Chapter # 4

TURNING EFFECTS OF FORCES

COMPREHENSIVE QUESTIONS:

Q1. What are force diagrams? Define like and unlike parallel force with examples.

Ans. Force Diagrams:

In force diagrams, the objects on which force are shown is reduced to a dot at its centre and the force acting on the object are represented by arrows pointing away from it.

Explanation:

If we were to draw a force diagram of a book (object) placed at rest on table, we would reduce book to a dot and draw two arrows representing forces acting on it. There are two forces acting on a book, one is the weight of the book, pulling it downward and the other force is normal force due to the table pushing the book upward. Both forces are equal in magnitude but opposite in direction. These two forces are an example of balanced force where they cancel out each other and the book (object) remains in state of equilibrium.

In case of free fall object:

In case of freefall objects, the force due to gravity on the book is unbalanced and the book accelerates downward, in this case the force diagram of a free fall book (object).

Like parallel force:

Like parallel force are those forces which are parallel to each other and having the same direction. They may have same or different magnitude.

Example:

When we lift a box with double support we are applying like parallel force from each support. These forces may not equal but parallel and act in the same direction as shown in fig.

Unlike parallel forces:

Unlike parallel forces are those force which are parallel to each other but they are opposite in direction.

For Example:

When we apply force with our both hands on steering wheel of a car to turn it. The force from one hand may be greater than other. Here, we are applying unlike parallel forces as shown in fig.

Q2. Explain the addition of forces, in connection with head to tail rules.

Ans. <u>Addition of Forces</u>:

Addition of forces is a process of obtaining a single force (Resultant force) which produces the same effect as produced by number of forces acting together.

<u>Explanation:</u>

Forces are vector quantities and may be added geometrically by drawing them to common scale and placing them head to tail.

The addition of forces is simple for parallel force. In case of like parallel forces, add the magnitude of vectors (forces) and in case of unlike parallel forces, subtract the magnitude of vectors.

<u>Addition of Non – Parallel Forces:</u>

When the forces are non-parallel that are acting at angle other than 0^{o} and 180^{o} Then for addition of such vectors (forces), we apply a special method called Head to tail rule in order to find their resultant force (Vector)

<u>Head to tail rule:</u>

According to head to tail rule, we will get a resultant force (vector) by drawing the representative lines of the given forces in such a way that the tail of first force vector joins with the head of last force vector.

<u>Resultant force:</u>

A resultant force is the sum of two or more forces which is obtained by joining the tail of first force vector to the head of last one. It is represented by "F_R". This method of adding forces is known as "head to tail rule" of addition of forces.

Example:

Consider two persons pulling a cart such that their force vectors are drawn to same scale to calculate the net or resultant force applying on a cart, the following steps must be followed to add the vectors by head to tail rule.

1. Draw a first force vector "F_A" which shows that the force exerted by first person on the cart and making an angle θ_A with x – axis.

Draw a second force "F_B" which shows that the force exerted by second person on the cart and making an angle θ_B with x – axis

2. Join the tail of second force vector "F_B" with the head of first force vector (F_A) in the given direction.

3. Now, the net or resultant force "F_R" can be obtained by joining the tail of first vector "F_A" to the head of the last force vector "F_B".
Mathematically, the magnitude of resultant vector can be written as:
$\mathbf{F_R = F_A + F_B}$
This rule for vector addition can be extended to any number of forces.

Q3. Define moment of a force. Give its mathematical description and elaborate the factors on which it depends?

Ans: <u>Torque or Moment of force:</u>

The turning effect produced in a body about a fixed point due to applied force is called torque or moment of force.

<u>Explanation:</u>

Torque is the cause of changes in rotational motion and is similar to force, which causes changes in translational motion. For example, opening a door or tightening a nut with spanner etc. Torque may rotate an object in clock wise or anticlock wise direction.

<u>Mathematical Form:</u>

Torque is equal to the product of applied force "F" and the moment arm "d" which is the perpendicular distance from the axis of rotation to the line of action of rotation. Mathematically, it can be written as:

Torque = Force × moment arm (perpendicular distance)

Or

$\tau = F \times d$

<u>Quantity and Unit:</u>

Torque is a vector quantity and its S.I unit is "Newton meter (Nm)"

<u>Factors Affecting Torque:</u>

Torque depends upon the following two factors

1. Magnitude of force (F)
2. Moment arm or perpendicular distance (d)

1. Magnitude of Applied Force (F):

Torque is directly proportional to the force applied "F" which means greater is the magnitude of force, greater will be the torque produced. If the force is applied near the axis of rotation, moment arm will be small and turning effect will be poor. But if the force is applied at the pivot point then it will cause no torque since the moment arm would be zero i-e d = 0

2. **Moment Arm (d):**

Moment arm plays an important role in producing torque and it is directly proportional to the torque. Greater is the moment arm, greater will be the torque produced by applying less effort and vice versa.

Example:

To open the door, force 'F' is applied at perpendicular distance "d" from the axis of rotation. By increasing the moment arm 'd' or applied force 'F', torque '$\mathcal{T}$' will also increases. So, the closer you are to the door hinges (i-e the smaller 'd' is), the harder it is to push. That is why, the door's handle is made at the maximum distance from the hinges.

Q4. What is resolution of forces? Explain with an example how force can be resolved into rectangular components.

Ans: RESOLUTION OF FORCES:

The process of splitting a force vector into two or more force vectors is called resolution of forces.

RECTANGULAR COMPONENTS:

A vectors (Force) is resolved into two components which are mutually perpendicular to each other, such components are called rectangular components of a force vector i. e horizontal component and vertical component.

Example:

Consider a force vector 'F' which is represented by line $\overrightarrow{OP}$ making an angle θ with x-axis.

Resolution of force (F):

To resolve the force vector $\vec{F}$ into its components, draw a perpendicular PQ on axis from point "P". Suppose $\overrightarrow{OQ}$ and $\overrightarrow{QP}$ represents two forces i-e $\vec{F}_x$ and $\vec{F}_y$. So,

i. Force 'OQ' is along x-axis i-e $\vec{F}_x$ represents horizontal component.

ii. Force 'QP' is along y-axis i-e $\vec{F}_y$ represents vertical components.

By applying head to tail rule, we see that sum of vector $\vec{F}_x$ and $\vec{F}_x$ is equal to resultant force vector $\vec{F}$ i-e

$$\vec{F} = \vec{F}_x + \vec{F}_y$$

Therefore, $\vec{F}_x$ and $\vec{F}_y$ are the rectangular components of force vector $\vec{F}$.

For Finding Magnitude of Rectangular Components:

The magnitude of $\vec{F_x}$ and $\vec{F_y}$ can be determined by using trigonometric ratios.

For Horizontal Component $\vec{F_x}$:

Now considering the right angle triangle ΔOPQ , we use the ratio $\cos\theta$ in order to find the value of $\vec{F_x}$

$$\text{Cos}\theta = \frac{Base}{Hypotenuse}$$

$$\text{Cos}\theta = \frac{OQ}{OP} \qquad \therefore OQ = F_x\ ,\ OP = F$$

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

By cross multiplication, we get

$$\vec{F_x} = F\cos\theta \text{ ---- (i)}$$

For Vertical Component F_y:

To find the value of F_y, we use the ratio sin θ

$$\text{Sin}\theta = \frac{Perpendicular}{Hypotenuse}$$

$$\text{Sin}\theta = \frac{QP}{OP} \qquad \therefore QP = F_y,\ OP = F$$

$$\text{Sin}\theta = \frac{F_y}{F}$$

By cross Multiplication, we get

$$F_y = F\ \text{Sin}\theta \text{ ---------- (ii)}$$

So, we can calculate the magnitude of $\vec{F_x}$ and $\vec{F_y}$ components of force vector by using eq (i) and (ii)

For finding magnitude of force $\vec{F}$:

If the values of rectangular components F_x and F_y of a force vector are known, we can determine the magnitude of Resultant force $\vec{F}$

According to Pythagoras theorem

$$(\text{Hyp})^2 = (\text{Base})^2 + (\text{Perpendicular})^2$$

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

Taking square root on both side:

$$\sqrt{F^2} = \sqrt{F_x^2 + F_y^2}$$

$$F = \sqrt{F_x^2 + F_y^2}$$

For Direction θ:

The direction (θ) of $\vec{F}$ in right angle triangle △OPQ is determined by using trigonometric ratio of tanθ.

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

$$\tan\theta = \frac{QP}{OQ}$$

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

$$\theta = \tan^{-1}\frac{F_y}{F_x}$$

Q5. What is Couple? Explain with examples.

Ans. <u>Couple:</u>

Two equal and opposite parallel forces acting along different lines on a body is called a couple.

Explanation:

Couple does not produce any translational motion but only rotational motion. In other words, the resultant force of a couple is zero but the resultant of a couple is not zero. It is a pure moment. The shortest distance between two couple forces is called couple arm.

Example:

Consider an example of steering wheel gripped by two hands is often a couple. Each hands grips the wheel at points on opposite sides of the shaft. When both hands apply a force F_1 and F_2 that is equal in magnitude but opposite in direction, the wheel rotates. So, a pure couple always consists of two opposite forces equal in magnitude. If both hands apply a force in same direction, the wheel will not rotate

Other Example:

Similarly, in our daily life, we come across many object which work on the principle of couple. e.g.

1. Exerting force on bicycle pedals
2. Winding up the spring of a toy car
3. Opening and closing the cap of a bottle
4. Turning of a water tap etc.

Q6. Define equilibrium. Explain its types and state the two conditions of equilibrium

Equilibrium:

Definition:

The state of a body in which under the action of several forces acting together, there is no change in translational motion as well as rotational motion is called equilibrium.

Or

If there is no change in state of rest or of uniform motion of a body, the body is said to be in state of equilibrium.

Type of Equilibrium:

There are two type of equilibrium which are as follow.

1. Static equilibrium
2. Dynamic equilibrium

1. Static equilibrium:

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

Example:

For example, a book is resting on the table and two forces are acting on it i-e weight of book and reaction force of table. Both forces are equal in magnitude but opposite in direction. So, the net force is zero and the book is said to be in state of static equilibrium.

2. Dynamic Equilibrium:

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

The dynamic equilibrium is further divided into two types

1. Dynamic Translational equilibrium
2. Dynamic Rotational Equilibrium

1. Dynamic Translational Equilibrium:

When a body is moving with uniform linear velocity, the body is said to be in dynamic translational equilibrium.

Example: For example, a paratrooper falling down with constant velocity is in state of dynamic translational equilibrium

2. Dynamic Rotational Equilibrium:

When a body is moving with uniform rotation, the body is said to be in dynamic rotational equilibrium.

Example: For example, a Compact disk (CD) rotating in CD player with constant angular velocity is in state of dynamic rotational equilibrium

Conditions of Equilibrium:

There are two conditions of equilibrium which are necessary for a body to be fulfilled

First Condition of Equilibrium:

When the sum of all the forces acting on the body is Zero, then first condition of equilibrium is satisfied

Mathematically: Mathematically, if $\vec{F}_{net}$ is the sum of force $\overrightarrow{F_1}, \overrightarrow{F_2}, \overrightarrow{F_3} \ldots\ldots\ldots\ldots \overrightarrow{F_n}$ then

$$\vec{F}_{net} = \overrightarrow{F_1} + \overrightarrow{F_2} + \overrightarrow{F_3} \ldots\ldots\ldots\ldots + \overrightarrow{F_n}$$

Or

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

Where $\sum$ represents the sigma or summation.

Second Condition of Equilibrium:

When the sum of all the torques acting on the body is zero then the second condition of equilibrium is satisfied.

Mathematically:

Mathematically , if τ_{net} is the sum of forces $\tau_1, \tau_2, \tau_3 \ldots \ldots \ldots \ldots \ldots \tau_n$, then

$$\overrightarrow{\tau_{net}} = \overrightarrow{\tau_1} + \overrightarrow{\tau_2} + \ldots\ldots\ldots \overrightarrow{\tau_n} = 0$$

Or

$$\overrightarrow{\boldsymbol{\tau_{net}}} = \sum \vec{\boldsymbol{\tau}} = \mathbf{0}$$

First condition is valid up to translational motion while the second condition is up to rotational motion. Thus, for complete equilibrium both the first and second conditions of equilibrium must be satisfied by a body.

Q7. State and explain principle of moments with example.

Ans. Principle of Moments:

Statement:

For an object to be in equilibrium the sum of the clockwise torque taken about the pivot must be equal to the sum of anti – clock wise torque taken about the same pivot this principle is known as principle of moments.

i.e. sum of Anti clock wise Torque = Sum of Clock Wise Torque

$$\Sigma\, \tau_1 = \Sigma\, \tau_2$$

Second condition of equilibrium is also called principle of moments.

Examples:

In the given figure, a rod is balance about pivot. Here torque produced by “w1” and “w2” is anti-clockwise and torque produced by “w3” is clockwise.

Mathematically

Clockwise torque = Anti-clockwise torque

$$\Sigma\, \boldsymbol{\tau_3} = \boldsymbol{\tau_1} + \Sigma\, \boldsymbol{\tau_2}$$

$$(6 \times 2) = (5 \times 2) + (2 \times 1)$$

$$12 = 12$$

Hence, there is only one clock wise moment about the turning point, but two anti-clock wise moments add up to balance it.

For second condition of equilibrium, the sum of all these torques must be zero.

$$\boldsymbol{\tau_1} + \Sigma\, \boldsymbol{\tau_2} + \boldsymbol{\tau_3} = \mathbf{10}\, \boldsymbol{Nm} + \mathbf{2}\boldsymbol{Nm} - \mathbf{12}\boldsymbol{Nm}$$

$$\boldsymbol{\tau_1} + \Sigma\, \boldsymbol{\tau_2} + \boldsymbol{\tau_3} = \boldsymbol{o}\, \boldsymbol{Nm}$$

Q8. What is centre of mass Or centre of gravity Explain how CM/CG can be determined? Is there any difference between CM and CG?

Ans: <u>Centre of Mass (CM):</u>

The centre of mass of the body is the point about which mass is equally distributed in all direction. It is denoted by "CM".

The identification of this point is possible by applying a force at this point which will produce linear acceleration.

<u>Center of Gravity (CG):</u>

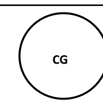
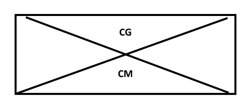
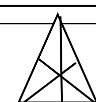
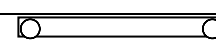
The Centre of gravity of the body is a point inside or outside a body at which whole weight of the body appears to act. It is denoted by "CG"

<u>Explanation:</u>

Everybody has a centre of mass (CM) where whole mass of a body is located and the CM is also the point at which the force of gravity is acting vertically downward i-e "CG". For most of the time, these two points are lie at the same position in an object.

<u>Determination of CG and CM for regular shaped bodies:</u>

The centre of gravity "CG" and centre of mass "CM" of regular shaped bodies is located at the geometrical centre of the body. So the CG and CM of different symmetric bodies are shown in following table.

	Name of Object	**Position of CM& CG**	**Shapes of objects**
1	Circle	Centre of circle	
2	Square or Rectangular plate	Intersection of diagonals	
3	Triangular Plate	Intersection of medians	 CG & CM
4	Uniform rod	Centre of rod	 CG & CM

<u>Determination of CG and CM for irregular shaped bodies:</u>

The CG or CM of irregular shaped bodies can be determined with the help of plumb line. If we take an irregular shaped object and make up a plumb line, then suspend it randomly from at least three different points and trace the plumb lines location. So, the point of intersection of all three plumb lines is the CG or CM of an object.

Difference between CG and CM:

The CG is based on weight of a body where as the CM is based on mass of a body. Also, CG depends on the gravitational field whereas CM does not depend upon the gravitational field. So, when the gravitational field across an object is uniform, the centre of mass and centre of gravity are in exactly the same position. However, near the surface of earth or on the surface of earth, the gravitational force is uniform, therefore CM and CG are present at the same point inside or outside a body. However, when gravitational field is non – uniform, the CM and CG does not lie at same point in an object. The CG will move closer to regions of the object in a stronger gravitational field, where as CM is unmoved.

Q9. Explain the stability of the objects with reference to position of centre of mass.

Stability:

The stability of an object refers to the ability of an object to come back in its original position after removing the force which was applied for its disturbance.

Or

Stability is a measure of how hard it is to displace on object or system from equilibrium

Explanation:

The degree of stability depends on how the position of centre of mass (CM) or centre of gravity (CG) of an object change when disturbed by some external force and how much it has the tendency to come back to its original position.

States of Equilibrium:

On the basis of stability of an object, there are three states of equilibrium which are as follow

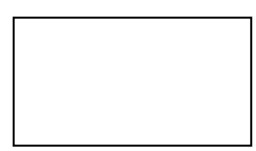
1. Stable Equilibrium
2. Unstable Equilibrium
3. Neutral Equilibrium

1. Stable Equilibrium:

When a body in equilibrium is slightly disturbed, its CM moves up and after removing external force, the CM of a body comes to its original position and regain its stability This state of equilibrium is called stable equilibrium.

Example:

It is observed that if a book lifted from its edge, the CM of the book raised and when released, it comes back to its original position because the vertical line of action of weight passing through CM of body still falls inside the base and the torque caused by the weight of the body brings back the body to its original position.



Book

Other examples of stable equilibrium are table, chair, box and brick lying on the floor.

2. Unstable Equilibrium:

When a body in equilibrium is slightly disturbed and its CM moves down and cannot come back to its original position after removing external force. This state of equilibrium is called unstable equilibrium.

Example:

A pencil is made to stand on its tip in equilibrium state. If it is slightly disturbed from its position, its CM will lower and it will not come back to its original position. Because the vertical line of weight passing through CG/CM of the body falls outside the base of the body and the torque caused by weight of pencil topples it rather than bring it back to its original position.

Other example of Unstable equilibrium are vertically standing cylinder cones and funnels etc.

3. <u>Neutral Equilibrium:</u>

When a body is slightly disturbed and its CM does not change from its original position. This state of equilibrium is called neutral equilibrium.

Example:

For example, when a ball is kicked to roll, its CM is neither raised nor lowered. This means the CM is at the same height as below and vertical line of action of weight always remain within the base of the body.

Topic Wise Questions

Q1. Explain the process of force for like and unlike parallel forces.

Ans. <u>Addition of Forces:</u>

Addition of forces is a process of obtaining a single force which produces the same effect as produced by a number of forces acting together

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

The addition of like parallel force can be done by adding the magnitudes of vectors.

For Example:

1. 5N → + 5N → = 10N →
2. 5N → + 10N → = 15N →

Where the length of arrow line shows the magnitude of force and the arrow head shows the direction of force.

<u>Addition of Unlike Parallel Forces:</u>

The addition of unlike parallel forces can be done by subtracting the magnitude of vectors.

For Example:

1. ↓ -5N ↑ +5N = 0N
2. ↓ -5N ↑ 10N = ↑ 5N
3. ↓ -10N ↑ 5N = ↓ -5N

By following these rules, we can add or subtract the parallel forces.

Q2. Define rotational motion and discuss the terms that cause the rotational motion in an object.

Ans. <u>Rotational Motion:</u>

Motion where all the points of an object moves about a single fixed axis is called rotational motion.

Examples:

The motion of a top, the wheel of a bicycle and car, the hands of clock and the blades of fan are the examples of rotational motion.

<u>Terms that causes Rotational Motion:</u>

There are the following terms that help to produce rotational motion in an object.

1. Rigid Objects
2. Axis of Rotation

1. <u>Rigid Objects:</u>

Rigid objects are objects of fixed form that do not distort or deform (change shape) as they move. For rotational motion, objects should be rigid because all particles are fixed and distance between particles does not change after applying an external force in rigid bodies.

2. <u>Axis of Rotation:</u>

Another term that causes rotational motion in an object is the axis of rotation. Axis of rotation is the line about which rotation takes place. This line remains at rest during rotational motion of the extended object while the other points of the body move in circles about this line. It may be a pivot, hinges or any other support around which all particles of an object can rotate.

Q3. Define the types of torque or Define the senses of rotation.

Ans. <u>Types of Torque:</u>

There are two types of torque which are as follow:

1. Clockwise torque
2. Anticlockwise torque

1. <u>Clockwise torque:</u>

If the object rotates in clockwise direction, the torque is known as clockwise torque. The clockwise torque is always taken negative.

2. <u>Anti-Clockwise torque:</u>

If the object rotates in anticlockwise direction, the torque is known as anticlockwise torque. The anticlockwise torque is always taken positive.

CONCEPTUAL QUESTIONS

Q1. Can the rectangular component of the vector be greater than vector itself? Explain

Ans. No, the magnitude of rectangular components cannot be greater than the magnitude of vector itself.

Reason:

In the given figure, "F_x" and "F_y" represents the rectangular components of a vector "F" which is given by:

$F_x = F\cos\theta$ ----(i)

And $F_y = F\sin\theta$ -----(ii)

As the values of $\sin\theta$ and $\cos\theta$ may be equal to "1" but cannot be greater than"1". So, according to eq (i) and (ii), "F_x" and "F_y" may be equal to "F" or will be less than "F" but cannot be greater than "F".

Q2. Explain why door handles are not put near hinges?

Ans. The door handles are not put near the hinges because in this way more turning effect is produced by applying less effort. As we know that torque depends upon force applied and moment arm. Greater is the moment arm, greater will be the torque produced by applying small force and the door will open easily.

Conversely by putting the door's handle near hinges, moment arm will be small and turning effect will be poor and the door will not open easily. That is why the handles are not put near the hinges.

Q3. Can a small force ever exert a greater torque than a larger force? Explain.

Ans. Yes, a small force can exert a greater torque than a larger force, if the small force has a large enough moment arm.

As we know that,

$\tau = F \times d$ -------(i)

Eq (i) clearly shows that torque depends on both applied force and moment arm. Moment arm also plays an important role in producing torque. If the moment arm at which small force is acting is greater than the moment arm at which large force is acting, then the torque produced by small force will be greater than the larger force.

For example,

Let $F_1 = 2N$ and $d_1 = 10m$

Then , $\tau_1 = F_1 \times d_1$

$\tau_1 = 2 \times 10$

$\tau_1 = 20$ Nm

And

Let $F_2 = 5N$ and $d_2 = 2m$

Then, $\tau_2 = F_2 \times d_2$

$\tau_2 = 5 \times 2$

τ_2 = 10Nm

It is clear from this example that $\tau_1 > \tau_2$. Thus, torque produced by smaller force is greater than larger force by taking large value of moment arm.

Q4. Why it is better to use a long spanner rather than a short one to loosen rusty nut?

Ans. As we know that torque depends upon force applied and moment arm. As torque is directly proportional to the moment arm which means greater is the moment arm, greater will be torque produced So, it is easier to loosen a rusty nut by using a long spanner rather than a short spanner because more turning effect is produced on the nut by increasing the moment arm with less effort.

Q5. The gravitational force acting on a satellite is always directed towards the center of the earth. Does this force exert torque on satellite?

Ans. The gravitational force is always directed towards the centre of the earth. In this situation, the line of gravitational force is passing through the centre of gravity of the satellite and the moment arm is equal to zero ($\theta=180^0$). Therefore, this force cannot exert torque on the satellite.

We can also prove it mathematically,

As we know that

$\boldsymbol{\tau = dF\sin\theta}$ ---------(i)

Here, the angle $\theta = 180^0$ between d and F. So, eq (i) becomes

$\tau = d\,F\sin 180^0$:. $\sin 180^0 = 0$

$\tau = dF(0)$

$\boldsymbol{\tau = 0}$

Hence, it shows that no torque is exerted on satellite by gravitational force.

Q6. Can we have situations in which an object is not in equilibrium, even though the net force on it is Zero? Give two examples.

Ans. As we know that for a complete equilibrium, the following two conditions must be satisfied i-e

(i) $\Sigma F = 0$

(ii) $\Sigma\tau = 0$

Now if ΣF is equal to zero but $\Sigma\tau$ is not equal to zero, then the body will rotate and will not be in state of complete equilibrium.

Example1:

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

Exqample2:

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

Q7. Why do tightrope walkers carry a long, narrow rod?

Ans: A tightrope walker uses long narrow rod for getting balanced condition and prevent himself from falling over the rope. For example, if the walker leans towards right and produces clockwise torque then he moves the rod in such a way to create anticlockwise torque. Both torques will cancel the effect of each other and thus, he will remain in state of equilibrium. The long and balancing rod also lowers the centre of gravity (CG) of walker which helps in maintaining the stability while walking over the tightrope

Q8. Why does wearing high – heeled shoes sometimes cause lower back pain?

Ans. Wearing high – heeled shoes causes lower back to arch more than normal because it pushes the body weight in the forward direction which exerts more pressure on the ball of the foot. So, the position of centre of gravity (CG) of a body is also shifts forward. As heel height increases, stability decreases. Now, to maintain the balanced condition, the body tries to change its positions and posture in order to oppose the forward push. In doing so, the back muscles become tense and over used and that can cause the lower back pain.

Q9. Why it is more difficult to lean backwards. Explain?

Ans: We know that the degree of stability of a body depends on how the position of centre of gravity (CG) changes when disturbed by applying force. So, when a person leans backward, the position of centre of gravity (CG) of the body changes in such a way that increase the instability. As a result, it becomes difficult for a body to remain in state of equilibrium. That's why it is more difficult to lean backward.

Q10. Can a single force applied to a body change both its translational and rotational motion Explain?

Ans. Yes, a single force applied to a body can change both its translational and rotational motion. As we know that a force applied at the centre of mass will cause translational motion and a torque will cause rotational motion. So, if the force is applied at the centre of mass of a body, it will perform translational motion only. But, if the force is applied at a point other than centre of mass (CM), the body will also rotate along with translational motion. For example, if a football is kick off, it will perform both translational and rotational motion because football will rotate as it moves forward.

Q11. Two forces produce the same torque Does it follow that they have the same magnitude? Explain Describe the path of the brick after you suddenly let go of the rope.

Ans. If two forces produce the same torque, then it does not necessary that they have the same magnitude. They may or may not have the same magnitude depending upon the values of both force and moment arm. Because torque depends upon forces as well as moment arm i .e $\tau = F \times d$.

<u>Case1:</u>

Let $F_1 = 5N$ and $d_1 = 1m$

then , $\tau_1 = F_1 \times d_1$

$\tau_1 = 5 \times 1$

$\tau_1 = 5$ Nm

And $F_2 = 5$ N and $d_2 = 1$ m

then , $\tau_2 = F_2 \times d_2$

$= 5 \times 1$

$=5$ Nm

In case 1, we can get the same torque for two same forces by taking the same value of moment arm.

Case 2:

Let, $F_1 = 5N$ and $d_1 = 2m$

then, $\tau_1 = F_1 \times d_2$

$= 5 \times 2 \Rightarrow 10Nm$

and, $F_2 = 10N$ and $d_1 = 1m$

then, $\tau_2 = F_2 \times d_2$

$=10 \times 1$

$= 10Nm$

In case 2, we can also get the same torque for two different forces by taking different values of moment arm.

CHAPTER: 04
NUMERICAL QUESTION

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

Data:

Force Applied = F = 15N

Angle = $\theta = 30^0$

Find:

(a) Horizontal component of force = F_x = ?

(b) Vertical Component of force = F_y = ?

Solution:

(a) For finding "Fx", we know that

$\mathbf{Fx = F\cos\theta}$

$Fx = F\cos30^0$:. $\cos30^0 = 0.866$

$Fx = 15 \times 0.866$

$Fx = 12.99N$

Or

$\mathbf{Fx = 13N}$

(b) For finding "Fy", we know that

$\mathbf{Fy = F\sin\theta}$

$Fy = 15 \sin 30^0$ $\because \sin 30^0 = 0.5$

$Fy = 15 \times 0.5$

$Fy = 7.5$ N

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

Data:

Torque = τ = 40Nm

Moment arm = d = 25cm

$d = \frac{25}{100}$

d = 0.25 m

Find:

Force Applied = F = ?

Solution:

As we know that

$\tau = F \times d$

Or

$$\mathbf{F = \frac{\tau}{d}}$$

Putting values

$F = \frac{40}{0.25}$

F = 160N

R.W

$\tau = F \times d$

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

$\frac{\tau}{d} = F$

or $F = \frac{\tau}{d}$

3. Sana whose mass is 43 kg, sits 1.8m from the centre of a see saw. Faiz whose mass is 52 kg, wants to balance Sana. How far from the centre of see saw should Faiz sit?

Data:

Mass of Sana = m_1 = 43 kg

Sana's moment arm = d_1 = 1.8 m

Mass of Faiz = m_2 = 52 kg

Find:

Faiz's moment arm = d_2 = ?

Weight of Sana = W_1 = ?

Weight of Faiz = W_2 = ?

Solution:

For finding "W_1", using formula

$\mathbf{W_1 = m_1 g}$

$W_1 = 43 \times 9.8$

$\mathbf{W_1 = 421.4N}$

For finding "W_2", using formula

$\mathbf{W_2 = m_2 g}$

$W_2 = 52 \times 9.8$

$W_2 = 509.6N$

Now, For finding "d_2" using the principle of moment.

Anticlockwise Torque= clockwise torque

$$\tau_1 = \tau_2$$

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

$$\frac{W1 \times d1}{W_2} = \frac{\cancel{W2} \times d2}{\cancel{W_2}}$$

$$\frac{W1 \times d1}{W_2} = d_2$$

Or

$$\mathbf{d_2 = \frac{W1 \times d1}{W_2}}$$

$$d_2 = \frac{421.4 \times 1.8}{509.6}$$

$$d_2 = \frac{758.52}{509.6}$$

$$d_2 = 1.48m$$

or **$d_2 = 1.5m$**

Hence, Faiz should sit at a distance of 1.5 m from the centre of seesaw.

4. Two kids of weighing 300N and 350N are sitting at the ends of 6m long seesaw. The seesaw is pivoted at its centre. Where would a third kid sit so that the seesaw is in equilibrium in the horizontal position? The weight of 3rd kid is 250N (Ignore the weight of seesaw).

Data:

Weight of 1st Kid = W_1 = 300N

Moment arm of 1st Kid = d_1 = 3m

Weight of 2nd kid = d_1 = 350N

Moment arm of 2nd kid = d_2 = 3m

Weight of 3rd kid = w_3 = 250N

Find: Moment arm of 3rd kid = d_3 = ?

Solution:

For finding "d_3" using the principle of moment

Sum of anticlockwise torque = Sum of clockwise torque

$$\tau_1 + \tau_3 = \tau_2$$

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

Subtract "W_1 x d_1" on both sides

$$\cancel{W_1 \times d_1} - \cancel{W_1 \times d_1} + W_3 \times d_3 = W_2 \times d_2 - W_1 \times d_1$$

$$W_3 \times d_3 = W_2 \times d_2 - W_1 \times d_1$$

Divide "W_3" on both sides

$$\frac{\cancel{W_3} \times d_3}{\cancel{W_3}} = \frac{W_2 \times d_{2-W1 \times d1}}{W_3}$$

$$\mathbf{d_3} = \frac{W_2 \times d_{2-W1\times d1}}{W_3}$$

By putting values

$$d_3 = \frac{350 \times 3 - 300 \times 3}{250}$$

$$d_3 = \frac{1050 - 900}{250}$$

$$d_3 = \frac{150}{250}$$

$$\mathbf{d_3 = 0.6m}$$

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

Data:

Force of 1st child = F_1 = 20N

Moment arm of 1st child = d_1 = 0.60m

Moment arm of 2nd child = d_2 = 0.50m

Find:

Force of 2nd child = F_2 = ?

Solution:

By using formula

$$\tau_1 = \tau_2$$

$$F_1 \times d_1 = F_2 \times d_2$$

Divide "d_2" on both sides

$$\frac{F_1 \times d_1}{d_2} = \frac{F_2 \times \cancel{d_2}}{\cancel{d_2}}$$

$$\frac{F_1 \times d_1}{d_2} = F_2$$

Or

$$\mathbf{F_2 = \frac{F_1 \times d_1}{d_2}}$$

Putting value

$$F_2 = \frac{20 \times 0.60}{0.50}$$

$$F_2 = \frac{12}{0.50}$$

$$\mathbf{F_2 = 24N}$$

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

Data:

Mass = m = 1500kg

Moment arm = d = 20 m

Find:

Torque = Ʈ = ?

Solution:

Using formula

$$Ʈ = F \times d \text{ --------(i)}$$

As we know that

$F = W \quad :. \quad W = mg$

$F = mg$

Putting values

$F = 1500 \times 9.8$

F = 14700 N

Now, putting the value of "F" in eq (i)

$Ʈ = F \times d$

$Ʈ = 14700 \times 20$

Ʈ = 294000 Nm

Data:

Force = F = 14700 N

Moment arm = d = 12m

Find:

Torque = Ʈ = ?

Solution:

As we know that

Ʈ = F × d

$Ʈ = 14700 \times 12$

Ʈ = 176,400 N

Assignments

4.1 Two force are applied one force is 25 N (20^0 with x – axis) and the other force is 10N (60^0 with x-axis). Find the net resultant force.

Data:

Force = F_1 = 25 N

Angle 1 = $\theta_1 = 20^0$ with *x* – axis

Force 2 = F_2 = 10N

Angle 2 = $\theta_2 = 60^0$ with *x*-axis

Find:

Resultant Force = F_R = ?

Solution:

1st we select a suitable scale

Let 5N = 1cm

Then, F_1 = 25N = 5cm
And, F_2 = 10N = 2cm

Now, for finding the resultant, we add $\vec{F}_2$ with $\vec{F}_1$ by head to tail rule.

Finally, we combine the tail of $\vec{F}_1$ with the head of $\vec{F}_2$ which gives us the resultant force "F_R" . Thus, $\overrightarrow{OB}$ = F represents the resultant force. Now, by measuring the length of vector "F_R" by meter rod, we get,

$$\mathbf{F_R = 6cm}$$

Now, according to given scale, 6cm will be equal to 30N. i-e, 6 × 5 = 30N

So, the magnitude of resultant force "F_R" = 30N And to measure the angle "θ" with protector i-e 30^0 with x-axis.

Hence,

$$\mathbf{F_R = 30N, \theta = 30^0 \text{ with x-axis}}$$

4.2 While tilling your garden, you exert a force on the handles of the tiller that has components Fx = 85 N and F_y = 13N. The x-axis is horizontal and y-axis points up. What are the magnitude and direction of this force?

Data:

Horizontal component of force = Fx = 85N

Vertical components of force = Fy = 13N

Find:

Magnitude of force = F = ?

Direction of force = θ = ?

Solution:

For finding the "F", using formula

$$\mathbf{F} = \sqrt{F_x^2 + F_y^2}$$

$$F = \sqrt{(85)^2 + (13)^2}$$

$$F = \sqrt{7225 + 169}$$

$$F = \sqrt{7394}$$

F = 85.9N

Or F = 86N

Now, for finding direction "θ", using formula

$$\theta = \tan^{-1} \frac{Fy}{Fx}$$

$$\theta = \tan^{-1} \frac{13}{85}$$

θ = $\tan^{-1}$ 0.1529

θ = 8.695^0

Or **θ = 8.7^0**

4.3 20Nm torque is required to open a soda bottle. A boy with a bottle opener apply a force perpendicularly at 0.1m, what is the magnitude of force required.

Data:

Torque = τ = 20Nm

Moment arm = d = 0.1m

Find:

Force applied = F=?

Solution:

As we know that

$$\tau = F \times d$$

Or

$$\mathbf{F} = \frac{\tau}{d}$$

$$F = \frac{20}{0.1}$$

$$\mathbf{F = 200N}$$

4.4 With a beam two masses m_1 and m_2 are suspended at distance 0.4m and 0.5m respectively from suspension point as shown in figure. Ignoring the weight of the balance, if m_2 = 1.6kg, what is the mass m_1?

Data:

Moment arm at left = d_1 = 0.4m

Moment arm at right = d_2= 0.5m

Mass at right =m_2 = 1.6kg

Find:

Mass at left = m_1 = ?

Weight at right = W_2 = ?

Weight at left = W_1 = ?

Solution:

As we know that

$$\mathbf{W_2 = m_2 g}$$

$$W_2 = 1.6 \times 9.8$$

$$\mathbf{W_2 = 15.68N}$$

For finding W1, using formula of principle of moment

$$\tau_1 = \tau_2$$

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

Divide "d_1" on the both sides

$$\frac{W_1 \times \cancel{d_1}}{\cancel{d_1}} = \frac{W_2 \times d_2}{d_1}$$

$$W_1 = \frac{W2 \times d2}{d_1}$$

$$W_1 = \frac{15.68 \times 0.5}{0.4}$$

$$\mathbf{W_1 = 19.6N}$$

Now, for finding "m_1" we know that

$$W_1 = m_1 g$$

Or

$$\mathbf{m_1 = \frac{W_1}{g}}$$

$$m_1 = \frac{19.6}{9.8}$$

$$\mathbf{m_1 = 2kg}$$