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# Physics 9

*Comprehensive Notes with Short Questions, Long Questions, MCQs, and Problems*

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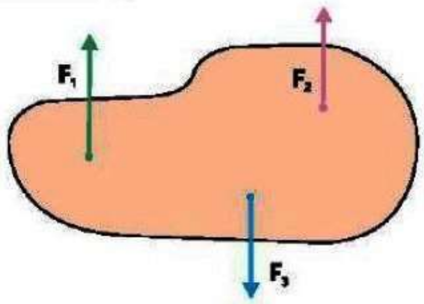
**** 1. Define like and unlike parallel forces. Illustrate with an example.**

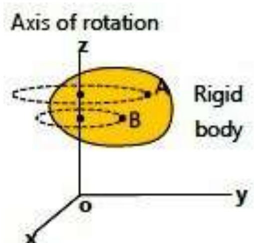
*If the **parallel forces** are acting in the same direction, then they are called **like parallel forces**, and if their directions are opposite to one another, they are called **unlike parallel forces**.*

Three forces $F_1$, $F_2$ and $F_3$ are shown in figure acting on a rigid body at different points. Here, the forces $F_1$ and $F_2$ are like parallel forces but $F_2$ and $F_3$ are unlike parallel forces.




**2. What is a 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**.

**3. What is the axis of rotation?**
During rotation, all the particles of the rigid body rotate along **fixed circles**. The **straight line** joining the centres of these circles is called the axis of rotation.




**4. What is the line of action of a force?**
The line along which the force acts is called the line of action of the force.

**5. What is a moment arm?**
The perpendicular distance of the **line of action of a force** from the **axis of rotation** is known as moment arm of the force, or simply moment arm.

**6. What is the turning effect of a force?**
The turning effect of a force is the force that causes a rigid body to rotate about an axis.

**7. What is the turning effect of a force? Explain with examples.**
When we open or close a door, we apply force. This force rotates the door about its hinge. This is called the **turning effect of force**. Similarly, we use turning effect of force when we open or close a water tap.

This shows that the turning effect of a force does not depend only on its magnitude but also on the location where it acts. Therefore:

- The greater the force, the greater is its turning effect.
- The larger the perpendicular distance of the force from the axis of rotation, the greater is its turning effect.

There are many other examples to observe the **turning or rotational effect** of a force:

It is **harder to open a door** by pushing it at a point closer to the hinge as compared to pushing it at the handle. That is why, door or window handles are always installed at larger distances from hinges to produce larger moment of force by applying **less force**.

Similarly, it requires **greater force** to open a **nut** by a **spanner** if you hold it **closer** (point A) than at a **farther point** (point B).


**** 8. What is meant by the moment of a force or torque? How is it defined and calculated?**
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.*

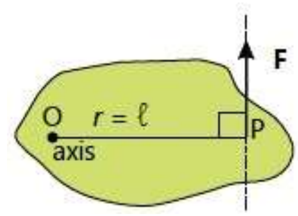
The magnitude of torque is given by:

$$\tau = F \times l$$

Where $\tau$ (tau) is the torque, $F$ is the applied force, and $l$ is the moment arm.

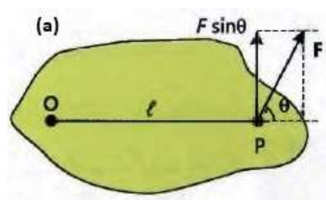
The **SI unit** of torque is newton metre ($Nm$).

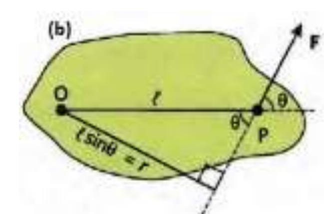
In figure, the line of action of a force $F$ is perpendicular to $r$, therefore, moment arm $l = r$. The **torque of a force is zero** when the line of action of the force passes through the axis of rotation, because its moment arm becomes zero.




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.

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 need to find a component of force $F$ that is perpendicular to $OP = l$ (as shown in Fig. a), or we can find $r$ the component of $l$ that is perpendicular to its line of action of force $F$ (as shown in Fig. b).

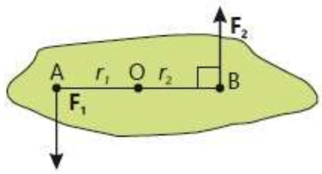


For this, we need to know the method of finding rectangular components of a force or any vector. This is also called as **resolution of forces**.

**9. What is a couple and how is it formed?**
When two equal and opposite parallel forces act at two different points of the same body, they form a **couple**. A couple is a special type of **torque**.

**10. Can you provide examples of a couple in daily life?**
Yes, we observe a couple in many situations when two equal and opposite parallel forces produce torque. Examples include:




**(i)** Opening or closing a water tap
**(ii)** Turning a key in a lock
**(iii)** Opening the lid of a jar
**(iv)** Turning the steering wheel of a motor car

In these cases, a pair of equal forces is applied in opposite directions, producing torque, which is known as a **couple**.

**** 11. How is a force resolved into its components?**

*By the head-to-tail rule, two or more vectors can be added to form a resultant vector. The reverse process is also possible, where a given vector can be divided into two or more parts, called its **components**. The process of dividing a force into its components is known as the resolution of a force.*

**Perpendicular component:** Typically, a force is resolved into two components that are perpendicular to each other. These components are called the perpendicular or rectangular components of the force.

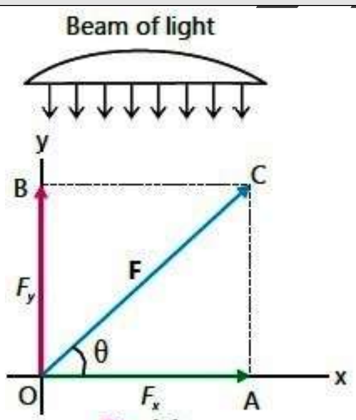


**Fig. (a)**

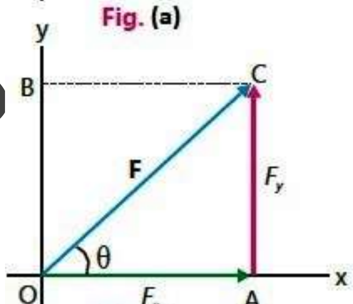


**Fig. (b)**

**Explanation:** Consider a force $\boldsymbol{F}$ acting on a body at an angle $\theta$ with the $x\text{-}axis$, as shown in Fig. (a). Imagine a beam of light placed above the vector $\boldsymbol{F}$. As the light falls perpendicularly to the $x\text{-}axis$, it casts a shadow $OA$ of vector $\boldsymbol{F}$ onto the $x\text{-}axis$. This shadow, $OA$, is called the $x\text{-}component$ of the vector $\boldsymbol{F}$. Similarly, if light is thrown perpendicular to the $y\text{-}axis$, the shadow $OB$ of vector $\boldsymbol{F}$ on the $y\text{-}axis$ is the $y\text{-}component$ of $\boldsymbol{F}$.

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

The $x$ and $y$ components of the force can be practically drawn by simply dropping perpendiculars from the tip of vector $\boldsymbol{F}$ onto the $x$ and $y\text{-}axes$, respectively. The $x\text{-}component$ of force $\boldsymbol{F}$ is denoted as $F_x$, and the $y\text{-}component$ is denoted as $F_y$.

From Fig. (b), it is clear that $\boldsymbol{F}$ is the resultant vector of components $F_x$ and $F_y$. Additionally, $F_x$ and $F_y$ are perpendicular to each other, so they are called the **perpendicular components** of vector $\boldsymbol{F}$. The magnitudes of the perpendicular components can be determined using the right-angled triangle **OAC** in Fig. (b).

**Horizontal components $\boldsymbol{F_x}$:** The components of force which is along $x - axis$ is called $x - components$ or horizontal components.

$$\cos\theta = \frac{Base}{Hypotenuse}$$
$$\cos\theta = \frac{OA}{OC}$$
$$\cos\theta = \frac{F_x}{F}$$
$$F_x = F\cos\theta$$

**Vertical components $\boldsymbol{F_y}$:** The components of force which is along $y - axis$ is called $y - components$ or vertical components.

$$\sin\theta = \frac{Perpendicular}{Hypotenuse}$$
$$\sin\theta = \frac{AC}{OC}$$
$$\sin\theta = \frac{F_y}{F}$$
$$F_y = F\sin\theta$$

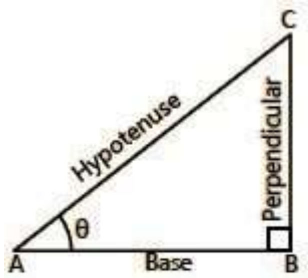
**12. How we determine a force from its perpendicular components?**
The magnitude and direction of a force can be found if its perpendicular components are known. Applying Pythagorean theorem to the right-angled triangle $OAC$ as shown in figure b.

$$(Hypotenuse)^2 = (Base)^2 + (Perpendicular)^2$$
$$(OC)^2 = (OA)^2 + (AC)^2$$
$$F^2 = F_x^2 + F_y^2$$
$$\sqrt{F^2} = \sqrt{F_x^2 + F_y^2}$$
$$F = \sqrt{F_x^2 + F_y^2} \quad \cdots (i)$$

Hence, using equation $(i)$ the magnitude $F$ of the required vector $\boldsymbol{F}$ can be determined. The direction of $\boldsymbol{F}$ is given by

$$\tan\theta = \frac{Perp.}{Base}$$
$$\tan\theta = \frac{AC}{OA}$$
$$\tan\theta = \frac{F_y}{F_x}$$
$$\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$$

**13. What is trigonometry and how are the sides of a right-angled triangle defined?**




Trigonometry 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 $\theta$ (theta), called the **angle of the right-angled triangle**.

- The side $AB$ is called the **base**.
- The side $BC$ is called the **perpendicular**.
- The side $AC$ is called the **hypotenuse**.

The **ratio of any two sides** is given specific names in trigonometry. These ratios form the basis of trigonometric functions.

$$\sin\theta = \frac{Perpendicular}{Hypotenuse}$$
$$\cos\theta = \frac{Base}{Hypotenuse}$$
$$\tan\theta = \frac{Perpendicular}{Base}$$

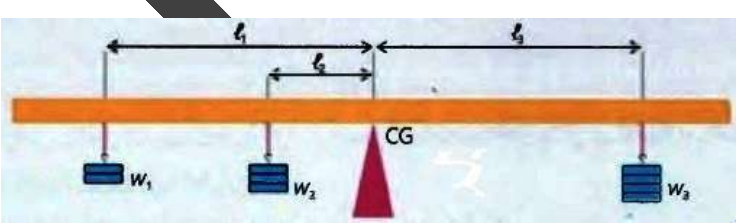
| Angle ($\boldsymbol{\theta}$) | $\sin\boldsymbol{\theta}$ | $\cos\boldsymbol{\theta}$ | $\tan\boldsymbol{\theta}$ |
|---|---|---|---|
| $0^\circ$ | $0$ | $1.0$ | $0$ |
| $30^\circ$ | $\frac{1}{2}$ | $\frac{\sqrt{3}}{2}$ | $\frac{1}{\sqrt{3}}$ |
| $45^\circ$ | $\frac{1}{\sqrt{2}}$ | $\frac{1}{\sqrt{2}}$ | $1.0$ |
| $60^\circ$ | $\frac{\sqrt{3}}{2}$ | $\frac{1}{2}$ | $\sqrt{3}$ |
| $90^\circ$ | $1.0$ | $0$ | $\infty$ |

**14. State and explain the principle of moments.**

The principle of moments is defined as:

*When a body is in balanced position, the sum of clockwise moments about any point equals the sum of anticlockwise moments about that point.*

To understand this principle, consider a metre rule balanced on a wedge at its centre of gravity (CG) so that the rule stays horizontal.




Suppose two weights $w_1$ and $w_2$ are suspended on one side of the metre rule at distances $l_1$ and $l_2$ from the centre, and a third weight $w_3$ is suspended on the other side at distance $l_3$, until the rule is again balanced.

- The weights $w_1$ and $w_2$ tend to rotate the rod **anticlockwise** about CG.
- The weight $w_3$ tends to rotate it **clockwise**.

The values of the **moments of the weights** are:

- $w_1 \times l_1$,
- $w_2 \times l_2$,
- $w_3 \times l_3$.

When the metre rule is balanced, then

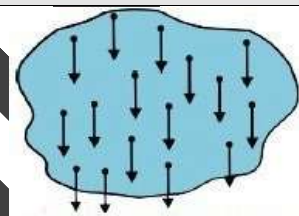
$$Total\ anticlockwise\ moments = Total\ clockwise\ moments$$
$$(w_1 \times l_1) + (w_2 \times l_2) = w_3 \times l_3$$

This equation verifies the principle of moments.

**** 15. What is meant by the centre of gravity of a body? How can it be found for regular shapes?**

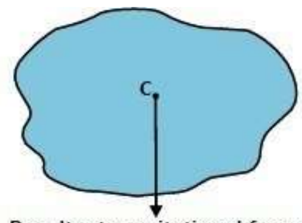
*Centre of gravity is that point where total weight of the body appears to be acting.*

An object is composed of a large number of small particles. Each particle is acted upon by the gravitational force directed towards the centre of the Earth (Fig. a). As the object is small as compared to the Earth, the value of $g$ can be taken as uniform over all particles. Therefore, each particle experiences the same force $mg$.



Gravitational force acting on various particles
**Fig. (a)**

Since all these forces are parallel and act in the same direction, their resultant, as shown in Fig. b, will be equal to the sum of all these forces. That is:




Resultant gravitational force
**Fig. (b)**

$$w = Mg, \qquad where\ M = \Sigma m = mass\ of\ the\ object$$

If a body is supported at its centre of gravity, it stays there without rotation.

The centre of gravity of an object of **regular shape** lies at its **geometrical centre**.

*Centre of Gravity of Some Regular Shapes*

| **Object** | **Centre of Gravity** |
|---|---|
| **Square, Rectangle** | Point of intersection of the diagonals |
| **Triangle** | Point of intersection of the medians |
| **Round plate** | Centre of the plate |
| **Sphere** | Centre of the sphere |
| **Cylinder** | Centre of the axis |
| **Metre rule** | Centre of the rod |

**** 16. What is meant by the centre of mass? How does it relate to Newton's second law of motion?**

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

Newton's second law of motion is applicable to a single particle or a system of particles. Even when the parts of a system have different velocities and accelerations, there is still **one point** in the system whose acceleration can be found by applying the second law. This point is called the **centre of mass** of the system.

Hence, the centre of mass behaves as if **all the mass** of the body or system is lying at that point.

In figure, a rotating **wrench** slides along a frictionless floor. There is no resultant force on the wrench. Therefore, its centre of mass, shown by a dot, follows a linear path with constant speed.

**17. How can the centre of gravity of an irregular shaped object be found?**

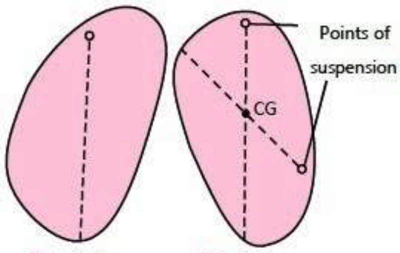


Fig. (a) Fig. (b)

To find the centre of gravity of an irregular shaped plane lamina, it can be suspended freely through different points (Fig. a). Each time the object is suspended, its centre of gravity lies on the vertical line drawn from the point of suspension using a plumbline.

The exact position of the centre of gravity is at the point where two such vertical lines cross each other, as shown in Fig. b.

**Note:** The *centre of gravity* can exist $inside$ a body or $outside$ the body as is the case with a $cup$. Centre of gravity of a $bowl$ is $outside\ the\ material$.

***18. What is meant by equilibrium? Explain its types with examples.**

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

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**, which can be stated as:

*A body is in equilibrium if the **resultant of all the forces** acting on it is zero.*

There are two types of equilibrium:

1. Static equilibrium
2. Dynamic equilibrium

***Static Equilibrium:** A body at rest is said to be in static equilibrium.*

An example of static equilibrium is a book lying on a table as shown in figure. Only two forces are acting on it:

**(i)** Its weight $w = mg$ acting downward, and
**(ii)** The normal force $F_n$ that the table exerts upward.

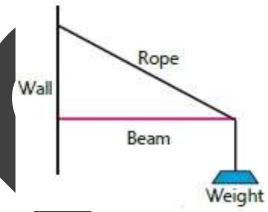
Since the book is at rest, it has **zero acceleration**. Therefore, the sum of all the forces acting on the book should be **zero**, so the book is said to be in equilibrium.

$$F_n - w = 0$$
$$F_n = w$$


This means that forces can act on a body without accelerating it, provided these forces balance each other.

Other examples of static equilibrium are:

**(i)** An electric bulb hanging from the ceiling of a room.
**(ii)** A man holding a box.
**(iii)** A beam held horizontal against a wall with the help of a rope.




***Dynamic Equilibrium:** A body moving with uniform velocity is said to be in dynamic equilibrium.*

A good example is a **paratrooper**. A few seconds after the free fall, the parachute opens and a little later, the paratrooper starts descending with a uniform velocity. In this state:

**(i)** The force of gravity acting vertically downward is balanced by
**(ii)** The resistance of air on the parachute acting upward.

Thus, the body moves with no acceleration, meaning it is in **dynamic equilibrium**.

***19. What is the First Condition of Equilibrium? Explain its mathematical form.**

*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.*

According to Newton's second law of motion,

$$F = ma$$

If the body is in translational equilibrium, then

$$a = 0$$

Therefore, net force

$$F = 0 \quad or \quad \sum F = 0$$

This is the **mathematical form** of the first condition of equilibrium, which states:

*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**.*

In case a number of **coplanar forces** $F_1$ , $F_2$ , $F_3$ ,... having their resultant equal to $F$, are acting on a body, these can be resolved into their rectangular components, and the first condition of equilibrium can then be written as:

**Along $x$-direction**:

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

**Along $y$-direction**:

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

Thus, the first condition of equilibrium can also be stated as:

*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.*

***20. What is the Second Condition of Equilibrium? Explain with example and mathematical form.**

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

Mathematically, we can write:

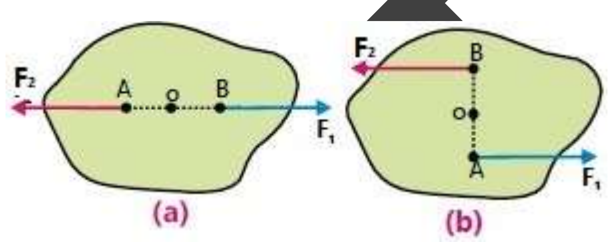
$$\sum \tau = 0$$

Hence, a body will be in complete equilibrium when,

$$\begin{cases} \sum F_x = 0 \\ \sum F_y = 0 \end{cases}$$
$$and \qquad \sum \tau = 0$$

*The second condition of equilibrium applies to **rotational equilibrium**, which means that the body should not rotate under the action of the forces.*

Consider the example of a rigid body shown in figure.




Two forces $F_1$ and $F_2$ of equal magnitude are acting on it:

**(i)** In case (a), both forces act along the same line of action.

**(ii)** In case (b), the lines of action of the two forces are different.

Since the magnitude of $F_1$ and $F_2$ are equal in both cases, the **resultant force** is zero. Thus, the **first condition of equilibrium** is satisfied.

However, in case (b), the forces form a **couple** which can produce torque and rotate the body about point $O$. Therefore, for the body to be in complete equilibrium.

**21. What are the steps to solve problems using the conditions of equilibrium?**

To solve problems by applying the **conditions of equilibrium**, the following steps should be followed:

1. **Select the object(s)** to which Eqs. $\sum F_x = 0$ and $\sum F_y = 0$ are to be applied.
   - Each object should be treated **separately**.
2. **Draw a diagram** showing the object and all the forces acting on it.
   - Only include the forces acting on the object, not the forces it exerts on other bodies.
3. **Choose a set of x and y axes** such that as many forces as possible lie **along the axes**.
   - This will reduce the number of forces that need to be resolved into components.
4. **Resolve all the forces** which are **not parallel** to either axis into their **rectangular components**.
5. Apply the **first condition of equilibrium** using:
   - $\sum F_x = 0$
   - $\sum F_y = 0$

   to obtain **two equations**.
6. If necessary, apply the second condition of equilibrium using:
   - $\sum \tau = 0$
     to obtain a **third equation**.

Solve the equations simultaneously to find the desired unknown quantities.

These steps ensure proper application of the **conditions of equilibrium** to solve force-related problems in mechanics.

**22. What are the states of equilibrium?**

An object is balanced when its $centre\ of\ mass$ and its $point\ of\ support$ lie on the same vertical line. Then, forces on each side are balanced, and the object is said to be in equilibrium.

There are three states of equilibrium in connection with the stability of the balanced bodies:

**(i)** Stable Equilibrium
**(ii)** Unstable Equilibrium
**(iii)** Neutral Equilibrium

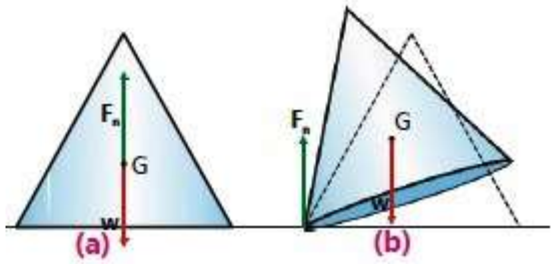
***23. What is stable equilibrium? Explain with an example.**

*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.

The cone shown in figure (a) is in the state of stable equilibrium. Its $weight$ $\boldsymbol{w}$ acting downward at the $centre\ of\ gravity\ G$, and the $reaction\ of\ the\ floor$ $\boldsymbol{F_n}$ acting upward, lie on the same vertical line.

Since these forces are equal and in opposite direction, they balance each other, and both the conditions of equilibrium are satisfied.



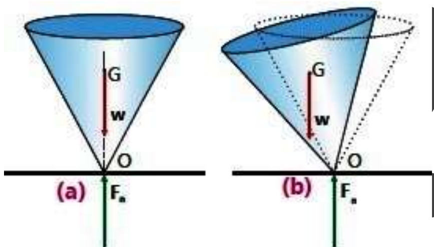

As you try to push over the cone slightly, its *centre of gravity is raised* but it still remains above the base of the cone. The *weight* $\boldsymbol{w}$ and the *normal force* $\boldsymbol{F_n}$ do not remain in the same line but act like two unlike parallel forces.

The cone does not remain in equilibrium. Unlike parallel forces produce a clockwise torque, which brings the cone back to its original position.

It is worth noting that the body remains in equilibrium as long as its centre of mass lies within the base.

***24. What is unstable equilibrium?**

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

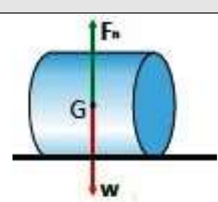



**Explanation:** Try to balance a cone on its tip. It may remain balanced for a moment because the *weight* $\boldsymbol{w}$ and the normal reaction $\boldsymbol{F_n}$ lie along the same vertical line. However, even a slight tilt causes it to fall over, because its centre of mass no longer remains above the base.

It topples because the *line of action* of the *weight* no longer lies inside the base. In this case, the centre of gravity is lowered on tilting and continues to fall further. It cannot rise up again because the *anticlockwise torque* produced by weight moves it further downward.

***25. What is neutral equilibrium?**

*A body is in neutral equilibrium if it comes to rest in its new position after disturbance without any change in its centre of mass.*




**Explanation:** A *cylinder* resting on a horizontal surface figure shows neutral equilibrium. If the cylinder is rotated slightly, there is no force or torque that brings it back to its original position or moves it further away. As the cylinder rotates, the *height of the centre of mass* remains *unchanged*.

In any position of the cylinder, its *weight* $\boldsymbol{w}$ and the *reaction of the ground* $\boldsymbol{F_n}$ lie in the same vertical line.

Other examples of neutral equilibrium are:

- A ball rolling on a horizontal surface
- A cone resting on its curved surface

***26. How can the stability of an object be improved?**

*Stability of an object depends on the position of its centre of gravity*.

It is our daily life observation that a *low armchair* is more stable than a *high chair* because of its **low centre of gravity**.

The position of the *centre of gravity* is very important when we are talking about stability. For example, a bus can be *stable* or *unstable* depending on how it is loaded:

**(i)** If the **heavy loads** are placed on the floor of the bus, its centre of gravity will be **low**. Now if it is disturbed slightly, a **torque** will bring it back to its original position. In this case, the bus is in stable equilibrium.

**(ii)** If the same bus is loaded with steel sheets **on the top**, the centre of gravity is **raised**. It is now near to a state of unstable equilibrium. A *couple* will turn it over if it is slightly tilted.

The same is the case for ***ships*** and ***boats***.

We can **improve the stability** of a system either by:

**(i)** Lowering the centre of gravity

**(ii)** Widening the base

**27. What are the applications of stability in real life?**

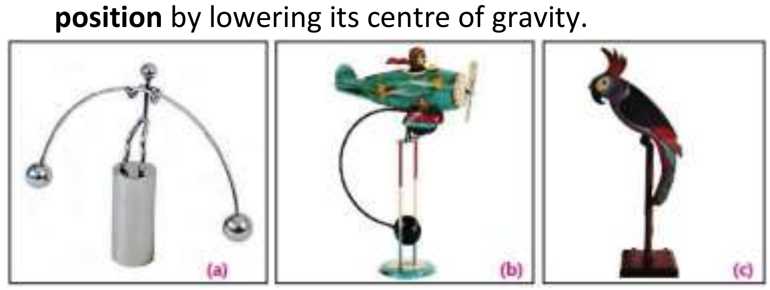
Stability is an important concept that is widely applied in engineering and daily life to ensure safety and balance in various systems.

**1. Racing Cars:** To prevent *toppling over* at high speeds and during sharp turns:

- Racing cars are designed with a low centre of mass.
- Their **base area** is made wide by placing the *wheels* farther apart and outside the main body. This design improves the car's **stability** and helps it stay balanced on the track.

**2. Balancing Toys:** Balancing toys are designed to always return to their original position after being disturbed.

- These toys have their centre of gravity below the pivot point, making them **very stable**.
- When tilted, the **centre of gravity rises**, making the toy temporarily unstable.
- Due to its design, the toy quickly **returns to its stable position** by lowering its centre of gravity.



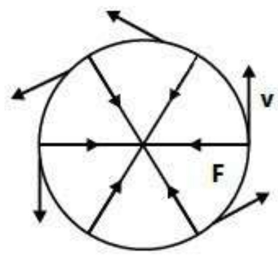
**28. What are the counterparts of velocity, acceleration, force, and momentum in rotational motion?**

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 the rotational motion that is played by the force in the translational motion.

**29. How does Newton's First Law apply to rotational motion?**

A rotating object will continue to rotate with constant angular velocity unless acted upon by a net external torque. This is similar to how an object in translational motion continues with constant velocity unless acted upon by a net external force.

**30. Why does a body moving in a circle need a perpendicular force?**




When a body is moving along a circular path, its velocity at any point is directed along the tangent drawn at that point. As shown in figure the direction of the tangent at each point on the circle is different, the velocity is constantly changing. Hence, a force perpendicular to the direction of motion is always required to keep the object moving with uniform speed in a circular path.

**31. Why must the force be perpendicular to the velocity in circular motion?**

It should be noted that $\boldsymbol{F}$ is essentially perpendicular to $\boldsymbol{v}$. If not, $\boldsymbol{F}$ would have a component in the direction of $\boldsymbol{v}$, which would change the magnitude of velocity. Since the body moves with constant speed, this is only possible if the component of force along $\boldsymbol{v}$ is $\boldsymbol{F}\cos 90^{\circ} = \boldsymbol{0}$.

***32. What is centripetal force?**

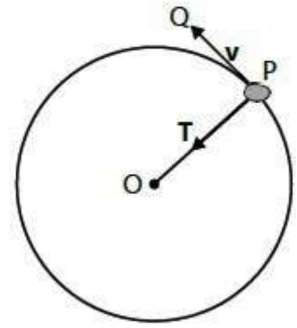
*The force that causes an object to move in a circle at constant speed is called the centripetal force.*

For an object of mass $m$ moving with uniform speed $v$ in a circle of radius $r$, the centripetal force $F_c$ is given by:

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

**33. What is the source of centripetal force when a stone is whirled in a circle by 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 as shown in figure. The **tension (T)** in the string provides the necessary **centripetal force** to keep the stone along the circular path. When we release the string, we stop applying force on the stone, and hence, it moves in a straight line along the tangent to the circle $PQ$, with constant velocity unless an unbalanced force acts upon it.




**34. What provides the centripetal force for the moon in its orbit around the Earth?**

The **gravity of the Earth** provides the necessary **centripetal force** to keep the moon in its orbit with constant speed.

**35. How does a washing machine dryer use centripetal force?**

A **washing machine dryer** is a metallic cylindrical drum with many small holes in its walls. When the cylinder rotates rapidly, **friction** between the clothes and the 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.

**36. How does a cream separator utilize centripetal force?**

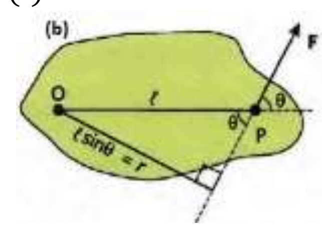
In a **cream separator**, milk is whirled rapidly. The lighter particles of cream experience less **centripetal force** and gather in the central part of the machine. The heavier particles of milk need greater centripetal force to keep their circular motion in circles of small radius $\boldsymbol{r}$. As a result, they move away towards the walls of the separator.

**** 37. Define moment of a force. Prove that $\boldsymbol{\tau} = \boldsymbol{rF}\sin\boldsymbol{\theta}$, where $\boldsymbol{\theta}$ is angle between $\boldsymbol{r}$ and $\boldsymbol{F}$.**

*Moment of a force or torque is defined as the product of the force and the moment arm.*

As

$$\tau = lF \quad \cdots (i)$$



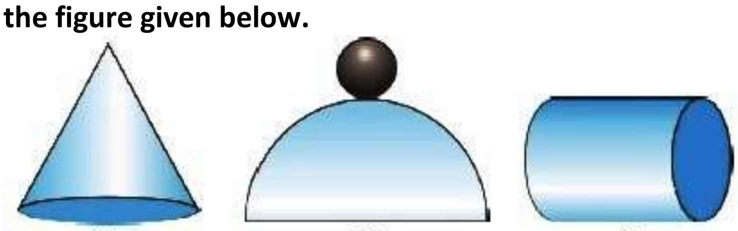

When force is applied at certain angle $\theta$ to position vector then its moment arm can be find resolving position vector or force into rectangular components. From figure

$$moment\ arm = l = r\sin\theta$$

Thus equation $(i)$ becomes

$$\boldsymbol{\tau} = (\boldsymbol{r}\sin\boldsymbol{\theta})\boldsymbol{F}$$
$$\boldsymbol{\tau} = \boldsymbol{rF}\sin\boldsymbol{\theta}$$

**** 38. Identify the state of equilibrium in each case in the figure given below.**



(a) (b) (c)

**(a)** In figure (a) cone resting on its base. This object is in **stable equilibrium**. Returns to original position after tilt.
**(b)** In figure (b) hemisphere with a ball on top. This object is in **unstable equilibrium**. Topples away after tilt.
**(c)** In figure (c) cylinder lying on its side. This object is in **neutral equilibrium**. Stays in new position.

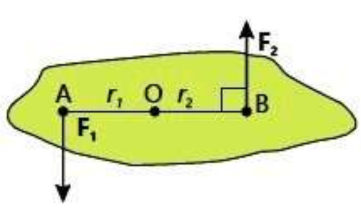
**** 39. Give an example of the body which is moving yet in equilibrium.**
A paratrooper falling at constant velocity is in **dynamic equilibrium** because:
(i) Gravitational force (down) = Air resistance (up)
$$\Rightarrow \sum F = 0$$
(ii) No acceleration because paratrooper is in **uniform motion**
(iii) Meets both equilibrium conditions

**** 40. What are two basic principles of stability physics which are applied in designing balancing toys and racing cars?**
The two basic principles of stability physics applied in designing balancing toys and racing cars are:
**(i)** Lowering the center of gravity
**(ii)** Widening the base area
These principles are implemented in:
**Racing cars:** Designed with low center of mass and wide wheelbase
**Balancing toys:** Configured with center of gravity below the pivot point

**** 41. How can you prove that the centripetal force always acts perpendicular to velocity?**
An object moves in a circular path with uniform speed only if a force is perpendicular to its velocity.

The direction of velocity is along the tangent at any point on the circle. The centripetal force is directed towards centre of circle perpendicular to velocity to keep the body in its circular path.

**** With the help of a diagram, show that the resultant force is zero but the resultant torque is not zero.**
Yes, it is possible the resultant force is zero but the resultant torque is not zero. They can occur when form do not lie along the same line and cause rotation.




For example, turning staring wheel of a motor car, we apply pair of equal forces in opposite direction the torque in this way couple.

**Unit 4 Turning Effects of Force**

**Important Formulas**

- **Resultant Force**
$$F = \sqrt{(F_x)^2 + (F_y)^2}$$
- **Angle**
$$\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$$
- **x-component of force**
$$F_x = F\cos\theta$$
- **y-component of force**
$$F_y = F\sin\theta$$
- **Torque**
$$\tau = r \times F$$
$$\tau = rF\sin\theta$$
- **1st Condition of Equilibrium** $\sum F = 0$
- **2nd Condition of Equilibrium** $\sum \tau = 0$
- **Principle of moments**
$$clockwise\ moments = Anti\ clockwise\ moments$$
- **Weight** $w = mg$

**4.1. A force of $200\ N$ is acting on a cart at an angle of $30^\circ$ with the horizontal direction. Find the x and y-components of the force.**

**Given Data**
$$Force = F = 200\ N$$
$$Angle = \theta = 30^\circ$$

**To Find**
$$x - component\ of\ force = F_x = ?$$
$$y - component\ of\ force = F_y = ?$$

**Solution**

By using formula of $F_x$
$$F_x = F\cos\theta$$
$$F_x = 200\cos 30^\circ$$
$$F_x = (200)(0.866)$$
$$\boldsymbol{F_x = 173.2\ N}$$

Now by using formula of $F_y$
$$F_y = F\sin\theta$$
$$F_y = F\sin\theta$$
$$F_y = 200\sin 30^\circ$$
$$F_y = (200)(0.5)$$
$$\boldsymbol{F_y = 100\ N}$$

**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?**

**Given Data**

$$Force\ applied = F = 300\ N$$
$$Distance\ from\ hinge = r = 1.2\ m$$

Force is applied perpendicularly, so $\theta = 90^{\circ}$

**To Find**

$$Torque = \tau = ?$$

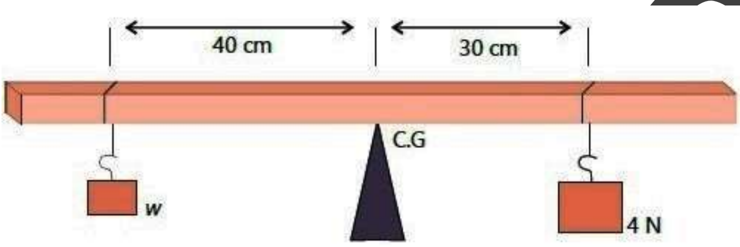
**Solution**

By using formula of torque, we have

$$\tau = rF\sin\theta$$
$$\tau = (1.2)(300)\sin 90^{\circ}$$
$$\tau = (1.2)(300)(1)$$
$$\boldsymbol{\tau = 360\ Nm}$$

Since the force turns the door counterclockwise, the torque 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.**




**Given Data**

$$Distance\ of\ unknown\ weight\ from\ C.G. = 40\ cm$$
$$= 40 \times 10^{-2}\ m$$
$$= 0.4\ m$$
$$Distance\ of\ 4\ N\ weight\ from\ C.G. = 30\ cm$$
$$= 30 \times 10^{-2}\ m$$
$$= 0.3\ m$$
$$Weight\ on\ right\ side = 4\ N$$

**To Find**

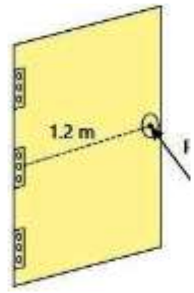
$$Unknown\ weight = w = ?$$

**Solution**

According to principle of moments,

$$clockwise\ moments\ = Anti\ clockwise\ moments$$
$$4 \times 0.3 = w \times 0.4$$
$$1.2 = 0.4w$$
$$\frac{1.2}{0.4} = w$$
$$3 = w$$
$$\boldsymbol{w = 3\ N}$$

**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 if the sea-saw is in equilibrium.**




**Given Data**

$$Mass\ of\ child\ A = m_A = 30\ N$$
$$Distance\ of\ child\ A\ from\ pivot = r_A = 2\ m$$
$$Mass\ of\ child\ B = m_B = 40\ kg$$
$$Distance\ of\ child\ B\ from\ pivot = r_B = 1.5\ m$$
$$Acceleration\ due\ to\ gravity = g = 10\ ms^{-2}$$

**To Find**

$$Total\ moment\ on\ each\ side = ?$$
$$Determine\ if\ the\ see-saw\ is\ in\ equilibrium = ?$$

**Solution**

By using formula of the moment (torque)

**Child A's Moment (Clockwise)**

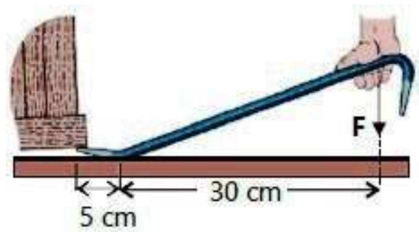
$$\tau_A = r_A \times F$$
$$\tau_A = r_A \times w$$
$$\tau_A = r_A mg \qquad \because w = mg$$
$$\tau_A = (2)(30)(10)$$
$$\boldsymbol{\tau_A = 600\ Nm}$$

**Child B's Moment (Anticlockwise)**

$$\tau_B = r_B \times F$$
$$\tau_B = r_B \times w$$
$$\tau_B = r_B mg \qquad \because w = mg$$
$$\tau_B = (1.5)(40)(10)$$
$$\boldsymbol{\tau_B = 600\ Nm}$$

Since both moments are **equal and opposite**, the **see-saw is in equilibrium**. $i.e\ \tau_A = \tau_B = 600\ Nm$

**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.**




**Given Data**

$$Downward\ force = F_1 = 250\ N$$
$$Distance\ from\ pivot\ to\ downward\ force = r_1$$
$$= 30\ cm$$
$$r_1 = 30 \times 10^{-2}\ m$$
$$r_1 = 0.3\ m$$
$$Distance\ of\ load\ from\ pivot\ = r_2 = 5\ cm$$

$$r_2 = 5 \times 10^{-2}\, m$$
$$r_2 = 0.05\, m$$

**To Find**

$$Weight\ bear\ at\ other\ end = F_2 = ?$$

**Solution**

According to principle of moments,

$$clockwise\ moments\ = Anti\ clockwise\ moments$$
$$r_1 \cdot F_1 = r_2 \cdot F_2$$
$$(0.3)(250) = (0.05)(F_2)$$
$$\frac{(0.3)(250)}{0.05} = F_2$$
$$15000 = F_2$$
$$\boldsymbol{F_2 = 15000\ N}$$

**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 given figure.**

**Given Data**

$$Length\ of\ spanner = r = 30\ cm$$
$$r = 30 \times 10^{-2}\ m$$
$$r = 0.3\ m$$
$$Torque = \tau = \ 150\ Nm$$

**To Find**

$$\text{Force} = F = ?$$

**Solution**

By using formula of torque, we have

$$\tau = rF$$
$$(150) = (0.3)(F)$$
$$\frac{150}{0.3} = F$$
$$500 = F$$
$$\boldsymbol{F = 500\ N}$$

**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 $60^\circ$ with the ceiling, as shown in the given figure. Determine the magnitude of $force\ F$ and $tension\ T$ in the string.**

**Given Data**

$$Weight\ of\ ball = w = 5\ N$$
$$Angle\ with\ ceiling = \theta = 60^\circ$$

**To Find**

$$Horizontal\ force = F = ?$$
$$Tension\ in\ string = T = ?$$

**Solution**

The tension $T$ in the rope has two components $i.e$

$$T_x = T\cos\theta$$
$$T_y = T\sin\theta$$

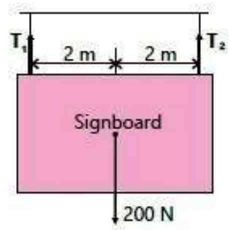
The upward force $T_y$ equals the ball's weight $w$ because it is in balance.

$$T_y = w$$
$$T\sin\theta = w$$
$$T\sin 60^\circ = 5$$
$$T = \frac{5}{\sin 60^\circ}$$
$$T = \frac{5}{0.866}$$
$$\boldsymbol{T = 5.8\ N}$$

The horizontal force $F$ is equal to the tension's horizontal part $T_x$

$$F = T_x$$
$$F = T\cos\theta$$
$$F = (5.8)\cos 60^\circ$$
$$F = (5.8)(0.5)$$
$$\boldsymbol{F = 2.9\ N}$$

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




**Given Data**

$$Weight\ of\ the\ board = w = 200\ N$$

**To Find**

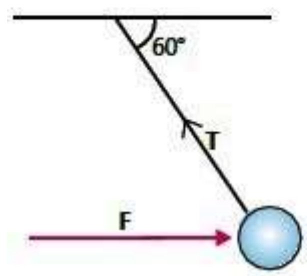
$$Tension\ in\ first\ string = T_1 = ?$$
$$Tension\ in\ second\ string = T_2 = ?$$

**Solution**

Since wires are symmetrically placed so tension in each string will be equal $i.e\ T = T_1 = T_2$

As signboard is in equilibrium. So

$$T = w$$
$$T_1 + T_2 = w$$
$$T + T = 200$$
$$2T = 200$$
$$T = \frac{200}{2}$$
$$T = 100\ N$$
$$\boldsymbol{T_1 = 100\ N}$$
$$\boldsymbol{T_2 = 100\ N}$$




**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?**

**Given Data**

$$Mass\ of\ first\ girl = m_1 = 30\ kg$$
$$Distance\ of\ first\ girl\ from\ axis = r_1 = 1.6\ m$$
$$Mass\ of\ second\ girl\ = m_2 = 40\ kg$$

**To Find**

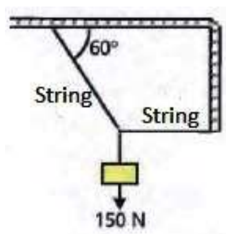
$$Distance\ of\ second\ girl\ from\ axis = r_2 = ?$$

**Solution**

According to principle of moments,

$$clockwise\ moments\ = Anti\ clockwise\ moments$$
$$r_1 \cdot F_1 = r_2 \cdot F_2$$
$$r_1 \cdot m_1 g = r_2 \cdot m_2 g$$
$$(1.6)(30)(10) = (r_2)(40)(10)$$
$$\frac{(1.6)(30)(10)}{(40)(10)} = r_2$$
$$1.2 = r_2$$
$$\boldsymbol{r_2 = 1.2\ m}$$

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



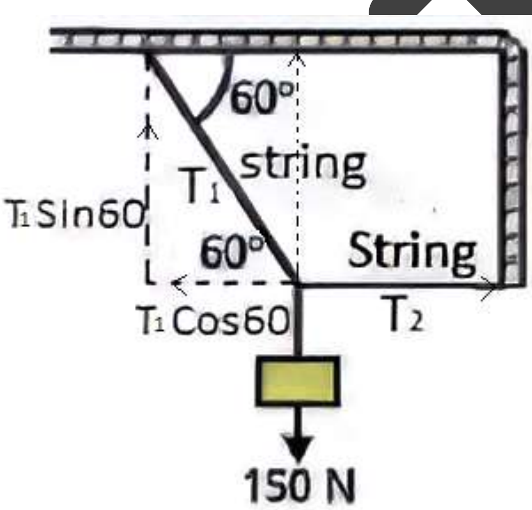

**Given Data**

$$Weight\ of\ block = w = 150\ N$$

**To Find**

$$Tension\ in\ first\ string = T_1 = ?$$
$$Tension\ in\ second\ string = T_2 = ?$$

**Solution**




As block is in equilibrium. So, the vertical component of $T_1$ balances the weight $w$

$$T_1 \sin\theta = w$$
$$T_1 \sin 60^\circ = 150$$
$$T_1 = \frac{150}{\sin 60^\circ}$$
$$T_1 = \frac{150}{0.866}$$
$$\boldsymbol{T_1 = 173.21\ N}$$

Now, the horizontal component of $T_1$ is balanced by $T_2$

$$T_1 \cos\theta = T_2$$
$$T_1 \cos 60^\circ = T_2$$
$$(173.21)\cos 60^\circ = T_2$$
$$(173.21)(0.5) = T_2$$
$$86.6 = T_2$$
$$\boldsymbol{T_2 = 86.6\ N}$$