CHAPTER

1

Force

Force may be defined as an external agency or cause (a push or a pull), which changes or tends to change the state of rest or of uniform motion or the direction of motion of a body.

In mathematical form, it is defined as the rate of change of linear momentum,

$$\text{Force, } F \propto \frac{\text{Change in momentum}}{\text{Time}}$$

$$F \propto \frac{p_1 - p_2}{t} \Rightarrow F \propto \frac{m(v-u)}{t} \Rightarrow F \propto ma \qquad \left[\because \frac{v-u}{t} = a\right]$$

$$\therefore \quad F = kma$$

The quantity k is a constant of proportionality. One unit of force is defined as the amount that produce an acceleration of 1 m/s^2 on an object of 1 kg-mass.

i.e. 1 unit of force $= k \times 1\,\text{kg} \times 1\,\text{m/s}^2 \Rightarrow k = 1$

Thus, the force can be written as $\boxed{F = ma}$

SI unit is newton (N) or kilogram-force (kgf), where 1 kgf $= g$N. If g is the acceleration due to gravity $= 9.8\ \text{ms}^{-2}$.

A force applied on an object can produce four types of effects such as

(i) Force can start a stationary object and can stop a moving object.
(ii) Force can change speed of a moving object making it to move slower or faster.
(iii) Force can change the direction of motion of an object.
(iv) Force can change the shape of an object.

Rigid Body

Every material object is made up of a large number of particles. A rigid body is one whose size and shape remains the same whatever force be applied to different parts of it.

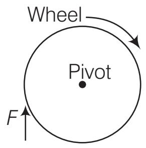
A rigid body has two types of motion

(i) **Translational Motion** When a force is applied on a stationary rigid body, the body starts moving in a straight path in the direction of applied force, this type of motion is called translational motion.

e.g., On pushing a ball lying on a floor it starts moving.

Chapter Objectives

(ii) **Rotational Motion** When a force is applied on fixed point of a body which is pivoted at a point, then body starts rotating about that point. This is called a rotational motion. e.g., If a wheel is pivoted at its centre and a force is applied tangentially on its rim as shown in figure, the wheel rotates about its centre.



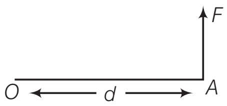
Rotational motion of a wheel

Turning Force

A force which provides rotational effect is called **turning force**. e.g., To open or close a door, we apply a normal force on the handle of the door. A door is a rigid body, which can rotates about a fixed vertical axis passing through the hinges.

Torque or Moment of a Force

The turning effect produced by a force on a rigid body fixed about a point (pivot or fulcrum) is called **moment of a force** or **torque.** Torque is equal to the product of the magnitude of the force and the perpendicular distance of the line of action of force from the axis of rotation. It is represented by τ.



i.e., Torque (moment of force)

= Force × Perpendicular distance of line of action of force from axis of rotation

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

where, d is the perpendicular distance of line of action of force from the axis of rotation (O).

It is a vector quantity. Its SI unit is newton-metre (N-m) and CGS unit is dyne-cm.

But, if force is measured in gravitational unit, then the unit of moment of force in SI system is kgf × m and in CGS system, the unit is gf × cm.

These units are related as follows

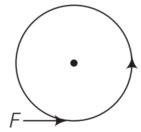
$$1\ \text{N-m} = 10^7\ \text{dyne-cm}$$

$$1\ \text{kgf} \times \text{m} = 9.8\ \text{N-m}$$

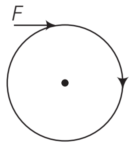
$$1\ \text{gf} \times \text{cm} = 980\ \text{dyne-cm}$$

Note
- The torque acting on a body is zero, if F = 0 or d = 0. It may be remembered that internal forces acting on the body do not contribute anything to the torque.
- Torque is maximum when the force is perpendicular to the axis of rotation but the two do not intersect.

Clockwise and Anti-clockwise Moments



Anti-clockwise (positive)



Clockwise (negative)

The direction of turning (sense of rotation) produced on the body depends on the point of application of force and the direction of force. If the turning effect on the body is anti-clockwise or positive, then the moment of force is called anti-clockwise moment.

On the other hand, if the turning effect on the body is clockwise or negative, then the moment of force is called clockwise moment.

Common Examples of Moment of Force

Some common examples of moment of force are given as below

(i) It is easier to open the door by applying force near the outer edge, away from the hinges or axis of rotation.

(ii) For turning a steering wheel, a force is applied tangentially on the rim of the wheel.

(iii) In a bicycle, the toothed wheel is rotated by applying less force on the foot pedal which is at a large distance from the axle of rear wheel.

Example 1. **A body is pivoted at a point. A force of 20 N is applied at a distance of 20 cm from the pivot. Find the moment of force about the pivot.**

Sol. Given, $F = 20$ N, $d = 20\,\text{cm} = 0.2\,\text{m}$

$\therefore$ Moment of force $= F \times d = 20 \times 0.2 = 4\,\text{N-m}$

Example 2. **The moment of a force of 10 N about a point X is 4 N-m. Find the distance of point of application of the force from the point X.**

Sol. Given, moment of force = 4 N-m, $F = 10$ N

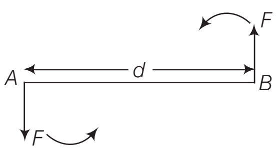
If the distance of point of application of force from the point X is d metre, then

moment of force = force × distance

$$4 = 10d \Rightarrow d = \frac{4}{10} = \frac{2}{5} = 0.4\,\text{m}$$

Moment of Couple

The pair of equal and opposite forces acting along parallel lines (not on the same line) forms a couple and the moment of couple is defined as the product of either force and the perpendicular distance between the lines of action of forces (or couple arm).



Moment of couple

i.e., Moment of couple

= Either force × Perpendicular distance between the line of action of forces

$= F \times d$

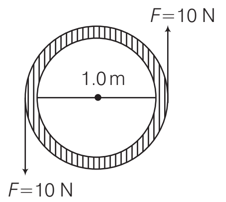
A couple always produces a rotational motion in a rigid body. Its SI unit is also newton-metre (N-m).

Some common examples of moment of couple are

(i) opening a tap
(ii) tightening a screw with a screw driver
(iii) steering of a four wheeler.

Example 3. **A steering wheel of diameter 1 m is rotated anti-clockwise by applying forces each of magnitude 10 N. Draw a diagram to show the application of forces and calculate the moment of the couple applied.**

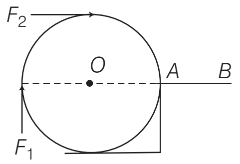
Sol. As the rotation is anti-clockwise, the moments must be anti-clockwise. The direction of the two forces will be as shown in figure. The two forces are forming a couple whose moments are



= One of the force × Arm of the couple

$= 10 \times 1.0 = 10\text{N-m}$

Example 4. **In figure, a roller of diameter 0.2 m is raised on the pavement *AB* by the forces F_1 and F_2 each of magnitude 20 N. Compare the torques produced by the two forces.**



Sol. Given, $F_1 = F_2 = 20\,\text{N}$

Perpendicular distance of point of rotation *A* from the force F_1 is $d_1 = 0.2\text{m}$

while that of force F_2 is $d_2 = \frac{1}{2} \times 0.2\text{m} = 0.1\text{ m}$

$$\therefore \frac{\text{Torque produced by force } F_1}{\text{Torque produced by force } F_2} = \frac{F_1 \times d_1}{F_2 \times d_2} = \frac{20 \times 0.2}{20 \times 0.1} = \frac{2}{1}$$

Equilibrium of an Object

An object is said to be in equilibrium, if a number of forces acting on it produce no change in its state of rest or of uniform motion. Its motion may be rotational or translational.

Types of Equilibrium

There are three types of equilibrium as given below

(i) **Static Equilibrium** A body is said to be in static (or stable) equilibrium, if it has a tendency to return to its original position, after being slightly disturbed from its equilibrium position.
e.g., We consider the beam balance, if the beam is balanced in the horizontal position, the clockwise moment is balanced by anti-clockwise moment and beam has no rotational motion. After disturbing from this balance, the beam will regain its position and hence beam is said to be in static or stable equilibrium.

(ii) **Dynamic Equilibrium** A body is said to be in dynamic (unstable) equilibrium, if it has no tendency to come to its original position after being disturbed from its equilibrium position.
e.g., When a body provided once in motion, then it moves on a smooth surface with a constant velocity and zero acceleration and hence the body is said to be in dynamic or unstable equilibrium.

(iii) **Neutral Equilibrium** A body is said to be in neutral equilibrium, if on being disturbed from its initial position, it stays in equilibrium in new position also.
e.g., When a cone lying on a horizontal surface along a slant height, then it is said that the cone is disturbed from its equilibrium position and it will acquire the equilibrium whenever it is released.

Conditions for Equilibrium

From the above types of equilibrium, we find that the following two conditions must be satisfied for a body to be in equilibrium.

(i) Vector sum of the forces acting on the body should be zero for translational equilibrium.
i.e., $\Sigma \mathbf{F}_i = 0$

(ii) Vector sum of moment of forces acting on the body should be zero for rotational equilibrium.
i.e., $\Sigma \tau_i = 0$

Principle of Moment

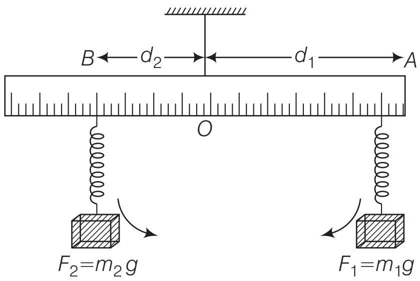
According to the principle of moment in equilibrium, if different forces act on a body capable to rotate about an axis, but no rotation takes place, then algebraic sum of moments of all the forces is zero.

Sum of the anti-clockwise moments
= Sum of the clockwise moments

Note The clockwise torques are taken negative and anti-clockwise torques are taken positive.

Verification of the Principle of Moments

Let us consider a meter rule suspended horizontally from a rigid support by a strong inextensible thread at O. Now, suspend some slotted weights, say $m_1 g$ and $m_2 g$ by two spring balances A and B on either side of the thread, so the meter rule may tilt to one side.



Verification of principle of moments

Now, adjust either the slotted weights on the spring balance or the position of the spring balance on either side of thread in such a way that the meter rule again becomes horizontal.

Let d_1 = distance of weight $m_1 g$ on RHS from O

d_2 = distance of weight $m_2 g$ on LHS from O

$m_1 g \times l_1$ = clockwise moment of first weight about the point O

and $m_2 g \times l_2$ = anti-clockwise moment of second weight about the point O.

Here, first weight tend to turn the meter rule clockwise, while the second weight turn the meter rule anti-clockwise.

In equilibrium, when the meter rule is horizontal, it is found that $m_1 g \times d_1 = m_2 g \times d_2$

or $$f_1 d_1 = f_2 d_2 \quad \left(\begin{array}{l} \because \; f_1 = m_1 g \\ \text{and } f_2 = m_2 g \end{array}\right)$$

i.e., clockwise moment = anti-clockwise moment

This verifies the principle of moments.

Similarly, **in case of fulcrum** (i.e., level system)

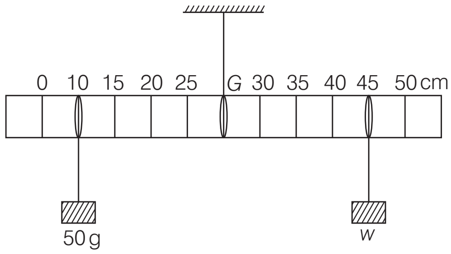
load × load arm = effort × effort arm

i.e., $$f_1 d_2 = f_2 d_2$$

This is called principle of moment of a lever.

Example 5. **A half meter ruler is suspended by a thread from the mid-point of the ruler as shown in the figure. It balances horizontally when a 50 g and an unknown weight was suspended respectively, from 10 cm and the 45 cm mark.**

Calculate the magnitude of weight w.



Sol. Since, the ruler is in equilibrium.

∴ According to the principle of moments,

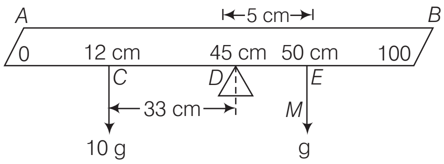
clockwise moment = anti-clockwise moment

$$w \times 20 \text{ cm} = 50 \text{ gf} \times 15 \text{ cm}$$

$$w = \frac{50 \text{gf} \times 15 \text{ cm}}{20 \text{ cm}} = 37.5 \text{ gf}$$

Example 6. **A meter scale is balanced on a knife-edge at its centre. 10 g weight is put one on top of the other at the 12 cm mark, the scale is found to be balanced at 45.0 cm. What is the mass of the meter scale?**

Sol. Let total mass of the meter scale be Mg.



Distance between mid-point E and new centre of gravity (DE)

$$= 50 - 45 = 5 \text{ cm}$$

Distance between 12 cm mark and new centre of gravity (CD),

$$= 45 - 12 = 33 \text{ cm}$$

From principle of moments in equilibrium,

$$Mg \times DE = 10 \times CD$$

$$M \times 5 = 10 \times 33$$

or $$M = 66 \text{ g}$$

∴ Mass of the meter scale is 66 g.

CHECK POINT 01

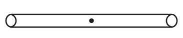
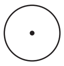
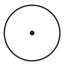
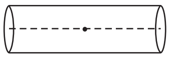
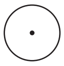
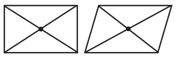
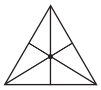
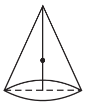
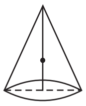
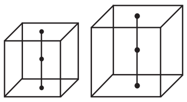
1. What is the basic difference between pure translational motion and pure rotational motion?
2. A door is hinged at one end and is free to rotate about a vertical axis. Does its weight cause any torque about its axis? Give reason for your answer.
3. The stone of a hand flour grinder is provided with a handle near its rim. Give reason.
4. A faulty balance with unequal arms has its beam horizontal. Are the weights of the two pans equal?
5. What is the principle of moment?

Centre of Gravity

Centre of gravity of a rigid body is the point at which its whole weight can be supposed to act. Its position depends upon the distribution of mass of the body. It may be inside or outside the body. If the body is of symmetrical shape whose weight is distributed uniformly, then the centre of gravity of the body lies at its geometrical centre.

e.g., The centre of gravity of a uniform straight wire is at its mid-point. But, if this wire is bent into the form of a circle, then its centre of gravity will be at the centre of circle.

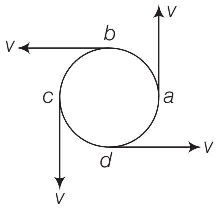
The following table shows the position of centre of gravity of different objects

Object	Figure of the Object	Centre of Gravity
Uniform rod		Mid-point of rod
Circular disc		Geometric centre
Sphere (solid or hollow)		Geometric centre of the sphere
Cylinder		Mid-point on the axis of the cylinder
Circular ring		Centre of the ring
Rectangle parallelogram		The point of intersection of the diagonals
Triangular lamina		The point of intersection of medians (centroid)
Hollow cone		At a height $\left(\frac{h}{3}\right)$ from the base on its axis
Solid cone		At a height $\left(\frac{h}{4}\right)$ from the base on its axis
Cube/Cuboid		At the point of intersection of diagonals

Note Centre of gravity is the point about which the algebraic sum of moment of weights of constituent particles of the body is zero. For the stable equilibrium of a body, its centre of gravity must be as low as possible and it must be above the base and near the geometric centre of the body.

Uniform Circular Motion

When a body moves with a constant speed in a circular path, then its motion is known as **uniform circular motion**. However, the direction of motion of the body changes at every point of the circular path. Due to this continuous change in direction of motion, the velocity is no longer uniform because it direction changes continuously (only magnitude remains same) i.e. the motion is an accelerated motion.

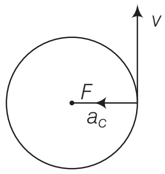


Speed in a circular path

Centripetal Force

The force which keeps a body moving with a uniform speed along a circular path and directed along the radius towards the centre is called centripetal force.

The magnitude of the centripetal force on an object of mass m moving at tangential speed v along a path with radius of curvature r is given by

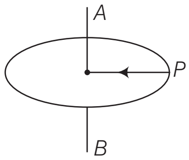


Centripetal force

$$F = ma_c = \frac{mv^2}{r}$$

where, a_c is centripetal acceleration.

The torque of the centripetal force about the axis of rotation AB is zero as it intersects the axis.



Torque of the centripetal force

Centrifugal Force

It is the apparent force that draws a rotating body away from the centre of rotation. It is caused by the inertia of the body as the body's path is continually redirected.

The centrifugal force is in the opposite direction to the direction of centripetal force, but it is not the force of reaction of centripetal force.

CHECK POINT 02

1. Can it be possible that the centre of gravity be situated outside the material of the body?
2. Why is the motion of a circulating fan non-uniform?
3. Draw a neat diagram for a particle moving in a circular path with a constant speed and show the direction of velocity at any instant.
4. Is it possible to have an accelerated motion with a constant speed? Explain.
5. Is centrifugal force, the force of reaction of centripetal force?

SUMMARY

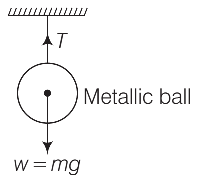
- A push or pull which changes the state of rest or of uniform motion or the direction of motion of a body is called force.
- A force that can rotate an object is called turning force.
- A rigid body is the one whose size and shape remains same whatever force be applied to different parts of it.
- Torque or moment of force is given by
  torque (τ) = force (F) $\times$ perpendicular distance (d)
- Torque is a vector quantity and its SI unit is newton-metre (N-m).
- A pair of equal and opposite forces acting on an object is called couple.
  Moment of couple = Either force $\times$ Perpendicular distance between the forces
- Principle of moment is given by
  sum of anti-clockwise moment = sum of clockwise moment
- Centre of gravity of a body is the point at which the algebraic sum of moments of weights of all the particles of the body is zero.
- When a body moves with a constant speed in a circular path, then its motion is known as uniform circular motion.
- The force that maintains the uniform circular motion of an object is called centripetal force and it is directed towards the centre of the circle.
- The apparent force that draws a rotating body away from the centre of rotation is called centrifugal force. It is a pseudo force.

EXAM PRACTICE

a 2 Marks Questions

1. A metallic ball is hanging by a string from a fixed support. Draw a neat labelled diagram showing the forces acting on the ball and the string. ***[2014]***

Sol.



where, T is tension in the string and w is weight of the ball, $T = mg$ or $T = w$ ***[2]***

2. (i) Define one newton.

(ii) Write the relation between SI unit and CGS unit of force.

Sol. (i) One newton is the amount of force required to produce an acceleration of 1 m/s^2 in a body of mass 1 kg. ***[1]***

(ii) *The relation between SI unit and CGS unit of force is*

$$1N = kg \times 1\,m/s^2 = 10^3\,g \times 10^3\ cm/s^2$$

$$(\because 1\ kg = 10^3\ g, 1\,m = 10^2 cm)$$

$\therefore\ 1N = 10^5$ dyne ***[1]***

3. (i) Define 1 kgf.

(ii) How is it related to the SI unit of force?

Sol. (i) 1 kgf is the force with which the earth pulls an object of mass 1 kg towards itself. ***[1]***

(ii) It is related by, 1 kgf $= mg = 9.8$ N

$(\because m = 1\,kg,\ g = 9.8\ m/s^2)$ ***[1]***

4. A force is applied on

(i) a rigid body and

(ii) a non-rigid body.

How does the effect of the force differ in the above two cases? ***[2014]***

Sol. When a force applied on a rigid body does not change the inter-spacing between its constituent particles and therefore it does not change the dimensions of the object, but causes motion in it. ***[1]***

On the other hand, when a force applied on a non-rigid body, it changes the inter-spacing between its constituent particles and therefore causes a change in its dimensions. ***[1]***

5. Give any two effects of a force on a non-rigid body. ***[2013]***

Sol. *The two main effects of a force on a non-rigid body are*

(i) It can change the state of rest or of motion of the body.

(ii) It can change the size or shape of the body. ***[1+1]***

6. In which condition, the following are produced by a force?

(i) Translational motion

(ii) Rotational motion

Sol. *The conditions are as follows*

(i) **For Translational Motion** When the body is free to move in a straight path. ***[1]***

(ii) **For Rotational Motion** When the body is pivoted at a point. ***[1]***

7. (i) Give one example of pure rotational motion.

(ii) Comment on the movement of particles on the axis of rotation in pure rotational motion.

Sol. (i) Rotation of a potter's wheel. ***[1]***

(ii) The particles on the axis of rotation are stationary in pure rotational motion. ***[1]***

8. (i) What is meant by the term moment of force?

(ii) If the moment of force is assigned a negative sign, then will the turning tendency of the force be clockwise or anti-clockwise? ***[2012]***

Sol. (i) The turning effect produced by a force on a rigid body about a point, pivot or fulcrum is called the moment of force. ***[1]***

(ii) If moment of the force is negative, then turning tendency of the force is clockwise. ***[1]***

9. What do you mean by the terms

(i) Static equilibrium and

(ii) Dynamic equilibrium?

Sol. Refer to theory (Page 3).

10. Where does the position of centre of gravity lie for

(i) a circular lamina?

(ii) a triangular lamina?

Sol. (i) The position of centre of gravity for a circular lamina lie at the centre of the circle. ***[1]***

(ii) The position of centre of gravity for a triangular lamina is lie at the centroid or the point of intersection of the medians. ***[1]***

11. (i) On what factor does the position of the centre of gravity of a body depend?

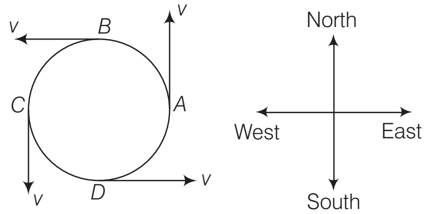
(ii) What is the SI unit of the moment of force?

Sol. (i) The position of centre of gravity of a body depends upon the shape and size of the body. ***[1]***

(ii) The SI unit of moment of force or torque is N-m, i.e., newton-metre. ***[1]***

12. Draw a neat labelled diagram for a particle moving in a circular path with a constant speed. In your diagram, show the direction of velocity at any instant.

Sol. *The labelled diagram for a particle moving in a circular path is shown as below*



Constant speed in circular path ***[2]***

13. Read each statement carefully and state with reasons, if it is true or false.

(i) For a body moving in a circular path with a constant speed, the acceleration is centripetal in nature.

(ii) The net acceleration of a particle in circular motion is always along the radius of the circle towards the centre.

Sol. (i) True, for a body moving in a circular path, the direction of acceleration is perpendicular to the direction of motion at every point. Its acts along the radius of the circle and is directed towards the centre. ***[1]***

(ii) False, because the net acceleration is directed towards the centre only in case of uniform circular motion. ***[1]***

14. (i) For a particle in uniform circular motion, what is the direction of its velocity at any point in its path?

(ii) A stone tied at the end of string is whirled in a circle. If the string breaks, then the stone flies away tangentially. Why?

Sol. (i) Along the tangent to the circle at that point. ***[1]***

(ii) When a stone is going around a circular path, then the instantaneous velocity of stone is along the tangent to the circle.

When the string breaks, then the centripetal force stops to act. Due to inertia, the stone continues to move along the tangent to circular path. So, the stone flies off tangentially to the circular path. ***[1]***

15. (i) Explain the motion of a planet around the sun in a circular path. ***[2015]***

(ii) What is the nature of centripetal force on the planet?

Sol. (i) A planet moves around the sun in a circular path for which the force of attraction on planet by the sun provides the necessary centripetal force. ***[1]***

(ii) The centripetal force on the planet is gravitational which is attractive in nature. ***[1]***

16. Explain the fictitious force and also explain how does it play an important role in a uniform circular motion?

Sol. A force which is not real is called fictitious force. ***[1]***

Centrifugal force is a fictitious force. It is the apparent force that draws a rotating body away from the centre of rotation. ***[1]***

17. Write the differences between centripetal and centrifugal force.

Sol. *Differences between centripetal force and centrifugal force are*

Centripetal Force	Centrifugal Force
A force which acts on an object towards the centre of a circle to produce centripetal acceleration, so that the object moves in a circle is known as centripetal force.	A force which does not act on the object moving in the circle but it is equal and opposite force to centripetal force called centrifugal force.
It is a real force.	It is a fictitious force.

[2]

b 3 Marks Questions

18. What do you meant by clockwise and anti-clockwise moments of force. Explain with the diagram.

Sol. Refer to theory (Page 2).

19. (i) Why does a rope walker hold a long pole in his hands?

(ii) The passengers in a boat are not allowed to stand while crossing a river. Why?

(iii) The screw drivers have long handles. Why?

Sol. (i) The rope walker holds a long pole in his hands to adjust the centre of gravity. When he feels that he is falling towards right, he shifts the pole towards left so that his centre of gravity is not disturbed and he can balance himself. ***[1]***

(ii) This is because, if the passengers stand, then the centre of gravity of the boat is raised. This may cause the boat to overturn as well as producing imbalance. ***[1]***

(iii) Torque = Force × Perpendicular distance = $F \times d$.

If the handle is long, the value is d is more, hence more torque is produced. ***[1]***

20. Explain the following

(i) You always keep your feet wide apart when receiving the charge from an opponent at football.

(ii) It is easier to knock over a person who is standing on one foot than one who is standing on two.

(iii) Why do the wine glasses have a heavy and broad base?

Sol. (i) While receiving the charge from an opponent at football, we keep our feet wide apart to adjust the centre of gravity as low as possible to maintain ourselves in stable equilibrium. Thus, on hitting we do not fall. Similarly, players do the same while playing cock-fighting. ***[1]***

(ii) It is easier to knock over a person who is standing on one foot than one who is standing on both because the person standing on one foot has a smaller base area than the person standing on both the feet. Thus, the person standing on one foot is in a less stable equilibrium and can easily knocked down. ***[1]***

(iii) Wine glass has a broad and heavy base because heavy base lowers its centre of gravity and broad base will adjust the line joining the centre of gravity and centre of the earth fall within the base and keep the glass in stable equilibrium.

Due to similar reason, base of bunsen burner, table lamp, flask and bottle, etc., have a heavy and broad base. ***[1]***

21. (i) Where is the centre of gravity of a uniform ring situated?

(ii) "The position of the centre of gravity of a body remains unchanged even when the body is deformed". State whether the statement is true or false.

Sol. (i) The centre of gravity of a uniform ring is situated at the centre of ring which is not part of the body. i.e., it is outside the body. ***[1½]***

(ii) The statement is false, because it changes its position when the body is deformed. ***[1½]***

22. A very small stone is placed near the periphery of a circular disc which is rotating about an axis passing through its centre.

(i) What will be your observation when you are standing outside the disc? Explain.

(ii) What will be your observation when you are standing at the centre of the disc? Explain.

Sol. (i) When we stand outside the circular disc which is rotating on its axis, then the stone seems to move in a circular path. ***[1½]***

(ii) When we are standing at the centre of disc, then it seems that the stone is moving away from us and falls down. ***[1½]***

C 4 Marks Questions

23. Explain briefly, how can you verify the principle of moment?

Sol. Refer to theory (Page 4).

24. Explain the moment of a force with diagram and formula for

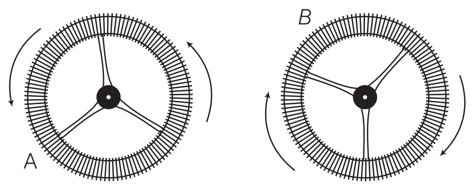
(i) the steering wheel of a car

(ii) the pedal and the rear wheel of a bicycle.

Sol. For turning a steering wheel, a force is applied tangentially on rim of the wheel.

The sense of rotation of wheel is changed by changing the point of application of force without changing the direction of force.

In Fig. (a), when force F is applied at the point A of the wheel, the wheel rotates anti-clockwise; while in Fig. (b), the wheel rotates clockwise when the force F in same direction is applied at the point B of the wheel.

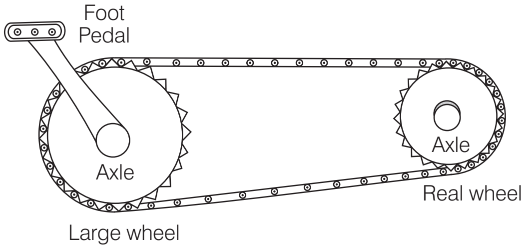


(a) Anti-clockwise rotation (b) Clockwise rotation

[2]

In the case of a bicycle wheel, a small force is applied at the pedal which is at large distance from the axle. Since, in one revolution, the pedal moves through a large distance than the links of the chain. Thus, the applied force gets multiplied and is passed on the rear wheel.

The two pedals provide two such forces and form a torque i.e., moment of force which rotates the wheel.



[2]

25. Draw sketch diagram and indicate the position of the centre of gravity of

(i) sphere (solid or hollow)
(ii) triangular lamina
(iii) parallelogram
(iv) cylinder

Sol. Refer to table (Page 5).

26. (i) Centre of gravity of a body on the earth coincides with its centre of mass for a small object and for a large object, it may not. What is qualitative meaning of small and large in this regard.
For which of the following two of them coincides, a building, a pond, a lake, a mountain.

(ii) The bottom of a ship is made heavy. Why?

Sol. (i) Centre of mass and centre of gravity are two different concepts. But, if g does not vary from one part of body to other than CG and CM will coincides.
So, when vertical height of the object is very small compared to radius of earth, we call object small, otherwise we call it extended.
In above context, building and pond are small objects and a deep lake and a mountain are large extended objects. *[2]*

(ii) The bottom of a ship is made heavy, so that its centre of gravity remains low. This ensures the stability of its equilibrium. *[2]*

27. (i) Which of the following remains constant in a uniform circular motion, speed or velocity or both?

(ii) Name the force required for a uniform circular motion. State its direction.

(iii) Explain the motion of a planet around the sun in a circular path.

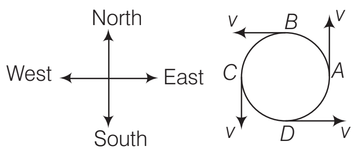
Sol. (i) Speed remains constant in a uniform circular motion. *[1]*

(ii) Centripetal force is required for a uniform circular motion. Centripetal force is always directed towards the centre. *[1]*

(iii) For a planet moving around the sun in a circular path, the gravitational force of attraction between the planet and the sun provides the necessary centripetal force. *[2]*

28. A uniform circular motion is an accelerated motion, explain using diagram.

Sol. A particle is moving in a circular path with uniform speed x in the anti-clockwise direction. The particle travels in each quarter path of the circle AB, BC, CD and DA in same time interval $t = \frac{T}{4}$. Thus, speed of the particle is constant. But the direction of motion of the particle is different at different points on the circular path. *[2]*



Velocity at point A is in North direction, at point B it is in West direction, at C it is in South direction and at point D it is in East direction. As velocity is changing at each point, hence the motion is said to be accelerated. *[2]*

Numerical Based Questions

29. A body of mass 1.5 kg is dropped from second floor of a building which is at a height of 12 m. What is the force acting on it during its fall? (Take, $g = 9.8\ m/s^2$)

Sol. Given, mass, $m = 1.5$ kg, height, $h = 12$ m

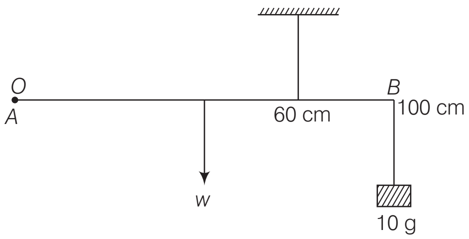
$\therefore$ Force acting on the body during its fall

$$= mg = 1.5 \times 9.8 = 14.7\ N$$

[2]

30. A uniform meter scale rests horizontally with a hard massless string at the 60 cm mark when a mass of 10 g is suspended from one end. From which end this mass be suspended? What is the mass of the meter scale?

Sol. It is clear from the figure, the weight w of the meter scale acts at the 50 cm mark. The mass of 10 g must be suspended from the other end i.e., from B. *[1]*



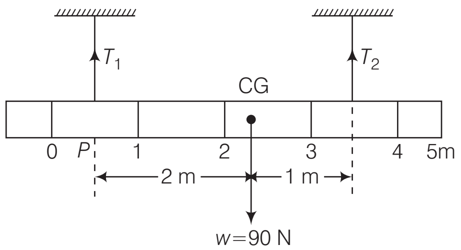
Since, the meter scale is in equilibrium.

$\therefore$ According to the principle of moment,

$$w \times (60-50) = 10 \times (100-60)$$
$$w \times 10 = 10 \times 40$$
$$w = 40 \text{ g}$$ **[1]**

31. A uniform metal rod of 5m in length and weight 90 N is suspended horizontally by two vertical wires attached at 50 cm and 3.5 m respectively, from one end of the rod. Find the tension in each wire.

Sol. Let tension in the wires be T_1 and T_2. As the rod is uniform its weight act as the centre of gravity of the rod i.e., at 25 m from one end. **[1]**



[1]

Now, according to the principle of moment,

sum of upward forces = sum of downward forces

i.e., $$T_1 + T_2 = 90 \text{ N} \quad \ldots\text{(i)}$$

Taking moment about Q_1,

clockwise moment = anti-clockwise moment

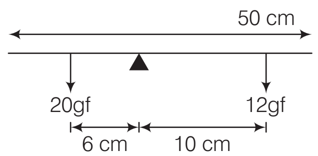
$$T_1 \times 2 \text{ m} = T_2 \times 1 \text{ m} \quad \ldots\text{(ii)}$$ **[1]**

On solving Eqs. (i) and (ii), we get

$$T_1 = 30 \text{ N}$$

and $$T_2 = 60 \text{ N}$$ **[1]**

32. A half- metre rod is pivoted at the centre with two weights of 20 gf and 12 gf suspended at a perpendicular distance of 6 cm and 10 cm from the pivot respectively as shown below.



(i) Which of the two forces acting on the rigid rod causes clockwise moment?

(ii) Is the rod in equilibrium?

(iii) The direction of 20 kgf force is reversed. What is the magnitude of the resultant moment of the forces on the rod? ***[2018]***

Sol. (i) Force due to 12 gf the rigid rod causes clockwise movement. **[1]**

(ii) Clockwise movement $= 12 \text{ gf} \times 10 \text{ cm}$
$= 120 \text{ gf cm}$

Anti-clockwise movement $= 20 \text{ gf} \times 6 \text{cm}$
$= 120 \text{ gf cm}$

$\therefore$ Clockwise movement = Anti-clockwise movement

Hence, the rod is in equilibrium. **[1]**

(iii) According to question, the direction of 20 gf force is reversed. Hence, the total thing will be move in clockwise direction.

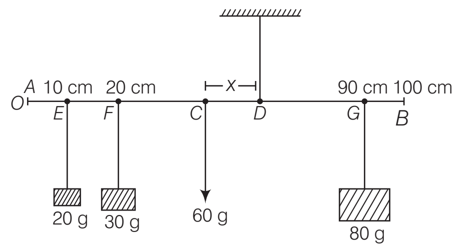
$\therefore$ Clockwise movement
= Resultant movement of force

Resultant movement of force

$= (12 \times 10) + (20 \times 6) = 120 + 120 = 240$ gf cm **[1]**

33. A uniform meter scale of mass 60 g, carrier masses of 20 g, 30 g and 80 g from points 10 cm, 20 cm and 90 cm marks. Where must be the scale hanged with string to balance the scale.

Sol. Let D is the position of tied hanged string, so that the meter scale and various masses are balanced.



Since, the meter scale is balanced.

$\therefore$ Sum of the clockwise moments must be equal to the sum of anti-clockwise moments. **[1]**

Taking moments about D, we get

$$80 \times GD = 20 \times ED + 30 \times FD + 60 \times CD$$

or $$80 \times (40 - x) = 20 \times (40 + x) + 30 \times (30 + x)$$

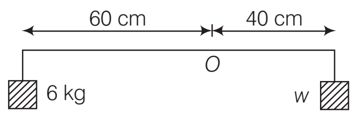
$$\Rightarrow \quad 3200 - 80x = 800 + 20x + 900 + 30x + 60x$$

$$\Rightarrow \quad 1500 = 190x$$

$$\Rightarrow \quad x = \frac{1500}{190} = 7.9 \text{ cm}$$ **[2]**

Hence, the string must be tied at $50 + 7.9 = 57.9$ cm to maintain balance of meter scale. **[1]**

34. A meter scale is balanced in horizontal position as shown in figure given below. Find the value of w.



Sol. Given, load, $F_1 = 6$ kg

Load arm, $d_1 = 60$ cm

Effort, $F_2 = w$

Effort arm, $d_2 = 40$ cm **[1]**

According to the principle of moments in equilibrium,

$$F_1 d_1 = F_2 d_2$$

$$\Rightarrow \quad 6 \times 60 = w \times 40 \Rightarrow w = \frac{6 \times 60}{40} = 9 \text{ kg}$$ **[1]**

35. A man can open a nut by applying a force of 150 N by using a lever handle of length 0.4 m. What should be the length of the handle, if he is able to open it by applying a force of 60 N?

Sol. Given, load, $F_1 = 150$ N, load arm, $d_1 = 0.4$ m

Effort, $F_2 = 60$ N, effort arm, $d_2 = ?$

By principle of moments,

$$F_1 \times d_1 = F_2 \times d_2$$ **[1]**

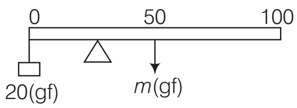
$$\Rightarrow \quad d_2 = \frac{F_1 \times d_1}{F_2} = \frac{150 \times 0.4}{60} = 1 \text{ m}$$ **[1]**

36. A uniform half meter rule balances horizontally on a knife-edge at 29 cm mark when a weight of 20 gf is suspended from one end.

(i) Draw a diagram of the arrangement.

(ii) What is the weight of the half meter rule? **(2017)**

Sol. (i) *Diagram of the arrangement is shown below*



[1½]

(ii) $20(29 - 0) = m(50 - 29)$ ($\because$ principle of moments)

$$\Rightarrow \quad m = 27.6 \text{ gf}$$ **[1½]**

37. A boy of mass 30 kg is sitting at a distance of 2 m from the middle of a see-saw. Where should a boy of mass 40 kg sit, so as to balance the see-saw? **[2012]**

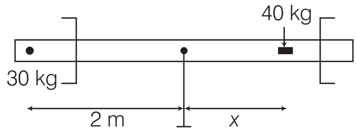
Sol. Let the distance of boy of mass 40 kg from the mean position be x metre. Using principle of moments,

load $\times$ load arm = effort $\times$ effort arm **[1]**

$$30 \times 2 = 40 \times x$$

$$\Rightarrow \quad x = 1.5 \text{ m}$$

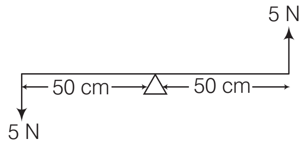
So, the boy of mass 40 kg should sit at a distance 1.5 m from the middle of see-saw



[1]

38. Two forces each of 5 N act vertically upwards and downwards, respectively. On the two ends of a uniform meter rule which is placed at its mid-point as shown in the diagram.

Determine the magnitude of the resultant moment of these forces about the mid-point.



Sol. Given, forces, $F_1 = F_2 = 5$ N **[1]**

Distances, $d_1 = d_2 = 50$ cm $= 0.5$ m

Resultant moment = torque, $\tau = ?$ **[1]**

$\therefore \quad \tau_1 = F_1 \times d_1 = 5 \times 0.5 = 2.5$ N-m

and $\quad \tau_2 = F_2 \times d_2 = 5 \times 0.5 = 2.5$ N-m

$\therefore$ Resultant moment,

$$\tau = \tau_1 + \tau_2 = 2.5 + 2.5 = 5 \text{ N-m}$$ **[1]**

39. Figure shows a uniform meter rule weighing 100 gf pivoted at its centre O. Two weights 150 gf and 250 gf hang from the meter rod as shown in the figure.

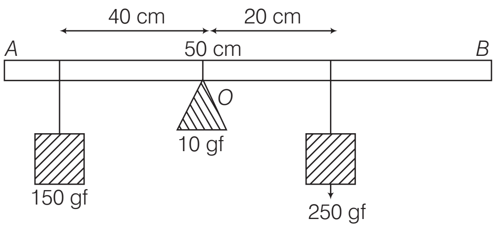
Calculate

(i) the total anti-clockwise moments about O.

(ii) the total clockwise moments about O.

(iii) the difference of anti-clockwise and clockwise moments about O.

(iv) the distance O, where a 100 gf weight should be placed to balanced the meter rule.



Sol. According to the figure, given in question, we get

(i) The moments of the weight of 150 gf

$$= 150 \text{ gf} \times 40 \text{ cm} = 6000 \text{ gfcm}$$ **[1]**

(ii) The moments of the weight of 250 gf

$$= -250 \times 20 = -5000 \text{ gfcm i.e., clockwise}$$ **[1]**

(iii) The difference of moments = 6000 gfcm

$$-5000 \text{ gfcm} = 1000 \text{ gfcm}$$ **[1]**

(iv) To balance these 1000 gfcm anti-clockwise moments, 100 gf weight must be at a distance

$$x = \frac{1000 \text{ gfcm}}{100 \text{ gf}} = 10 \text{ cm on the right side of } O.$$ **[1]**

40. A car is of weight 1800 kg. The distance between its front and back axles is 1.8 m. Its centre of gravity is 1.05 m behind the front axle. Determine the force exerted by the level ground on each front wheel and each back wheel.

Sol. Total mass of the car $= 1800$ kg

Let m and $(900 - m)$ kg be the masses of each front wheel and each back wheel, respectively.

Distance of centre of gravity from the front axle $= 1.05$ m

$\therefore$ Distance of centre of gravity from the back axle

$$= 1.80 - 1.05 = 0.75 \text{ m}$$ **[1]**

Taking torque about centre of gravity,

$$m \times 1.05 = (900 - m) \times 0.75$$

or $\quad 1.05\, m + 0.75\, m = 900 \times 0.75$

or $\quad 1.80\, m = 900 \times 0.75$

or $\quad m = \dfrac{900 \times 0.75}{1.80} = 375$ kg

$\therefore \quad (900 - m) = 900 - 375 = 525$ kg **[1]**

$\therefore$ Weight of each front wheel $(w_1) = m_1 g$

$$= 375 \times 9.8$$

$$= 3675 \text{ N}$$ **[1]**

Force exerted by the level ground on each front wheel
= Force exerted by each front wheel on the level ground $(w_1) = 3675$ N

Weight of each back wheel $(w_2) = m_2 g$

$$w_2 = 525 \times 9.8 = 5145 \text{ N}$$

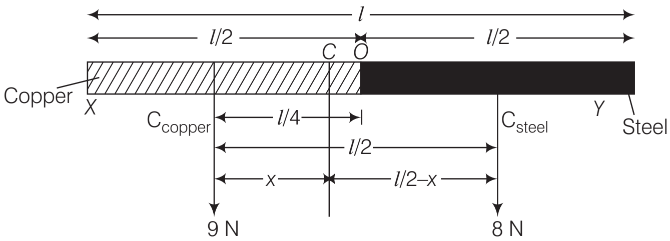
$\therefore$ Force exerted by the level ground on each back wheel
= Force exerted by each back wheel on level ground (w_2)

$$= 5145 \text{ N}$$ **[1]**

41. In a meter rod, half of it is made of copper and rest half of steel. Weights of copper and steel are 9 N and 8 N, respectively. Is the centre of gravity of the rod at its geometric centre? If not, where is it?

Sol. Since, the rod is not uniform, half portion of the rod is made up of copper is heavier.

So, its centre of gravity is not at the geometrical centre. **[1]**



Let l is the length of rod XY, and C_{copper} and C_{steel} be the centre of gravity of copper and steel part, respectively. If C is the centre of gravity of the combination, then by making moment about C

$$9 \times x = 8 \times \left(\frac{l}{2} - x\right)$$

$$\Rightarrow \quad 9x = 8 \times \frac{l}{2} - 8x \quad \Rightarrow 17x = 4l$$

$$\therefore \quad x = \frac{4}{17}l \quad \text{and} \quad OC = \frac{l}{4} - \frac{4}{17}l = \frac{1}{68}l$$

Hence, the centre of gravity of the combined rod is at point C at a distance of $\dfrac{1}{68}l$ from the geometrical centre O of the rod towards the copper half. **[3]**

CHAPTER EXERCISE

2 Marks Questions

1. Give any two effects of a force on a rigid body.

2. (i) What do you understand by negative and positive moments of a force?
(ii) If the moment of force is assigned a positive sign, then will the turning tendency of the force be clockwise or anti-clockwise?

3. A body is acted upon by two forces each of magnitude F but in opposite directions. State the effect of the force, if
(i) the two forces act at two different points of the body at a separation.
(ii) both forces act at the same point of the body.

4. (i) When a knife is sharpened with the help of a rotating grinding stone, then the spark always travel tangentially to it, why?
(ii) Can a body move on a curved path without having acceleration?

5. (i) Justify that a uniform circular motion is an accelerated motion.
(ii) A women rides in a carnival ferris wheel. What is the direction of her centripetal acceleration at the lowest point?

3 Marks Questions

6. What is uniform circular motion? Draw a diagram to explain it.

7. With reference to their direction of action, how does a centripetal force differ from a centrifugal force? ***[2013]***

4 Marks Questions

8. Define couple, prove that

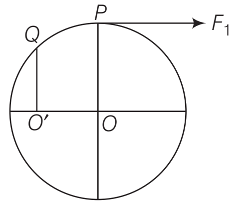
moment of couple = force × couple arm.

9. How an object is said to be in equilibrium. Explain the types of equilibrium.

Numerical Based Questions

10. Two forces each of magnitude 20 N acting at the point A and B at a separation of 100 cm, in opposite directions, calculate the resultant moment of two forces about the point (i) A (ii) B and (iii) O, situated exactly at the middle of the two forces.
(i) 2 N-m (clockwise) (ii) 2 N-m (clockwise)
(iii) 2 N-m (clockwise) ***Ans.*** 20 N-m

11. In the given diagram, wheel shown has a fixed axle passing through O. The wheel is kept stationary under the action of two forces F_1 and F_2 such that (i) a horizontal force F_1 at P and diagram (ii) a vertical force F_2 at Q. Show that the direction of F_2 in the diagram. Which is the greater force? Find the ratio between the forces.



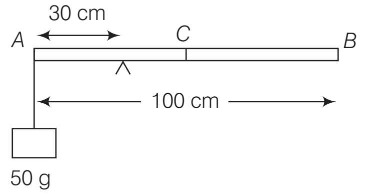
(Given, $PO = 2.5\,\text{cm}, OQ' = 1.5\,\text{cm}$ and $OO' = 2.0\,\text{cm}$)

Ans. $\frac{F_2}{F_1} = \frac{4}{5}$

12. A uniform half meter rule is suspended from its mid-point. A weight of 50 gf is suspended at one end of it. Where should a weight of 100 gf be suspended to keep the rule horizontal.
Ans. At distance 25 cm from the other end

13. A uniform meter scale balances horizontally with a string attached at 55 cm mark when a mass of 25 g is suspended from one end. Draw a diagram of this arrangement. Calculate the mass of the scale.
Ans. 225 gf

14. A one meter scale AB is balanced horizontally across a knife-edge as shown in the figure.



Calculate
(i) the mass of the scale,
(ii) the force on the knife-edge and
Ans. (i) 75 g, (ii) 125 g