drawn from the *suspension point, which is located using a* plumb line. The exact position of the center of gravity is at the point where the two vertical lines, drawn from different suspension points, intersect. The center of gravity can exist either inside or outside the body. For instance, the center of gravity of a cup lies outside the object.

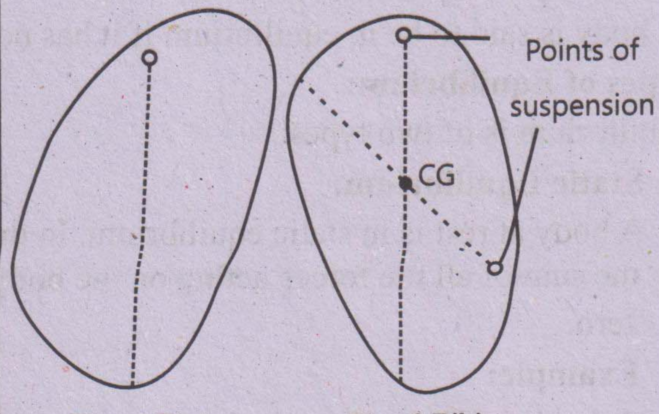


Fig. 4.7(a) Fig. 4.7(b)

Irregular shaped plane lamina

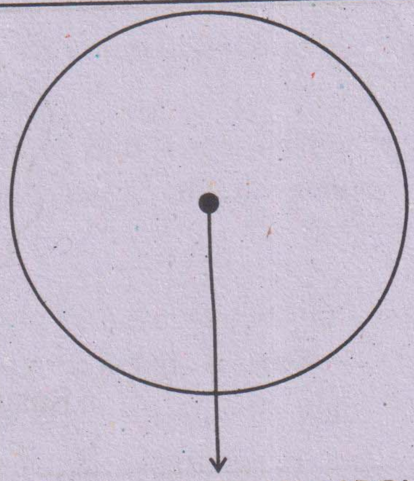
Q.11. Explain the concept of the center of mass. How does it relate to the center of gravity? 09104011

Ans: Center of Mass:

The center of mass of a body is that point where the whole mass of the body is assumed to be concentrated.

Relation with Center of Gravity:

On the surface of the Earth, where gravitational acceleration (g) is nearly uniform, the center of mass coincides with the **center of gravity**. This means the point at which all the mass is assumed to be concentrated (center of mass) is also the point where the total gravitational force acts.



Centre of gravity (CG)
Fig.4.8

Q.12. What is equilibrium? Explain its types with suitable examples. **09104012**

Ans: Equilibrium:

We know that if a number of forces act on a body such that their resultant is zero, the body remains at rest or continues to move with uniform velocity if already in motion. This state of the body is known as equilibrium. It can be stated as:

"A body is said to be in equilibrium if it has no acceleration."

Types of Equilibrium:

Equilibrium is of two types:

1. **Static Equilibrium:**

A body at rest is in static equilibrium. In this state, the sum of all the forces acting on the body is zero.

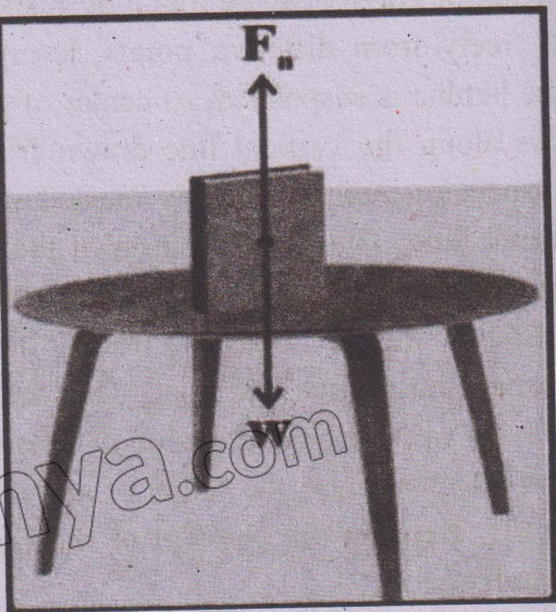
Example:

A book lying on a table is an example of static equilibrium. Only two forces act on it:

Weight (W=mg) acting downward.

Normal force (F_n) acting upward.

Since the book is at rest and has zero acceleration:

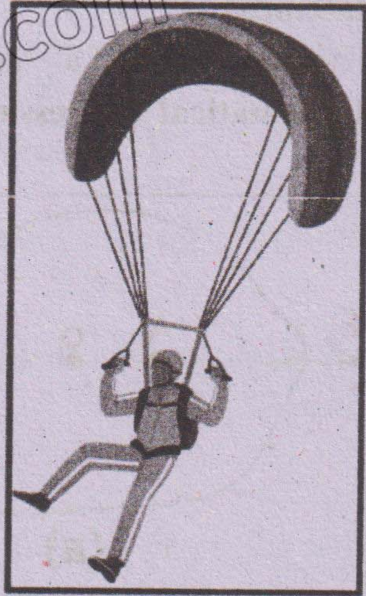


$$F_n - W = 0 \quad \text{or} \quad F_n = W$$

Other examples include an electric bulb hanging from the ceiling, a man holding a box, and a beam held horizontally against a wall with the help of a rope.

2. Dynamic Equilibrium:

A body moving with uniform velocity is in dynamic equilibrium. In this case, the forces acting on the body balance each other, and there is no acceleration.



Example:

A paratrooper descending with a uniform velocity after the parachute opens. In this state, the downward force of gravity acting on the paratrooper is balanced by the upward air resistance:

$$F_{gravity} = F_{air\ resistance}$$

Q.13. What are the conditions of equilibrium? Explain the first and second conditions with mathematical expressions and examples. **09104013**

Ans: Conditions of Equilibrium:

For a body to be in equilibrium, two main conditions must be satisfied: the first condition relates to translational motion, and the second condition relates to rotational motion.

First Condition of Equilibrium:

According to Newton's second law of motion F = ma

If a body is in translational equilibrium, then a=0, therefore, the net force F acting on the body must also be zero.

Mathematical Expression:

$$\Sigma F=0 \ldots\ldots\ldots\ldots (1)$$

Statement:

"A body is said to be in translational equilibrium only if the vector sum of all the external forces acting on it is equal to zero."

Resolving Forces into Components:

In the case of coplanar forces (F_1, F_2, F_3 , etc.), this condition can be broken into rectangular components: F_1, F_2, F_3

Along the x-axis:

$F_{1x}+F_{2x}+F_{3x}+\cdots=0$ Or $\Sigma F_x=0$

Along the y-axis:

$F_{1y}+F_{2y}+F_{3y}+\cdots=0$ Or $\Sigma F_y=0$

"The sum of all the components of forces along the x-axis should be zero, and the sum of all the components of forces along the y-axis should also be zero." In other words we can say that sum of all the forces acting on the body is equal to zero. i.e. $\sum F = 0$

Second Condition of Equilibrium:

This condition applies to rotational equilibrium which means that the body should not rotate under the action of the forces.

Statement:

"The vector sum of all the torques acting on a body about any point must be zero."

Mathematical Expression:

$$\Sigma\tau = 0$$

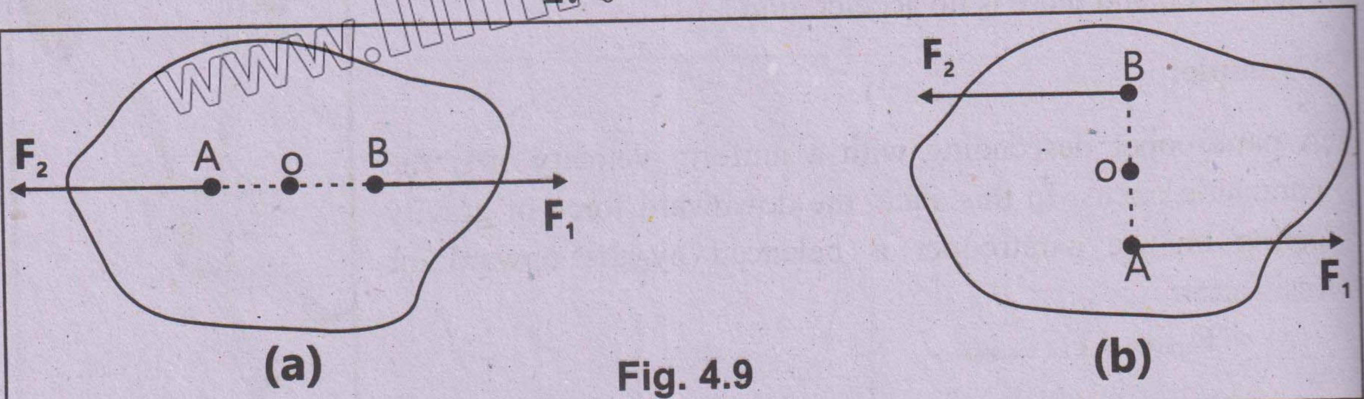


Fig. 4.9

Explanation:

Consider the example of a rigid body in, (Fig.4,5). Two forces F_1 and F_2 of equal magnitude are acting on it. In case (a), both the forces act along the same line of action. In case (b), the lines of action of the two forces are different. Since magnitude of F_1 and F_2 are equal, so the resultant force is zero in both the cases. Thus, first condition of equilibrium is satisfied. But you can observe that in case(b), the forces are forming a couple which can apply torque to rotate the body about point O. Therefore, for a body to be completely in equilibrium, a second condition is also required. That is, no net torque should be acting on the body.

Complete Equilibrium:

For a body to be in complete equilibrium, both conditions must be satisfied:

1. $\Sigma F_x = 0$
2. $\Sigma F_y = 0$
3. $\Sigma\tau = 0$

Q.14. Explain the steps involved in solving problems by applying conditions of equilibrium. **09104014**

Ans: To solve problems by applying conditions of equilibrium, the following steps will help:

1. **Select the Objects:** First of all, select the objects to which $\Sigma F_x=0$ and $\Sigma F_y=0$ is to be applied. Each object should `be treated separately.
2. **Draw a Diagram:** Draw a diagram to show the objects and forces acting on them. Only the forces acting on the objects should be included. The forces which the objects exert on their environment should not be included.
3. **Choose a Set of Axes:** Choose a set of x, y axes such that as many forces as possible lie directly along the x-axis or y-axis. It will minimize the number of forces to be resolved into components.

4. **Resolve Forces into Components:** Resolve all the forces which are not parallel to either of the axes into their rectangular components.
5. **Apply Equilibrium Equations:** Apply $\Sigma F_x=0$ and $\Sigma F_y=0$ to get two equations.
6. **Apply Torque Equation (if needed):** If needed, apply $\Sigma\tau=0$ to get another equation.
7. **Solve the Equations:** The equations can be solved simultaneously to find out the desired unknown quantities.

Q.15. Describe the three states of equilibrium with detailed explanations and examples of each state. **09104015**

Ans: States of Equilibrium:

An object is balanced when its center of mass and its point of support lie on the same vertical line. When forces on each side are balanced, the object is said to be in equilibrium. There are three states of equilibrium related to the stability of balanced bodies.

1. Stable Equilibrium:

A body is said to be in a state of stable equilibrium if, after a slight tilt, it comes back to its original position.

Explanation:

Stable equilibrium occurs when the torques arising from the rotation (tilt) of the object compel the body back towards its equilibrium position.

Example:

The cone shown in Figure 4.10 (a) is in a state of stable equilibrium. Its weight w, acting downward at the center of gravity G, and the reaction of the floor F_n, acting upward, lie on the same vertical line. Since these forces are equal and in opposite directions, they balance each other, satisfying both conditions of equilibrium.

When the cone is pushed slightly Figure 4.10(b), its center of gravity is raised but remains above the base. The weight w and the normal force F_n act like two unlike parallel forces, producing a clockwise torque that returns the cone to its original position.

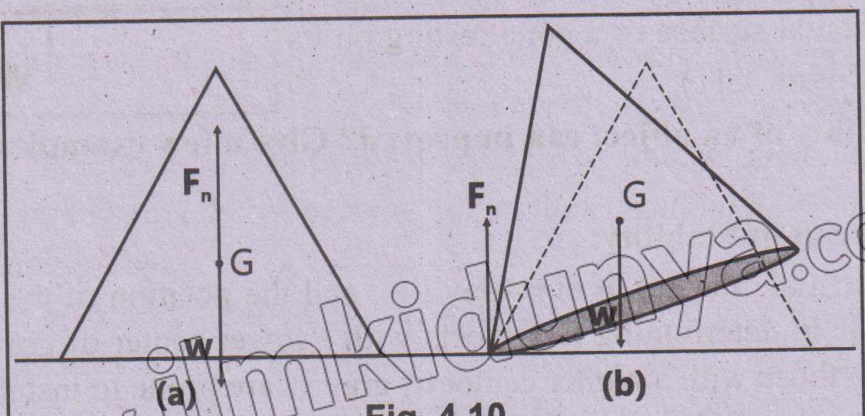


Fig. 4.10

Key Point: The body remains in equilibrium as long as its center of mass lies within the base.

2. Unstable Equilibrium:

A body is in a state of unstable equilibrium if, after a slight tilt, it tends to moves further away from its original position.

Explanation:

In unstable equilibrium, when the body is slightly disturbed, its center of mass no longer remains above the base, and the body topples over. The center of gravity lowers and continues to fall further, preventing the body from returning to its original position.

Example:

Balancing a cone on its tip (Figure 4.11) is an example of unstable equilibrium. The weight w and the normal force F_n lie along the same line momentarily. However, even a slight tilt shifts the center of gravity outside the base, creating an anticlockwise torque that causes the cone to fall.

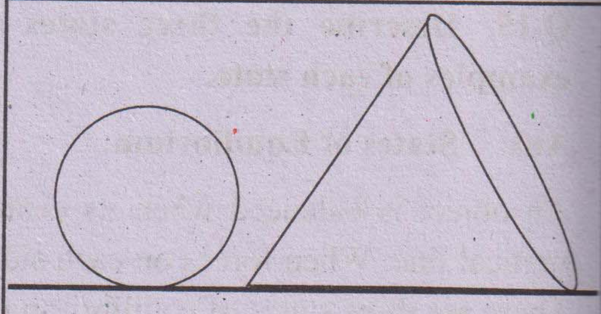


Fig. 4.11

3. Neutral Equilibrium:

A body is in neutral equilibrium if it comes to rest in its new position after disturbances without any change in its center mass.

Explanation:

In neutral equilibrium, tilting or moving the object does not create any torque to return it to its original position or move it further away. The center of mass remains at the same height.

Example:

A cylinder resting on a horizontal surface (Figure 4.12) demonstrates neutral equilibrium. When the cylinder is rotated, the height of its center of mass remains unchanged, and the weight w and the ground's reaction force remain in the same vertical line. Other examples of neutral equilibrium are a ball rolling on a horizontal surface or a cone resting on its curved surface. (Figure 4.11).

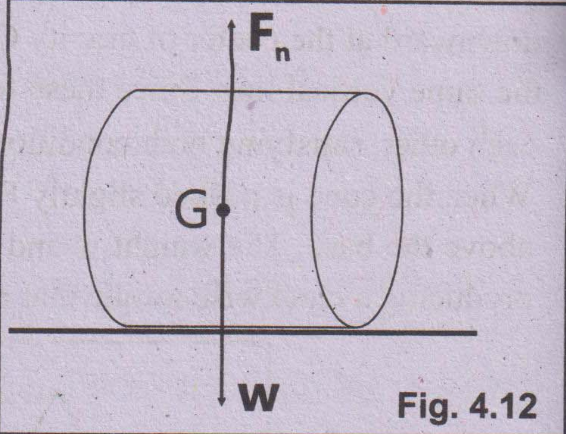


Fig. 4.12

Q.16. How stability of an object can improved? Give a few examples to support your answer.

Ans: Improvement of Stability: **09104016**

Stability is an essential concept in everyday life, and the position of the center of gravity plays a crucial role in determining it. Objects with a lower center of gravity are generally more stable, while those with a higher center of gravity are prone to instability.

Importance of Center of Gravity:

The position of the center of gravity significantly affects an object's stability. A low center of gravity ensures that the object remains in stable equilibrium. For example, a low armchair is more stable than a high chair because of its lower center of gravity. If disturbed slightly, the torque acting on the low chair brings it back to its original position.

Methods to Improve Stability:

1. **Lowering the Center of Gravity:**
   Placing heavier objects at a lower point within a system lowers the center of gravity, enhancing stability.
2. **Widening the Base:**
   Increasing the base area provides better support and reduces the chances of tipping over, thereby improving stability.

Stability in Vehicles:

The stability of vehicles, such as buses, depends on how they are loaded:

- **Stable Loading:**
  When heavy loads are placed on the floor of the bus, its center of gravity remains low. In this condition, if the bus is disturbed slightly, a torque will bring it back to its original position. Therefore, the bus is in stable equilibrium.
- **Unstable Loading:**
  If heavy loads, like steel sheets, are placed on the top of the bus, the center of gravity is raised. This makes the bus near a state of unstable equilibrium. A slight tilt could cause a couple that may turn it over.

Application in Ships and Boats:

Ships and boats follow similar stability principles. If heavy cargo is loaded at a lower level, the center of gravity remains low, improving stability. Conversely, placing heavy loads higher raises the center of gravity, making the vessel unstable and more likely to tip over.

Q.17. How is the concept of stability applied in real-life engineering, particularly in racing cars and balancing toys. 09104017

Ans: Stability in Racing Cars

The concept of stability is widely applied to engineering technology, especially in manufacturing racing cars. As racing cars are driven at very high speeds and also have sharp turns in the track, the chances of the cars toppling over increase. To enhance the stability of racing cars, their centres of mass are kept as low as possible. Their base areas are also increased by keeping the wheels outside of their main bodies.

Stability in Balancing Toys

Balancing toys are also very interesting for both children and elders. The physics behind these toys is that stability is built into them. These toys are basically in a completely stable state, and their centres of gravity always remain below the pivot point. If the toys are disturbed in any direction, the centre of gravity is raised, and it becomes unstable for a moment. However, it comes back to its initial stable position by lowering its centre of gravity. The kids learn from these toys about stable systems and how they return to their state of initial rest position after being disturbed. Educational games based on the principles of balancing toys have also been developed for kids, as shown in the figure.

Q.18. How do torque and force relate in rotational and translational motion, and how does the application of torque affect a rotating object? 09104018

Ans. Counterparts of Translational and Rotational Motion

Counterparts of velocity, acceleration, force, and momentum in translational motion are angular velocity, angular acceleration, moment of force (torque), and angular momentum respectively in rotational motion. It suggests that the torque plays the same role in rotational motion that is played by the force in translational motion.

Effect of Torque on Rotating Objects

Therefore, we are justified to predict that analogous to Newton's first law of motion, a rotating object will continue to do so with constant angular velocity unless acted upon by a resultant moment (torque). However, if a resultant torque is applied to a rotating object, it will accelerate depending on the direction of the torque relative to the axis of rotation.

This fundamental principle enhances our understanding of how objects move and interact with their environment whether in linear or rotational motion scenarios.

Q.19. Define and explain circular motion and force perpendicular to the circular motion. 09104019

Ans: Velocity in Circular Motion

When a body is moving along a circular path, its velocity at any point is directed along the tangent drawn at that point. Figure 4.13 shows that the direction of the tangent at each point on a circle is different, therefore, the velocity of an object moving with uniform speed in a circle is changing constantly.

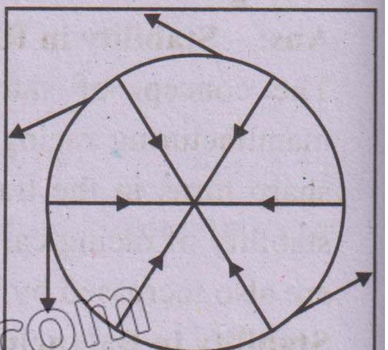


Fig. 4.9

Role of Force:

A force perpendicular to the direction of motion is always required to keep the object moving with uniform speed in a circular path. For instance, if it is not perpendicular to the velocity, the force (F) will have a component in the direction of velocity, which will change the magnitude of velocity. As the body moves with constant speed, this is possible only if the component of force along the velocity direction is zero, i.e., F cos 90° = 0.

Q.20. Define centripetal force. Write down its mathematical expression. Explain real-life examples of centripetal force. 09104020

Ans: Centripetal Force

We have studied above that an object can move in a circular path with uniform speed only if a force perpendicular to its velocity is acting constantly on it. This force is always directed towards the centre of the circle. It is called centripetal force and can be defined as:

"The force that causes an object to move in a circle at constant speed is called the centripetal force."

Formula for Centripetal Force

For an object of mass (m) moving with uniform speed v in a circle of radius r, the magnitude of centripetal force F_c, acting on it can be calculated by using the relation:

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

Sources of Centripetal Force (Real Life Examples):

We have learned that centripetal force has to be supplied if the body is to be maintained in its circular path. What could be the sources of centripetal force?

(i) **Tension in a String:** If we tie a stone to one end of a string and whirl it from the other end, we will have to exert a force on the stone through the string. If we release the string when it is at any point P, the stone will fly off along the tangent (PQ) to the circle. Then, it will move along the same straight line with constant velocity unless an unbalanced force acts upon it. In fact, the tension in the string was providing the stone the necessary centripetal force to keep it along the circular path. When we release the string, we stop applying force on the stone and hence it moves in a straight line.

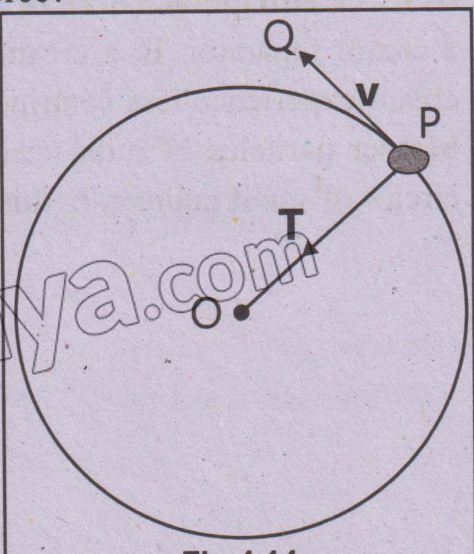
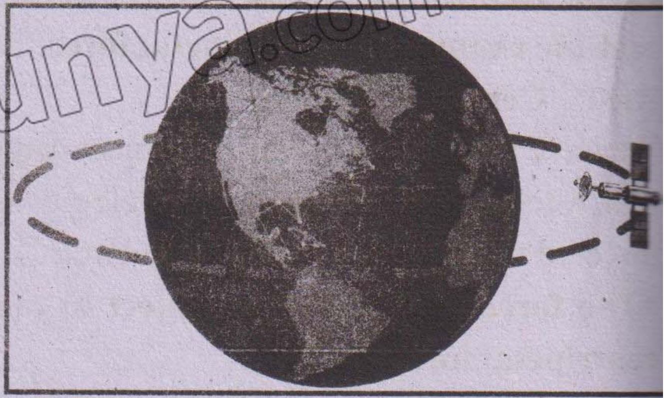


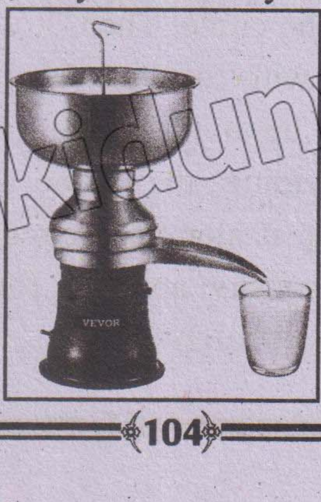
Fig.4.14

(ii) Gravitational Force (Example of the Moon): Now consider the case of the moon, which moves around the Earth at constant speed. The gravity of the Earth provides the necessary centripetal force to keep it in its orbit. The same is the case of satellites orbiting the Earth in circular paths with uniform speed. The gravitational pull of the Earth provides the centripetal force.



(iii) Friction in a Washing Machine: One of the real-life examples is a washing machine dryer. A dryer is a metallic cylindrical drum with many small holes in its walls. Wet clothes are put in it. When the cylinder rotates rapidly, friction between clothes and drum walls provides the necessary centripetal force. As the water molecules are free to move, they cannot get the required centripetal force to move in circular paths and escape from the drum through the holes. This results in quick drying of clothes.

(iv) Centripetal Force in a Cream Separator: Another interesting example is that of a cream separator. In a cream separator, milk is whirled rapidly. The lighter particles of cream experience less centripetal force and gather in the central part of the machine. The heavier particles of milk need greater centripetal force to keep their circular motion in circles of small radius r. In this way, they move away towards the walls.



Examples

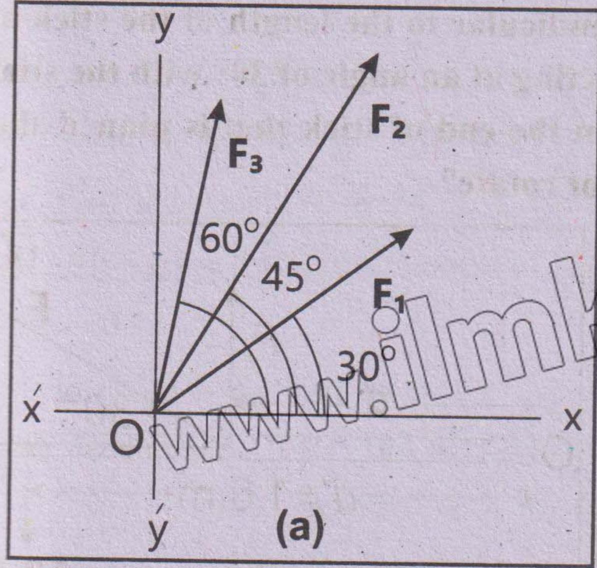
Example 4.1

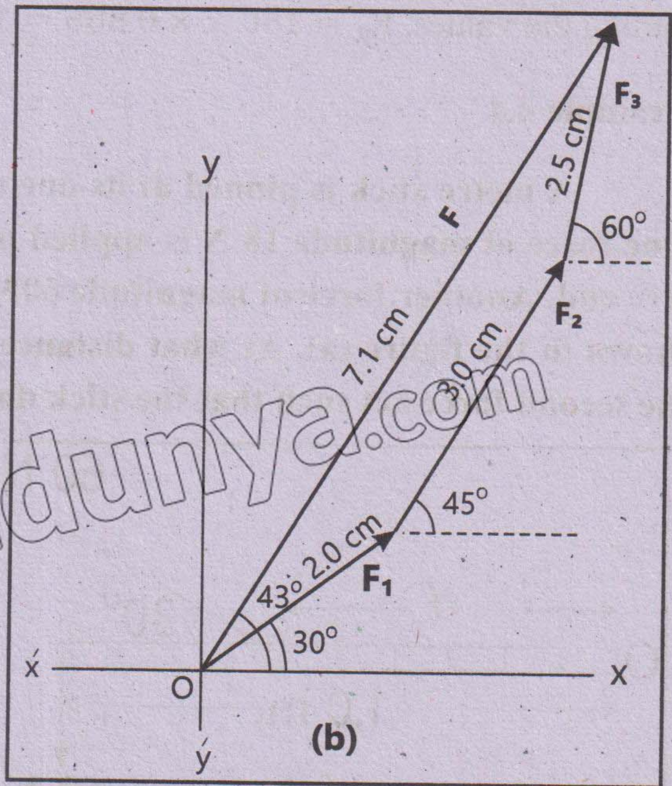
09104021

Let us add three force vectors F_1, F_2 and F_3 having magnitudes of 200 N, 300 N and 250 N acting at angles of $30^0, 45^0, 60^0$ with $x-axis$. By selecting a suitable scale $100\ N = 1\ cm$, we can draw the force vectors as shown in Fig.(a).

To add these vectors, we apply head-to-tail rule as sown in Fig.(b).

Measured length of resultant force is 7.1 cm. according to selected scale, magnitude of the resultant force F is 710 N and direction is at an angle 43^0 with $x-axis$.





Example 4.2

09104022

A spanner 25 cm long is used to open a nut. If a force of 400 N is applied at the end of a spanner shown in Fig., what is the torque acting on the nut?

Solution:

Length of Spanner $\ell = 25\ cm = 0.25\ m$

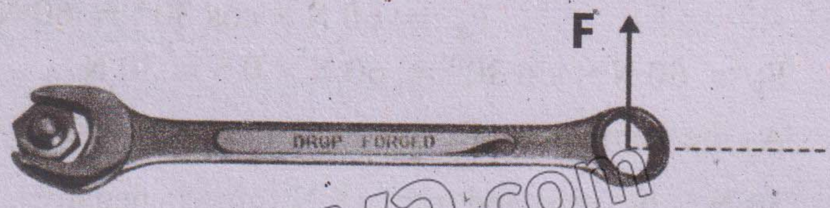
Force = F = 400 N

Torque $\tau = ?$

From Eq. $\tau = F \times \ell$

Putting the values,

$\tau = 400\,N \times 0.25\,m = 100\,N\,m$



Examples 4.3

09104023

A force of 160 N is acting on a wooden box at an angle of 60^0 with the horizontal direction. Determine the values of its x and y components.

Solution:

Magnitude of force F = 160 N

Angle $\theta = 60^0$

Using calculator, $\sin\theta = \sin 60^0 = 0.866$

$\cos\theta = \cos 60^0 = 0.5$

x-component is given by Eq.

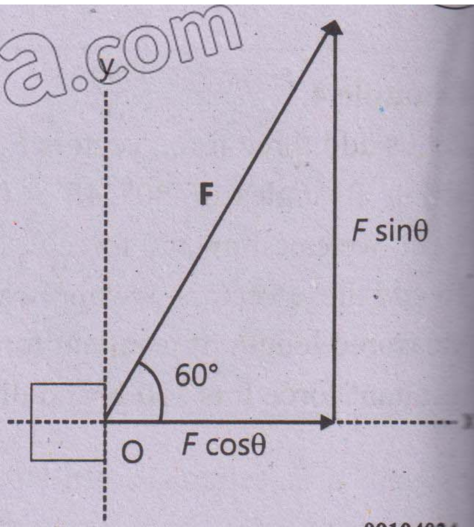
$$F_x = F\cos\theta$$

Putting the values, $F_x = 160\text{ N} \times 0.5 = 80\text{ N}$

y-component is given by Eq.

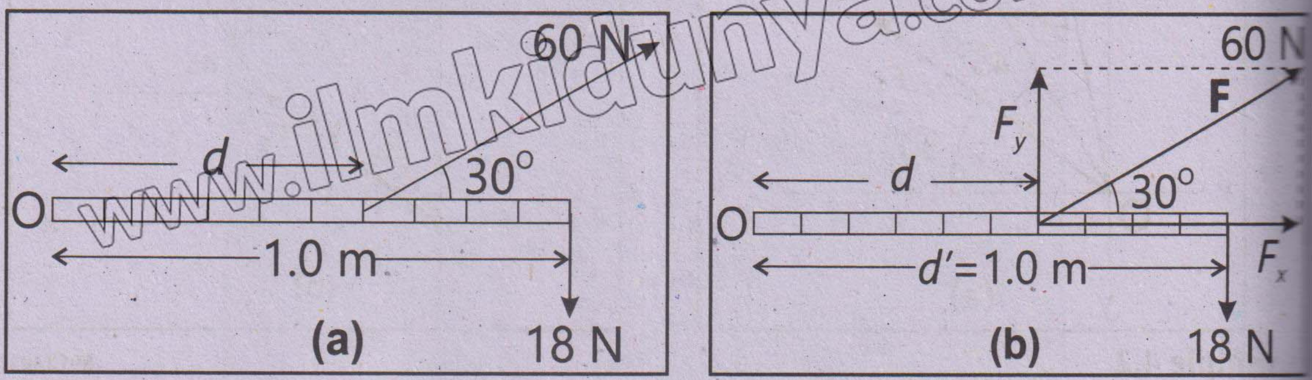
$$F_y = F\sin\theta$$

Putting the values, $F_y = 160\text{ N} \times 0.866 = 138.6\text{N}$



Example 4.4 09104024

A metre stick is pinned at its one end O on a table so that it can rotate freely. One force of magnitude 18 N is applied perpendicular to the length of the stick at its free end. Another force of magnitude 60N is acting at an angle of 30° with the stick as shown in the figure (a). At what distance from the end of stick that is pinned should the second force act such that the stick does not rotate?



Solution:

Weight of the stick does not affect in the horizontal plane. Resolving force **F** of magnitude = 60 N into rectangular components that act at distance d from point O:

$$F_x = 60\text{ N} \times \cos 30^0 = 60\text{ N} \times 0.866 = 51.96\text{ N}$$

$F_y = 60\text{ N} \times \sin 30^0 = 60\text{ N} \times 0.5 = 30\text{ N}$

As the component F_x passes through the axis of rotation, its torque is zero. Torque τ_1 of 30 N is positive and τ_2 of 18 N force is negative. The stick will not rotate when these two torques balance each others, i.e. $\tau_1 = \tau_2$ or $F_y \times d = F_y' \times d'$

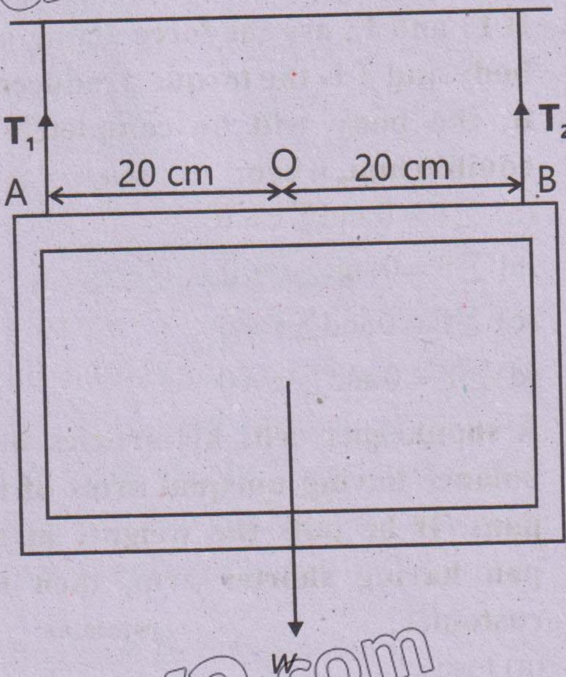
$$30\text{ N} \times d = 18\text{ N} \times 1\text{ m}$$

$$d = \frac{18\text{ N} \times 1\text{ m}}{30\text{ N}} = 0.6\text{m}$$

09104025

Examples 4.5

A picture is suspended by means of two vertical strings as shown in fig. The weight of the picture is 5 N, and it is acting at its centre of gravity. Find the tension T_1&T_2 in two strings.



Solution:

Total upward force $= T_1 + T_2$

Total downward force $= w = 5$ N

Tensions in the strings, $T_1 = ?$, and $T_2 = ?$

Since, there is no horizontal force, so $\sum F_x = 0$

Already $\sum F_x = 0$

Putting $\sum F_x = 0$

$T_1 + T_2 - w = 0$ ....(i)

Apply $\sum \tau = 0$, selecting point B as point of rotation. Here, torque τ_1 of T_1 is negative whereas torque τ_2 of w is positive about B. T_2 produces zero torque as it passes through the point of rotation. Hence,

$\tau_1 - \tau_2 = 0$

or $w \times AO - T_1 \times AB = 0$

putting the values, $w \times 0.2\text{ m} - T_1 \times 0.4\text{m} = 0$

or $5\text{ N} \times 0.2\text{ m} - T_1 \times 0.4\text{ m} = 0$

or $T_1 = \dfrac{5\text{ N} \times 0.2\text{ m}}{0.4\text{ m}} = 2.5\text{ N}$

putting the value of T_1 and w in Eq.(i), we have

$$2.5\text{ N} + T_2 - 5\text{ N} = 0$$

or $T_2 = 2.5$ N

Exercise

(A) Multiple Choice Questions

1. **A particle is simultaneously acted upon by two forces of 4 and 3 newtons. The net force on the particle is:** 09104026
   (a) 1 N
   (b) between 1 N and 7 N
   (c) 5 N
   (d) 7 N

2. **A force F is making an angle of 60^o with x-axis. Its y-component is equal to:** 09104027
   (a) F
   (b) F sin60^o
   (c) F cos60^o
   (d) F tan60^o

3. **Moment of force is called:** 09104028

(a) moment arm (b) couple

(c) couple arm (d) torque

4. **If F_1 and F_2 are the force acting on a body and T is the torque produced in it, the body will be completely in equilibrium, when:** 09104029

(a) $\sum F = 0$ and $\sum \tau = 0$

(b) $\sum F = 0$ and $\sum \tau \neq 0$

(c) $\sum F \neq 0$ and $\sum \tau = 0$

(d) $\sum F \neq 0$ and $\sum \tau \neq 0$

5. **A shopkeeper sells his articles by a balance having unequal arms of the pans. If he puts the weights in the pan having shorter arm, then the customer:** 09104030

(a) loses

(b) gains

(c) neither loses nor gains

(d) not certain

6. **A man walks on a tight rope. He balances himself by holding a bamboo stick horizontally. It is an application of:** 09104031

(a) law of conservation of momentum

(b) Newton's second law of motion

(c) principle of momentums

(d) Newton's third law of motion

7. **In stable equilibrium the centre of gravity of the body lies:** 09104032

(a) at the highest position

(b) at the lowest position

(c) at any position

(d) outside the body

8. **The centre of mass of a body:** 09104033

(a) lies always inside the body

(b) lies always outside the body

(c) lies always on the surface of the body

(d) may lie within, outside or on the surface

9. **A cylinder resting on its circular base is in:** 09104034

(a) stable equilibrium

(b) unstable equilibrium

(c) neutral equilibrium

(d) none of these three

10. **Centripetal force is given by:** 09104035

(a) rF (b) $rF\cos\theta$

(c) $\frac{mv^2}{r}$ (d) $\frac{mv}{r^2}$

Answer Key

1.	(b)	2.	(b)	3.	(d)	4.	(a)	5.	(a)
6.	(c)	7	(b)	8.	(d)	9.	(a)	10.	(c)

SLO based Additional MCQs

Principle of Moments

1. **A seesaw balances perfectly with two children of equal weight sitting at equal distances from the fulcrum. If one child moves closer to the fulcrum:** 09104036

(a) The seesaw remains balanced.

(b) The seesaw tips towards the child who moved closer.

(c) The seesaw tips towards the child who stayed further away.

(d) The seesaw topples.

Torque

2. **When line of action of the applied force passes through its pivot point then momnet of force acting on the body is:** 09104037
(a) maximum
(b) minimum
(c) zero
(d) infinite

3. **If a body is at rest or moving with uniform rotational velocity, then torque acting on the body will be:** 09104038
(a) maximum (b) minimum
(c) zero (d) infinite

4. **You are trying to loosen a nut using a spanner, but it is not working. In order to open the nut, you need to:** 09104039
(a) insert a pipe to increase length of spanner
(b) use a spanner of small length
(c) use plastic and soft spanner
(d) tie a rope with spanner

Equilibrium

5. **A body in equilibrium must not have:** 09104040
(a) speed
(b) quantity of motion
(c) velocity
(d) acceleration

6. **A uniformly rotating fan is said to be in:** 09104041
(a) static equilibrium only
(b) dynamic equilibrium only
(c) both in static and dynamic equilibrium
(d) not in equilibrium

7. **A tightrope walker is carrying a long pole while walking across a rope. The stability of the walker is affected if the pole is:** 09104042
(a) long and placed vertically
(b) long and placed horizontally
(c) short and placed vertically
(d) short and placed horizontally

Centre of Mass

8. **You throw a weighted fishing net into a calm lake. As the net sinks, it opens fully underwater, spreading out its mesh evenly. Compared to the moment it left your hand, where is the net's center of mass now?** 09104043
(a) Higher is the water column.
(b) Lower in the water column.
(c) At the same depth but slightly shifted horizontally.
(d) Unchanged from its position when thrown.

Friction

9. **It is more difficult to walk on a slippery surface than on a nonslippery one because of:** 09104044
(a) reduced friction
(b) increased friction
(c) high grip
(d) lower weight

Terminal Velocity

10. **For an object moving with terminal velocity, its acceleration:** 09104045
(a) increases with time
(b) decrease with time
(c) is zero
(d) first increase then decreases

11. The correct order of comparison for the terminal speeds of a raindrop, snowflake, and hailstone is: 09104046

(a) Raindrop> Snowflake > Hailstone
(b) Hailstone > Raindrop > Snowflake
(c) Snowflake > Raindrop > Hailstone
(d) Raindrop = Snowflake = Hailstone

Centripetal Force

12. The force that always changes direction of velocity and not its magnitude is called: 09104047

(a) gravitational force
(b) electrical force
(c)centripetal force
(d) friction

13. The reason that a car moving on a horizontal road gets thrown out of the road while taking a turn is: 09104048

(a) the reaction of the ground
(b) rolling friction between tyre and road
(c) gravitational force
(d) lack of sufficient centripetal force

Circular Motion

14. A car drives at steady speed around a perfectly circular track: 09104049

(a) The car's acceleration is zero.
(b) The net force on the car is zero.
(c) Both the acceleration and net force on the car point outward.
(d) Both the acceleration and net force on the car point inward.

Orbital Speed

15. A satellite of mass 'm' is revolving around the earth with an orbital speed 'v'. If mass of the satellite is doubled, its orbital speed will become: 09104050

(a) double
(b) half
(c) one fourth
(d) remain the same

Answer Key

1.	(b)	2.	(c)	3.	(c)	4.	(a)	5.	(d)
6.	(b)	7.	(b)	8.	(a)	9.	(a)	10.	(c)
11.	(a)	12.	(c)	13.	(d)	14.	(d)	15	(d)

(B) Short Questions

4.1 Define like and unlike parallel forces. 09104051

Ans: Like Parallel Forces:

If the parallel forces are acting in the same direction, then they are called like parallel forces. The resultant of like parallel forces is equal to the sum of the magnitudes of all the forces and acts in the same direction as the individual forces.

Example: Two people pushing a car in the same direction.

Unlike Parallel Forces:

If the parallel forces are acting in the opposite direction, then they are called like parallel forces. The resultant of unlike parallel forces is the difference between the magnitudes of the forces and acts in the direction of the larger force.

Example: Two people pushing a table from opposite sides with unequal forces.

4.2 What are rectangular components of a vector and their values? 09104052

Ans: The components of a force which are mutually perpendicular to each other are called rectangular components.

(i) Horizontal components $F_x = F\cos\theta$

(ii) Vertical component $F_y = F\sin\theta$

4.3 What is the line of action of a force? 09104053

Ans: The line along which the force acts is called the line of action of the force. It represents the direction and path of the force and passes through the point of application of the force.

4.4 Define moment of a force. Prove that τ=rFsinθ, where θ is angle between r and F. 09104054

Ans: Moment Arm:

The perpendicular distance from the axis of rotation to the line of action of the force is known as the moment arm. A larger moment arm results in a greater turning effect.

Proof τ=rFsinθ

Torque is the cross product of the force and the perpendicular distance from the axis of rotation to the line of action of the force:

$$\tau = F \times d$$

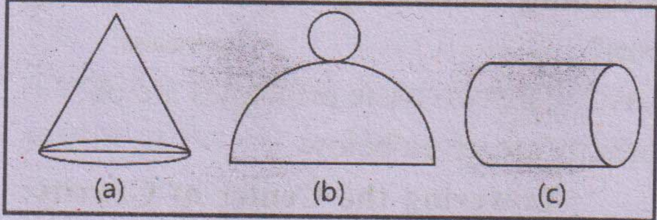
The perpendicular distance from the axis to the line of action of the force is $d = r\sin\theta$. Thus, the torque is:

$$\tau = F \cdot d = F \cdot (r\sin\theta)$$

$$\tau = rF\sin\theta$$

This shows that the moment of a force depends on the magnitude of the force, the distance r, and the angle θ between r and F.

4.5 Identify the state of equilibrium in each case in the figure given below. 09104055



Ans:

a) Stable equilibrium
b) Unstable equilibrium
c) Neutral equilibrium

4.6 Give an example of the body which is moving yet in equilibrium. 09104056

Ans: A **paratrooper** coming down with terminal velocity is in equilibrium because his weight in downward direction is equal to the force of air friction of air in upward direction. Paratrooper is moving with uniform velocity, so the paratrooper is in equilibrium.

(i) A car moving with **uniform velocity** on levelled road is the example of equilibrium.

4.7 Define center of mass and center of gravity of a body. 09104057

Ans: Center of Mass:

"The center of mass of a body is that point where the whole mass of the body is assumed to be concentrated" A force applied at such a point in the body does not produce any torque in it.

Centre of gravity:

"Centre of gravity is that point where total weight of the body appears to be acting vertically down ward" If a body is supported at its center of gravity, it remains balanced without rotating.

4.8 What are two basic principles of stability physics which are applied in designing balancing toys and racing cars? **09104058**

Ans: The two basic principles are of stability are given below.

1. **Lowering the Center of Gravity:** Placing heavier objects at a lower point within a system lowers the center of gravity, enhancing stability.

2. **Widening the Base:** Increasing the base area provides better support and reduces the chances of tipping over, thereby improving stability.

Examples:

Racing Cars: To enhance the stability of racing cars, their centers of mass are kept as low as possible. Their base areas are also increased by keeping the wheels outside of their main bodies.

Balancing Toys: These toys have a low center of gravity to ensure they return to their upright position when tilted. This makes them stable and resistant to falling over.

4.9 How can you prove that the centripetal force always acts perpendicular to velocity? **09104059**

Ans: Centripetal force always acts perpendicular to the velocity in uniform circular motion because the velocity is tangent to the circle, while the centripetal force is directed toward the center. This force changes the direction of the velocity, keeping the object in circular motion, without altering its speed. Therefore, centripetal force is perpendicular to the velocity vector at all times.

SLO based Additional Short Questions

Turning Effect of Forces

4.1 How does the moment of force apply to the working of a bottle opener? **09104060**

Ans: The moment of force is applicable in the working of a bottle opener. A small force applied at a longer moment arm produces more torque, making it easier to open a bottle.

4.2 Why are smaller diameter steering wheels used in vehicles with power steering? **09104061**

Ans: Smaller diameter steering wheels are used because they allow for quicker and easier turning of the wheel. With power steering less force is needed and a smaller diameter reduces the amount of rotation required to turn the wheels making steering more responsive and effortless.

Principle of moments

4.3 How does a tight rope walker balance himself? **09104062**

Ans: A tight rope walker balances himself by holding a bamboo stick which helps distribute his weight evenly and lowers his center of gravity. This is done by applying the principle of moments to maintain stability.

4.4 Why do tightrope walkers carry a long, narrow rod? **09104063**

Ans: As we know lower the centre of gravity greater will be stability in order to lower the center of gravity acrobats hold a long rod in their hands to that the acrobats may remain in stable equilibrium.

Trigonometric Ratio

4.5 What are trigonometry and trigonometric ratios? 09104064

Ans: Trigonometry is a branch of mathematics that deals with the properties of a right-angled triangle. The trigonometric ratios are the relationships between the sides of a right-angled triangle.

Sine θ = Perpendicular / Hypotenuse

Cosine θ = Base / Hypotenuse

Tangent θ = Perpendicular / Base

Application of stability in real life

4.6 How is the stability of a racing car enhanced? 09104065

Ans: The stability of a racing car is enhanced by keeping its center of mass as low as possible and increasing its base area by positioning the wheels outside of its main body.

Turning Effect

4.7 Why door knobs are fixed at the edge of door? What will happen if the door knob is at the middle of the door? 09104066

Ans. From the relation of torque:

$$\tau = r \times F \Rightarrow \tau \propto r$$

When force is constant, the torque is directly proportional to moment arm. So, greater the moment arm, greater will be the torque and vice versa. That's why door knobs (handles) are fixed at the edge of door to increase the moment arm. In this way even a small force is sufficient to produce the required torque, which helps in the opening or closing of the door.

If the door knob is at the middle of the door, the moment arm will become half and you will need a double force to open/close the door as compared to the edge knob.

4.8 The gravitational force acting on a satellite is always directed towards the centre of the earth. Does this force exert torque on satellite? 09104067

Ans. We know that, $\tau = rF\,sin\theta$

When a satellite of mass "m" is moving around the earth in a circular orbit of radius "r", then the gravitational force is acting toward the centre of earth, so "F_g" is antiparallel to moment arm "r", so we put $\theta = 180^0$ in equation (1) we get,

$$\tau = rFsin\,180^0 = rF \times 0 => \tau = 0$$

Thus the gravitational force acting on a satellite does not exert any torque on it.

Equilibrium

4.9 Can we have situations in which an object is not in equilibrium, even though the net force on it is zero? Give two examples. 09104068

Ans. For complete equilibrium, the following two conditions must be satisfied. i.e.

(i) $\sum F = 0$ and (ii) $\sum \tau = 0$

Now $\sum F = 0$ and $\sum \tau = 0$, then the body will rotate and will not be in state of complete equilibrium. We can have situations in which an object is not in equilibrium, even though the net force on it is zero.

Example (i): When a steering wheel of a car is rotated with two equal and opposite forces, then it will not be in state of equilibrium. Here the net force is zero but the net torque is not zero and hence the wheel is not in state of equilibrium.

Example(ii): When the pedals of a bicycle are rotated, the net force is equal to zero but net torque exists in the system. Therefore, due to net torque, the system is not in state of equilibrium.

(C) Constructed Response Questions

4.1 A car travels at the same speed around two curves with different radii. For which radius the car experiences more centripetal force? Prove your answer. 09104069

Ans: If the car travels at the same speed on two curves, the curve with the smaller radius requires a larger centripetal force to keep the car on the path.

The centripetal force F_c required to keep an object moving in a circular path is given by the formula:

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

From the formula, we can see that **centripetal force is inversely proportional** to the radius (r) of the curve. That is, as the radius decreases, the centripetal force increases, assuming the mass and speed are constant. Therefore, for the same speed, the car will require a **larger centripetal force** when traveling around a curve with a **smaller radius**.

4.2 A ripe mango does not normally fall from the tree. But when the branch of the tree is shaken, the mango falls down easily. Can you tell the reason? 09104070

Ans: A ripe mango does not normally fall from the tree because it is held in place by a strong attachment between the stem and the tree. This attachment exerts an inward force that keeps the mango secure. However, when the branch is shaken, it creates vibrations and external disturbances, which weaken the connection between the mango and the tree. The shaking reduces the force holding the mango in place, allowing gravity to pull it down more easily. Thus, the external force from shaking the branch causes the mango to detach and fall.

4.3 Discuss the concepts of stability and center of gravity in relation to objects toppling over. Provide an example where an object's Center of gravity affects its stability, and explain how altering its base of support can influence stability. 09104071

Ans: The stability of an object depends on its **center of gravity (CG)** and **base of support**. An object is stable if its CG is positioned above its base of support. A lower CG increases stability, making the object less likely to topple. For example, **balancing toys**, such as those that return to their upright position after being disturbed, have their CG positioned below the pivot point. When disturbed, the toy momentarily becomes unstable as the CG rises, but it quickly returns to its stable position as the CG lowers again. This behavior illustrates how the center of gravity plays a key role in stability. Similarly, increasing the base of support can improve stability, as seen in objects with a wide base, making them less likely to topple.

4.4 Why an accelerated body cannot be considered in equilibrium? 09104072

Ans: An accelerated body cannot be considered in equilibrium because, in equilibrium, the net force acting on an object must be zero. Equilibrium occurs when all the forces acting on an object balance out, resulting in no change in its state of motion. However, if a body is experiencing acceleration, it means there is a net force acting on it. Therefore, a body undergoing acceleration is not in a state of equilibrium.

4.5 Two boxes of the same weight but different heights are lying on the floor of a truck. If the truck makes a sudden stop, which box is more likely to tumble over? Why? 09104073

Ans: The **taller box** is more likely to tumble over when the truck makes a sudden stop because its **center of gravity** is higher, making it less stable. When the truck stops abruptly, inertia causes the boxes to resist the change in motion. The taller box, with a higher center of gravity, is more likely to tip over as its center of gravity can easily move outside its base of support. In contrast, the shorter box has a lower center of gravity, providing more stability and reducing the risk of it toppling.

(D) Comprehensive Questions

4.1 Explain the principle of moments with an example. 09104074

Ans: See question No 9

4.2 Describe how could you determine the centre of gravity of an irregular shaped lamina experimentally. 09104075

Ans: See question No 10

4.3 State and explain two conditions of equilibrium. 09104076

Ans: See question No 13

4.4 How the stability of an object can be improved? Give a few examples to support your answer. 09104077

Ans: See question No 17

(E) Numerical Problems

4.1 A force of 200 N is acting on a cart at an angle of 30° with the horizontal direction. Find the x and y-components of the force. 09104078

Solution:

Given data:

$F = 200\ N$

$\theta = 30^o$

To find:

$F_x = ?$

$F_y = ?$

$F_x = F\cos\theta$

So, $F_x = 200\cos30^o$

$F_x = 200 \times 0.866$

$F_x = 173.2\ N$

and $F_y = F\sin\theta$

$F_y = 200 \times \sin30^o$

$F_y = 200 \times 0.5$

$F_y = 100$ N

Result:

Hence the x and y component of force is 173.2 N and 100 N respectively.

4.2 A force of 300 N is applied perpendicularly at the knob of a door to open it as shown in the given figure if the knob is 1.2 m away from the hinge, what is the torque applied? Is it positive or negative torque? **09104079**

Solution:

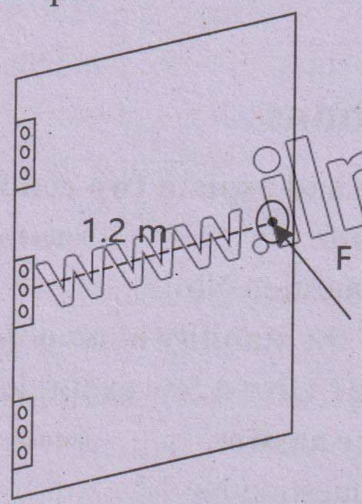
Given data:

Force F = 300 N

Perpendicular distance from hinge $= \ell = 1.2$ m.

To find:

Torque =?



Direction (positive or negative) =?

$\tau = \ell \times F$

$\tau = 1.2 \times 300$

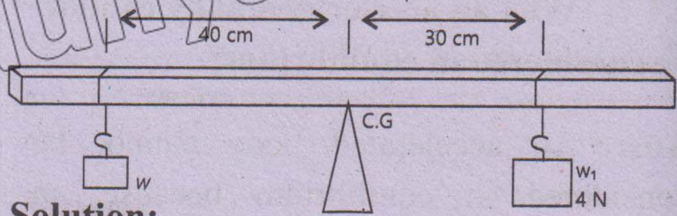
$\tau = 360$ Nm

Since the force in such a way that it opens the door Anticlockwise, it is considered positive torque.

Result:

Hence the 360 Nm is applied which is positive.

4.3 Two weights are hanging from a metre rule at the positions as shown in the given figure. If the rule is balanced at its centre of gravity (C.G), Find the unknown weight w. **09104080**



Solution:

Given data:

Distance of weight w from the C.G $= 40 \text{ cm} = \frac{40}{100} = 0.4$ m

Distance of weight (w_1) from the center of gravity $= 30 \text{ cm} = \frac{30}{100} = 0.3$ m

Weight on the right side $= w_1 = 4$ N

To find:

Unknown weight on left side = w =?

According to principle of moments.

Clockwise moment = Anticlockwise moment

$w \times 0.4 = 4 \times 0.3$

$w \times 0.4 = 1.2$

$w = \frac{1.2}{0.4}$

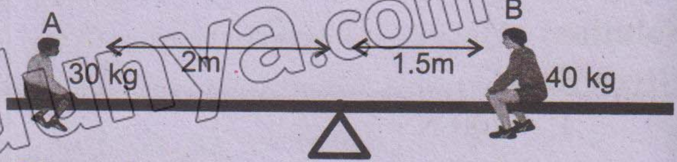
$w = 3$N

Result: The unknown weight is 3 N.

4.4 A see-saw is balanced with two children sitting near either end. Child A weighs 30 kg and sits 2 metres away from the pivot, while child B weighs 40 kg and sits 1.5 metres from the pivot. Calculate the total moment on each side and determine it the sea-saw is in equilibrium.

09104081

Solution:



Given data:

Mass of child 'A' (m_a) = 30 kg

Distance of child A from the pivot (d_A) = 2m

Mass of child 'B' (m_b) = 40 kg

Distance of child B from the pivot (d_B) = 1.5m

To find:

Total moment on each side =?

Weight of child A

$W_A = m_a g = 30 \times 10 = 300$ N

Weight of child B

$W_B = m_b g = 40 \times 10 = 400$ N

Now the moment of force by child A

$Moment_A = W_A \times d_A$

$= 300 \times 2$

$= 600$ Nm

Now calculate the moment of force by child B

$Moment_B = W_B \times d_B$

$= 400 \times 1.5$

$= 600$ Nm

Result:

As the clockwise moment equal to the anticlockwise moment so see-saw is equilibrium.

4.5 A crowbar is used to lift a box as shown in the given figure. If the downward force of 250 N is applied at the end of the bar, how much weight does the other end bear? The crowbar itself has negligible weight.

09104082

Solution:

Given data:

Applied Force = F = 250

Distance from the pivot where force is applied = d_1 = 30 cm = $\frac{30}{100}$ = 0.3 m

Distance from the pivot to the box = d_2 = 5 cm = $\frac{5}{100}$ = 0.05 m

To Find:

Weight that the other end bears = w = ?

According to principle of moment

Moments of applied force = Moment of weight lifted

$F \times d_1 = w \times d_2$

$250 \times 0.3 = w \times 0.05$

$W = \frac{250 \times 0.3}{0.05}$

$W = \frac{75}{0.05}$

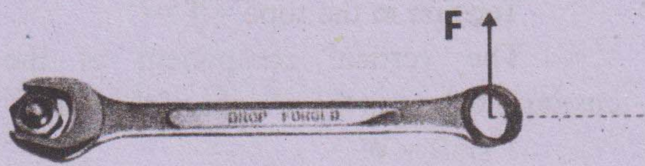
W = 15000 N

Result:

The weight that the other end bears is 15000 N.

4.6 A 30 cm long spanner is used to open the nut of a car. If the torque required for it is 150 N m, how much force F should be applied on the spanner as shown in the figure given below.

09104083



Solution:

Given Data:

Torque = τ = 150 Nm

Length of spanner = ℓ = 30cm = $\frac{30}{100}$ = 0.3 m

To find:

Force F = ?

The torque is calculated by using the formula

$\tau = F \times \ell$

$150 = F \times 0.3$

$F = \frac{150}{0.3}$

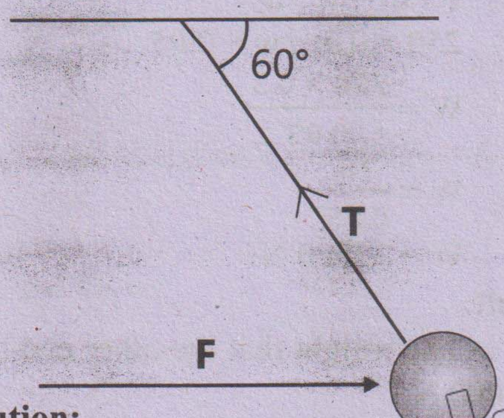
$F = 500\ N$

Result:

The Force that should be applied on the spanner is 500 N.

4.7 A 5 N ball hanging from a rope is pulled to the right by a horizontal force F. The rope makes an angle of 60° with the ceiling, as shown in the given figure. Determine the magnitude of force F and Tension T in the string.

09104084



Solution:

Given data

Weight of the ball = w = 5 N

Angle of the rope with ceiling, $\theta = 60^\circ$

To find:

Magnitude of horizontal force = F =?

Tension in the rope = T =?

The vertical component of the tension T balances the weight of the ball.

$$T \sin\theta = W$$

$$T = \frac{W}{\sin\theta}$$

$$T = \frac{w}{\sin 60}$$

$$T = \frac{5}{\sin 60}$$

$$T = \frac{5}{\sqrt{3}/2}$$

$$T = \frac{5 \times 2}{\sqrt{3}}$$

$$T = \frac{10}{\sqrt{3}} \approx 5.8 N$$

The horizontal component of tension T is balanced by horizontal force F.

$$T \cos\theta = F$$

$$F = 5.8 \cos 60$$

$$F = 5.8 \times 0.5$$

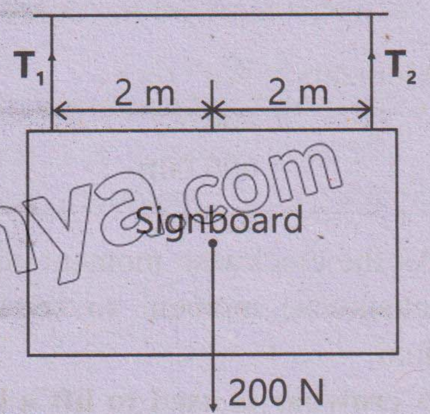
$$F = 2.9\ N$$

Result:

The magnitude of horizontal Force is 2.9 N and tension in the rope is 5.8 N.

4.8 A signboard is suspended by means of two steel wire as shown in figure. If the weight of the board is 200 N, what is the tension in the strings?

09104085



Solution:

Given data:

Weight of sign board = w = 200 N

Two wire are equidistant from the center of the board which is = 2 m each side

To Find:

Tension in the string

T_1 =?

T_2=?

Since the signboard is in equilibrium and symmetrically supported by two wires, the weight is equally distributed between the two wires.

So, $T_1 + T_2 = w$

Since the distance from the center are equal, the tension in each string will also be equal.

$T_1 = T_2$

Therefore,

$$T_1 + T_1 = 200$$

$$2T_1 = 200$$

$$2T_1 = \frac{200}{2}$$

$$2T_1 = 100\ \text{N}$$

Result:

The tension in each string is 100 N.

4.9 One girl of 30 kg mass sits 1.6 m from the axis of a see-saw. Another girl of mass 40 kg wants to sit on the other side, so that the see-saw may remain in equilibrium. How far away from the axis, the other girl may sit? **09104086**

Solution:

Given data:

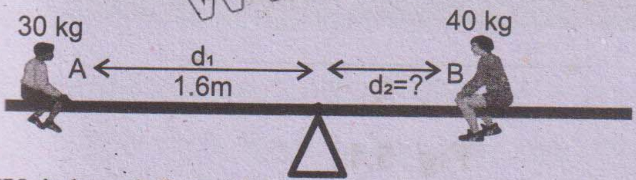
Mass of one girl = m_1 = 30 kg

Distance of one girl from the axis = d_1 = 1.6 m

Mass of second girl = m_2 = 40 kg

To Find:

Distance of second girl for the axis = d_2 =?



Weight of first girl = $w_1 = m_1 g = 30 \times 10 = 300$ N

Weight of second girl = $w_2 = m_2 g = 40 \times 10 = 400$ N

According to principle of moments

Clockwise moment = Anticlockwise moment

$$W_1 \times d_1 = W_2 \times d_2$$

$$300 \times 1.6 = 400 \times d_2$$

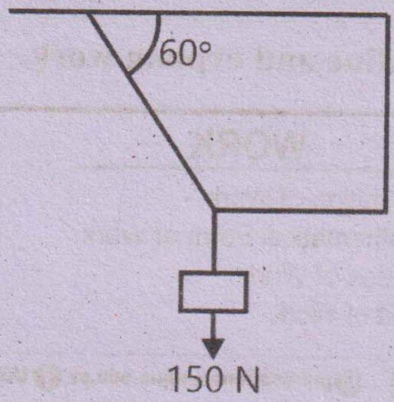
$$\frac{300 \times 1.6}{400} = d_2$$

$$d_2 = 1.2\ \text{m}$$

Result:

The second girl must sit 1.2 meters away from the axis.

4.10 Find the tension in each string of them as shown in given figure, if the block weighs 150 N. **09104087**



Solution:

Given data:

Weight of the block (w)=150 N

Angle $\theta = 60^\circ$

To find:

Tension in the inclined string = T_1= ?

Tension in the vertical string = T_2 =?

In the vertical direction.

$$T_1 \sin\theta = w$$

$$T_1 = \frac{w}{\sin\theta}$$

$$T_1 = \frac{150}{\sin 60}$$

$$T_1 = \frac{150}{\sqrt{3}/2}$$

$$T_1 = \frac{150 \times 2}{\sqrt{3}}$$

$$T_1 = \frac{300}{\sqrt{3}}$$

$$T_1 \approx 173.2\text{N}$$

In horizontal direction

$$T_2 = T_1 \cos\theta$$

$$T_2 = 173.2 \times 0.5$$

$$T_2 = 86.6$$

Result:

Hence the tension in the vertical and inclined string is 173.2 N and 86.6 N respectively.