TURNING EFFECT OF FORCE

4

KIPS MULTIPLE CHOICE QUESTIONS

1. **If a number of forces act on a body such that their points of action are different but lines of action are parallel to each other then these forces are known as -------------- forces:**
   a) Same b) Parallel c) Perpendicular d) None of above
2. **If the direction of parallel forces is the same, then these are called ------------------- forces:**
   a) Same b) Like Parallel c) Unlike Parallel d) All of above
3. **If the direction of parallel forces is the opposite, then these are called ------------------ forces:**
   a) Same b) Like Parallel c) Unlike Parallel d) All of above
4. **Addition of vectors are done by:**
   a) Head to tail rule b) Left hand rule
   c) Right hand rule d) None of above
5. **Component of a vector acting along the x – axis is called:**
   a) x – component b) horizontal component
   c) vertical component d) both a and b
6. **component of a vector acting along the y – axis is called:**
   a) x – component b) horizontal component
   c) vertical component d) both a and b
7. **Value of sin 30^0:**
   a) 0.5 b) 0.866 c) 0.707 d) none of them
8. **During rotation the particles of the body rotate along fixed circles. The straight line joining the centres of these circles is known as:**
   a) Parallel line b) Axis of rotation c) Both a & b d) None of above
9. **The rotational effect of a body is measured by a quantity known as:**
   a) Acceleration b) Velocity c) Displacement d) Torque
10. **The rotation produced in a body depends upon ---------- factors:**
    a) 1 b) 2 c) 3 d) 4
11. **Torque is a --------------- quantity:**
    a) Base b) Vector c) Scalar d) Both a & b
12. **The direction of torque is determined by ---------------- rule:**
    a) Left hand b) Right hand c) Both a & b d) None of above
13. **If the rotation is produced is anticlock wise direction then the torque is taken as:**
    a) Positive b) Negative c) Opposite d) Perpendicular
14. **If the rotation is produced is clock wise direction then the torque is taken as:**
    a) Positive b) Negative c) Opposite d) Perpendicular
15. **According to right hand rule, if ----------- is along the curl of the fingers of the right hand then the thumb points in the direction of the torque:**
    a) Rotation b) Parallel c) Force d) Weight
16. **In System International, the unit of torque is:**
    a) N b) Nm^{-2} c) Nm^{-1} d) Nm

17. **The force which is acting perpendicularly downwards towards the earth is called:**
a) Torque b) Weight c) Force of gravity d) Both b & c

18. **The point at which whole weight of the body appears to acts is called:**
a) Origin b) Couple c) Centre of Gravity d) Reference point

19. **The position of the centre of gravity depends upon the ----- of the body:**
a) Size b) Shape c) Weight d) Force

20. **The centre of gravity of parallelogram, rectangle, square is the:**
a) Point of intersection of the medians b) Central point of axis
c) Point of intersection of the diagonals d) Centre of parallelogram

21. **The centre of gravity of a regular shaped body is always on its centre of ----------------:**
a) Body b) Symmetry c) Medians d) Axis

22. **The centre of gravity of triangle is the:**
a) Point of intersection of the medians b) Central point of axis
c) Point of intersection of the diagonals d) Centre of parallelogram

23. **The centre of gravity of cylinder is the:**
a) Point of intersection of the medians b) Central point of axis
c) Point of intersection of the diagonals d) Centre of parallelogram

24. **When two equal, opposite and parallel forces act at two points of the same body, they form a:**
a) Torque b) Moment of a couple c) Force d) Couple

25. **A ----------- is always acting while opening or closing water tap, a lock, stopper of a bottle or jar:**
a) Couple b) Weight c) Force d) Mass

26. **The perpendicular distance between the line of action of force and centre of rotation and denoted by 'r' is called:**
a) Centre of gravity b) Moment arm c) Displacement d) Force

27. **The torque produced in a body due to a couple is equal to the product of one of the force and the ------------------:**
a) Couple b) Force c) Like parallel force d) Couple arm

28. **There are ------------ conditions of equilibrium:**
a) 1 b) 2 c) 3 d) 4

29. **When the sum of all the force acting on the body is the zero or the object is moving with uniform velocity then it will be in ---------------:**
a) Rest b) Motion c) Equilibrium d) None of above

30. **According to First condition of equilibrium, the sum of all the forces acting on the body should be ----------------:**
a) Positive b) Zero c) None d) All of above

31. **First condition of equilibrium is represented by:**
a) $\sum F = 0$ b) $\sum F_x = 0$ c) $\sum F_y = 0$ d) All of above

32. **According to Second condition of equilibrium, the sum of all the torques acting on the body should be ----------------:**
a) Positive b) Zero c) None d) All of above

33. **Second condition of equilibrium is represented by:**
a) $\sum \tau = 0$ b) $\sum F = 0$ c) Both a & b d) All of above

34. **Sigma ($\sum$) is the Greek letter which is used to represent:**
a) Addition b) Subtraction c) Multiplication d) Division

35. **There are ------------ states of equilibrium:**
a) 1 b) 2 c) 3 d) 4

36. **The equilibrium in which the body comes back to its original condition when set free after slightly lifting from one side is --------- equilibrium:**
a) Stable b) Unstable c) Neutral d) None of above

37. **The equilibrium in which the body does not come back to its original condition when set free after slightly lifting from one side is --------- equilibrium:**
a) Stable b) Unstable c) Neutral d) None of above

38. **The type of equilibrium in which after disturbance, the body again comes to rest position and enter of gravity remains unchanged:**
a) Stable b) Unstable c) Neutral d) None of above

39. **In Stable equilibrium, the centre of gravity is ------------ than the original position:**
a) Raised b) Lowered c) Remain same d) All of above

40. **In Unstable equilibrium, the centre of gravity is ------------ than the original position:**
a) Raised b) Lowered c) Remain same d) All of above

41. **In Neutral equilibrium, the centre of gravity ------------ than the original position:**
a) Raised b) Lowered c) Remain same d) All of above

42. **When an object is resting on the smooth horizontal surface, the weight of the object is balanced by --------------------:**
a) Normal Reaction b) Torque c) Friction d) Couple

43. **A meter rod on a wedge is an example of ------------ equilibrium**
a) Stable b) Unstable c) Neutral d) None of above

44. **A book lying on the table is an example of ---------------- equilibrium:**
a) Stable b) Unstable c) Neutral d) None of above

45. **Motion of the football on the ground is an example of ------- equilibrium:**
a) Stable b) Unstable c) Neutral d) None of above

46. **The ------------ of a racing car is kept low to make its stable:**
a) Width b) Height c) Length d) Weight

47. **If the centre of gravity of the body is below the fulcrum then the body will be in ---------------- equilibrium:**
a) Stable b) Unstable c) Neutral d) None of above

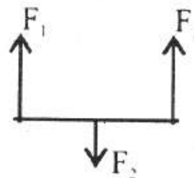
ANSWER KEY

Q.	Ans	Q.	Ans	Q.	Ans	Q.	Ans	Q.	Ans
1	b	11	b	21	b	31	d	41	c
2	b	12	b	22	a	32	b	42	a
3	c	13	a	23	b	33	a	43	b
4	a	14	b	24	d	34	a	44	a
5	d	15	a	25	a	35	c	45	c
6	c	16	d	26	b	36	a	46	b
7	a	17	d	27	d	37	b	47	a
8	b	18	c	28	b	38	c		
9	d	19	b	29	c	39	a		
10	b	20	c	30	b	40	b		

KIPS SHORT QUESTIONS

Q.1 What is meant by parallel forces?

Ans: In a plane, if number of parallel forces act on a body such that point of action are different but lines of action are parallel to each other, then these forces are called parallel forces. In the given figure, the force $\mathbf{F_1}$, $\mathbf{F_2}$, $\mathbf{F_3}$ are acting at points A, B, C are parallel forces.



Q.2 What is meant by like parallel forces? Also give examples.

Ans:

Like parallel forces are the forces that are parallel to each other and have the same direction.

Examples

In the second figure, the direction of the parallel forces $\mathbf{F_1}$ and $\mathbf{F_3}$ is the same, so these are like parallel forces.

Q.3 What are unlike parallel forces?

Unlike parallel forces are the forces that are parallel but have direction opposite to each other.

Example

In the second figure, the parallel forces $\mathbf{F_1}$, $\mathbf{F_2}$ and $\mathbf{F_2}$, $\mathbf{F_3}$ are acting in opposite direction, so these are unlike parallel forces.

Q.4 Define head to tail rule.

According to this rule, vectors are drawn in such a way that head of first vector is joined with the tail of the second vectors.

When forces are added, we get the resultant force. We can define resultant force as:

Resultant Force

A resultant force is a single force that has the same effect as the combined effect of the all the forces to be added. And resultant vector is drawn in such a way that tail of first vector is joined with the head of the last vector.

Q.5 Define resolution of vectors.

Ans: The decomposition or division of a vector into its rectangular components is called resolution of a vector.

OR

The splitting of a single vector into two mutually perpendicular components is called the resolution of that force.

Q.6 Define torque or moment of force.

Ans: "The rotational effect of a force is measured by a quantity, known as torque".

Q.7 Define centre of mass.

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

Q.8 Define centre of gravity.

Ans: A point in a body where the weight of the body appears to act vertically downward is called the centre of gravity.

The centre of gravity can exist inside a body or outside the body. Position of the centre of gravity depends upon the shape of the body.

Q.9 Define couple and give examples.

Ans: A couple is formed by two unlike parallel forces of the same magnitude but not along the same line.

Examples

- While turning a car, the forces applied on the steering wheel by hands provide the necessary couple.
- While opening or closing a water tap,
- While locking or opening the stopper of a bottle or a jar.

Q.10 Define equilibrium.

If no force is acting on the body or a number of forces act on a body in such a way that their resultant is zero, then if the body is at rest it will remain at rest and if the body is in motion, it will continue moving with a uniform velocity. This condition of the body is called equilibrium.

Q.11 State conditions of equilibrium.

First Condition of equilibrium

A body will be in equilibrium if the resultant of all the forces acting on it is zero. This is first condition of equilibrium.

Second Condition of equilibrium

If a number of forces act on a body so that the total sum of the torques of these forces is zero, the body will be in equilibrium.

Q.12 Define stable equilibrium.

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

When body is in stable equilibrium, its centre of gravity is at the lowest position. When it is tilted, its centre of gravity rises. It returns to its stable state by lowering its centre of gravity. A body remains in stable equilibrium as long as the centre of gravity acts through the base of the body.

Examples

Table, chair, box and brick lying on a floor.

Q.13 Define unstable equilibrium.

If a body does not returns to its previous position when sets after a slightest tilt is said to in unstable equilibrium.

The centre of gravity of the body is at its highest point in the state of unstable equilibrium. As the body topples over about its base, its centre of gravity moves towards its lower position and does not return to its previous position.

Examples

- A stick standing vertically on the tip of a finger.
- A cone standing on the tip of a finger.

Q.14 Define neutral equilibrium.

Neutral equilibrium

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

Example

- A ball lying on the horizontal surface
- Motion of wheel on plane surface.

Q.15 Define rigid body and axis of rotation.

Ans: Rigid body

A body is composed of large number of particles. If the distance between all these pairs of particles of the body do not change by applying a force then it is called a rigid body.

Axis of rotation

During rotation, the particles of the rigid body move in circles with their centres all lying on a line. This straight line is called the axis of rotation of the body.

Q.16 What is meant by principle of moments?

In balanced body, if the sum of clockwise moments acting on the body is equal to the sum of anticlockwise moments acting on it.

A body initially at rest does not rotate if sum of all the clockwise moments acting on it is balanced by the sum of all the anticlockwise moments acting on it. This is known as the principle of moments.

Examples

A pencil, a sphere, and cylinder, a roller, an egg lying horizontally on a flat surface.

Q.17 How stability of a body is related with the Position of centre of mass?

Ans: To make the body stable, their centre of mass must be kept as low as possible. It is due to the reason, racing cars are made heavy at the bottom and their height is kept to be minimum.

Q.18 Differentiate between axis of rotation and point of rotation?

Axis of Rotation	Point of Rotation
Axis of rotation is a line about which the whole body rotates. **Example** When we open the door, the door will move about its hinges or axis of rotation.	Point of rotation is just a point about which the body rotates. **Example** If we move a stick about its centre of gravity, then that point becomes the point of rotation.

Q.19 On what factors rotation produce in a body depend?

Ans: Rotation produced in a body depends on the following two factors:

(i) Magnitude of the force.

(ii) The perpendicular distance between the line of action of the force and the axis of rotation, that is known as moment arm.

Q.20 How can we increase torque by keeping the force constant?

Ans: We can increase the torque by increasing the perpendicular distance from the line of action of force to the point of rotation that is moment arm by keeping the force constant, according to the relation $\tau = rF$

Q.21 Can a moving body be in equilibrium? Explain.

Ans: Yes, if a body is moving with uniform velocity then the body is in equilibrium because neither linear nor rotational acceleration is produced in the body.

Q.22 Will a body be in equilibrium under the action of a single force?

Ans: No, the body will not be in equilibrium because first condition of the equilibrium will not be fulfilled. Since single force can never be zero and linear acceleration will be produced. Therefore we can say that a body cannot be equilibrium under the action of a single force.

Q.23 Can a body be in equilibrium if it is revolving clockwise under the action of a single force?

Ans: No, the body will not be in equilibrium because second condition of the equilibrium will not be fulfilled. Since single torque can never be zero and rotational acceleration will be produced. Therefore we can say that a body cannot be equilibrium under the action of a single torque.

Q.24 Give an example of a case when the resultant force is zero but resultant torque is not zero.

Ans: In case of couple, two equal and opposite forces are acting on a same body but even then the body rotates. In this case resultant force is zero but resultant torque is not zero.

Example

While turning a car, the forces applied on the steering wheel by hands produce rotation in the steering wheel.

Q.25 How do we know whether a body is in a stable or unstable equilibrium due to position of its centre of gravity?

Ans: If after disturbance, the centre of gravity of the body is raised up as compared to the initial position then the body will be in the state of stable equilibrium and if after disturbance, the centre of gravity of the body is lowered down as compared to the initial position then the body will be in the state of unstable equilibrium.

LONG QUESTIONS

4.2 ADDITION OF FORCES

Q.No.1 Which method is used for addition of forces? Explain with example.

Ans: Force is a vector quantity. It has magnitude as well direction; therefore forces are not added by ordinary arithmetic rules. They are added by a method known as head to tail rule.

Head to Tail rule

According to this rule, vectors are drawn in such a way that head of first vector is joined with the tail of the second vectors.

When forces are added, we get the result force. We can define resultant force as:

A resultant force is a single force that has the same effect as the combined effect of the all the forces to be added. And resultant vector is drawn in such a way that tail of first vector is joined with the head of the last vector.

Method

The method of addition of two vectors is given below:

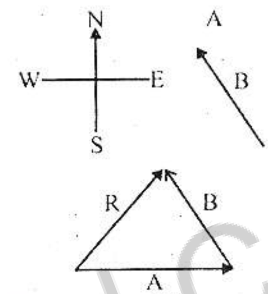


Figure 4.5: Adding vectors by head to tail rule.

- Select the frame of reference and suitable scale and draw the representative line of vectors of all the forces according to the scale; such as vector **A** and **B**.
- Take any one of the vectors as first vector e.g. vector **A**. then draw next vector **B** such that its tail coincides with the head of the first vector **A**. Similarly draw the next vector for the third force (if any) with its tail coinciding with the head of the previous vector and so on.
- Now draw a vector **R** such that its tail is at the tail of vector **A**, the first vector, while its head is at the head of vector **B**.
- Vector R represents the resultant force completely in magnitude and direction.
- The length of the line according to scale represents the magnitude of the resultant vector.
- The direction of the resultant vector is from the tail of the first vector towards the head of the second.

4.3 RESOLUTION OF FORCES

Q.No.2 Resolve the vector into its rectangular components.

Ans: The decomposition or division of a vector into its components is called resolution of a vector.

OR

The splitting of a single vector into two mutually perpendicular components is called the resolution of that force.

The process of splitting up vectors (forces) into their component forces is called resolution of force. If a force is formed from two mutually perpendicular components then such components are called **perpendicular components**.

Determination of Rectangular components of a vector

Suppose a vector **F** acts on a body by making an angle θ with the x-axis which is represented by the vector **OA** as shown in the figure. Draw perpendicular **BA** from the **A** on x-axis as **AB**. According to head to tail rule, **OA** is the resultant vector of **OB** and **BA**.

So $\quad$ **OA = OB + BA** .... (1)

Since the angle between **BA** and **OB** is 90^0, hence these are called the perpendicular components of the vector OA representing F.

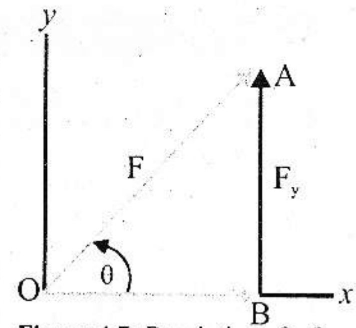


Figure 4.7: Resolution of a force

Horizontal or x-component

The component **OB** along x-axis is represented by $\mathbf{F_x}$ and is called the X-component or horizontal component of the vector **F**.

Vertical or y-component

The component **BA** is represented by $\mathbf{F_y}$ and is called the y-component or vertical component of the vector **F**.

So equation (1) can be represented by,

$$\mathbf{F} = \mathbf{F_x} + \mathbf{F_y}$$

Magnitude of Rectangular components

The magnitude of the perpendicular components F_x and F_y of forces $\mathbf{F_x}$ and $\mathbf{F_y}$ can be found by using the trigonometric ratios. In right angled triangle OAB,

$$\cos\theta = \frac{OB}{OA} \qquad \text{Or} \qquad OB = OA\cos\theta$$

But $OB = F_x$ and $OA = F$

Hence

$$\boxed{\mathbf{F_x = F\cos\theta}}$$

Similarly,

$$\sin\theta = \frac{BA}{OA} \qquad \text{or} \qquad BA = OA\sin\theta$$

But $BA = F_y$ and $OA = F$

Therefore,

$$\boxed{\mathbf{F_y = F\sin\theta}}$$

These two components are the two sides of the right-angled triangle where as hypotenuse represent the magnitude of the actual vector.

Determination of a Force from Its Perpendicular Components

Q.No.3 Find the magnitude and direction of a vector whose rectangular components are given.

Ans: If we have the perpendicular components of any vector then we can find the magnitude and direction of the resultant vector. It is reverse of resolving the vector.

As we know that x-component $\mathbf{F_x}$ of the force **F** is **F cos θ** and the y-component $\mathbf{F_y}$ is **F sin θ**. These two perpendicular components are represented by lines OP and PR respectively as shown in the figure.

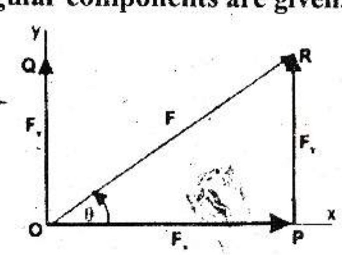


Figure 4.8: Determination of a force by its perpendicular components.

According to head to tail rule:

$$OR = OP + PR$$

Thus OR will completely represent the force F where x and y-components are Fx and Fy respectively.

$$F = Fx + Fy$$

Magnitude of actual vector

The magnitude of the force F can be determined using the right angled triangle OPR as,

$$(OR)^2 = (OP)^2 + (PR)^2$$
$$F^2 = F_x^2 + F_y^2$$

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

Direction of actual vector

Direction of the force F with x-axis is given by,

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

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

The value of the angle can be determined by using trigonometric tables or calculator.

4.4 TORQUE OR MOMENT OF A FORCE

Q.No.4 Explain torque or moment of a force.

Ans: Definition

"The rotational effect of a force is measured by a quantity, known as torque".

Dependence of Torque

Rotation (torque) produced in a body depends on the following two factors:
(i) Force.
(ii) Moment arm

Force

Greater is the force; greater is the moment of the force (torque).

Example

While riding the bicycle, if you press the pedal hard with your feet, its wheels start rotating fast and the speed of the bicycle increases. Similarly if you press the pedal softly, the wheel will rotate slowly and the speed of the bicycle will be less.

Line of action of Force

The line along which a force acts is called the line of action of force. In figure the line BC is the line of action of force.

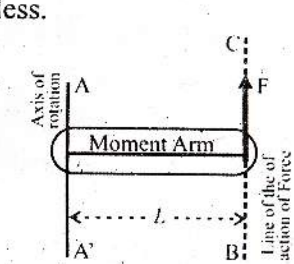


Figure 4.12: Factors affecting the moment of a force

Moment arm

The perpendicular distance between the line of action of the force and the axis of rotation, this is known as moment arm.

Longer is the moment arm greater is the moment of force.

Example

Mechanics loosen or tighten the nut or a bolt with the help of a spanner. A spanner having long arm helps him to do it with greater ease then the one having short arm. It is because the turning effect of the force is different in the two cases. The moment produced by the same force but using a spanner of short arm

Mathematical Form

Torque depends upon the force F and the moment arm r. torque is determined by the product of force F and its moment arm L. So we can write,

Torque = Moment arm x Force

$$\tau = F \times L$$

Unit

In the system international, the unit of torque is Newton meter (Nm). A torque of 1 N m is caused by a force of 1 N acting perpendicular to the moment arm of 1m long.

Sign conventions

Under the action of the torque if the rotation produced is anticlockwise, the torque is considered to be positive. If the rotation produced is clockwise, then the torque is taken as negative.

4.6 CENTRE OF MASS

Q.No.5 What is Centre of Mass? Explain its effect on rotation.

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

Explanation

It is observed that the centre of mass of a system as if its entire mass is confined that point. A force applied at such a point in the body does not produce any torque in it i.e. the body moves in the direction of net force F without rotation.

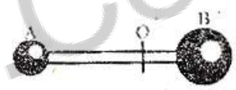


Figure 4.16: Centre of mas of two unequal masses.

Example

Consider a system of two particles A and B connected by a light rigid rod as shown in fig. let O is the point anywhere between A and B such that the force F is applied at point O as shown in fig. if the system moves in the direction of force F without rotation, then point O is the centre of mass of the system.

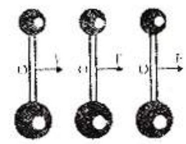


Figure 4.17: A force applied at COM moves the system without rotation

System move without rotation if the force acts elsewhere on it.

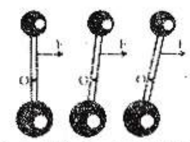


Figure 4.18: The system moves as well as rotates when a force is applied away from COM.

(i) Let the force be applied near the lighter particle as shown in fig. the system will move as well as rotate.

(ii) Let the force be applied near the heavier near the heavier particle as shown in fig. in this case, also the system moves as well as rotate.

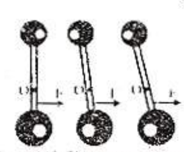


Figure 4.19: The system moves as well as rotates when a force is appaed away from COM

4.6 CENTRE OF GRAVITY

Q.No.6 What is meant by centre of gravity of a body? Explain an experiment to find the centre of gravity of a plate of uniform thickness.

Ans: A point in a body where the weight of the body appears to act vertically downward is called the centre of gravity.

The centre of gravity can exist inside a body or outside the body. Position of the centre of gravity depends upon the shape of the body.

Method

A body is made up of a large number of particles as shown in figure. Earth attracts each of these particles vertically downwards towards its centre. The pull of the Earth acting on a particle is equal to its weight. These forces acting on the particles of a body are almost parallel. The resultant of all these parallel force is a single force equal to the weight of the body. A point where this resultant force acts vertically towards the centre of the Earth is called the centre of gravity G.

Centre of Gravity of Some Symmetrical Objects

The centre of gravity of objects which have symmetrical shapes can be found from their geometry.

Examples

- The centre of gravity of a uniform rod lies at a point where it is balanced The balance point is its middle point G.
- The centre of gravity of a uniform square or a rectangular sheet is the point of intersection of its diagonals
- The centre of gravity of a uniform circular disc is its centre
- The centre of gravity of a solid sphere or hollow sphere is the centre of the spheres
- The centre of gravity of uniform triangular sheet is the point of intersection of its medians.
- The centre of gravity of a uniform circular ring is the centre of the ring
- The centre of gravity of a uniform solid or hollow cylinder is the middle point on its axis

Centre of Gravity of an Irregular Shaped Thin Lamina

A simple method to find the centre of gravity of a body is by the use of plumb line. A plumb line consists of small metal bob (lead or brass) supported by a string. When the bob is supported is suspended freely by the string, it rests along the vertical direction due to its weight acting vertically downward as shown in figure. In this state, centre of gravity of the bob is exactly below its point of suspension.

Experiment

Take an irregular piece of cardboard. Make holes A, B and C as shown in the figure near its edge. Fix a nail on a wall. Support the cardboard on the nail through one of the holes (let it be A), so that the cardboard can swing freely about A. the cardboard will come to rest with its centre of gravity just vertically below the nail. Vertical line from A can be located using a plumb line hung from the nail. Mark the line on the cardboard behind the plumb line. Repeat it by supporting the cardboard from hole B. The line from B will intersect at a point G. Similarly, draw another line from the hole C. Note that this line also passes through G. it will be found that all the vertical lines from holes A, B, and C have a common point G. this common point G is the centre of gravity of the cardboard.

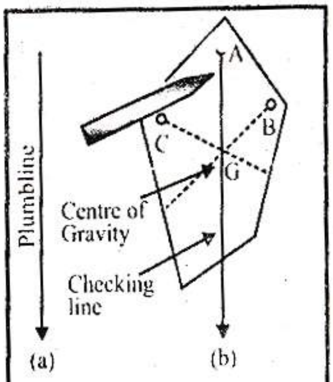


Figure 4.23 (a) Plumbline (b) Locating the centre of gravity of a piece of cardboard by using plumbline.

4.7 COUPLE

Q.No.7 Define Couple. Give examples and find torque produced by couple.

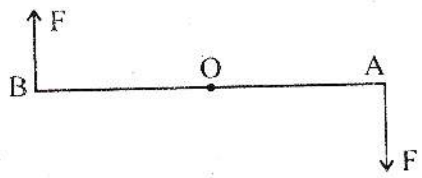
A couple is formed by two unlike parallel forces of the same magnitude but not along the same line.

Examples

- While turning a car, the forces applied on the steering wheel by hands provide the necessary couple.
- While opening or closing a water tap,
- While locking or opening the stopper of a bottle or a jar.

Explanation

A double arm spanner is used to open a nut. Equal forces each of magnitude F are applied on ends A and B of a spanner in opposite direction as shown in figure. These forces form a couple that turns the spanner about a point O. the torques produced by both forces of the couple have same direction. The total torque produced by the couple will be,



Total torque of the couple = F x OA + F x OB

= F (OA + OB)

Torque of the couple = F x AB

The above equation shows that torque produced by the couple of forces F and F separated by distance AB. The toque of a couple is given by the product of one of the two forces and perpendicular distance between them.

Couple arm

The perpendicular distance "r" between the two forces of the couple is called the couple arm.

4.8 EQUILIBRIUM

Q.No.8 What is equilibrium? State and explain the conditions of equilibrium.

Ans: Equilibrium

If no force is acting on the body or a number of forces act on a body in such a way that their resultant is zero, then if the body is at rest it will remain at rest and if the body is in motion, it will continue moving with a uniform velocity. This condition of the body is called equilibrium.

First Condition of Equilibrium

A body will be in equilibrium if the resultant of all the forces acting on it is zero. This is first condition of equilibrium.

Explanation

Let n number of forces $F_1, F_2, F_3, \ldots\ldots, F_n$ are acting on a body such that

$F_1 + F_2 + F_3 + \ldots\ldots + F_n$

$\sum F = 0$ .... (1)

The symbol $\sum$ is a Greek letter called sigma used for summation. The first condition of equilibrium for equilibrium can also stated in terms of x and y-component of the forces on the body as:

$$F_{1x} + F_{2x} + F_{3x} + \ldots\ldots + F_{nx} = 0$$

And $$F_{1y} + F_{2y} + F_{3y} + \ldots\ldots + F_{ny} = 0$$

OR $$\sum F_x = 0 \quad \ldots\ldots\ldots\ldots \quad (2)$$

$$\sum F_y = 0 \quad \ldots\ldots\ldots\ldots \quad (3)$$

Examples

Examples of bodies satisfying the first condition of equilibrium are given below:

- A book lying on a table or a picture hanging on a wall are at rest
- A paratrooper coming down with terminal velocity (constant velocity)

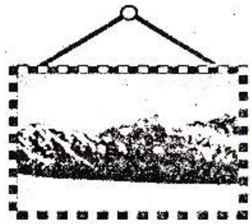


Figure 4.27: A wall hanging is in equilibrium

Linear acceleration

When the 1st condition of equilibrium is satisfied, no linear acceleration is produced in the body.

Second Condition of Equilibrium

If a number of forces act on a body so that the total sum of the torques of these forces is zero, the body will be in equilibrium.

$$\sum \tau = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

This is called the 2nd condition of equilibrium. If these two conditions are satisfied, the body is completely in equilibrium.

Explanation

Consider a body pulled by two forces F_1 and F_2 as shown in figure. The two forces are equal but opposite to each other. Both are acting along the same line, hence their resultant will be zero. According to first condition of equilibrium, the body will be in equilibrium. Now shift the location of the forces as shown in the figure. In this situation, the body is not in equilibrium although the first condition of equilibrium is still satisfied. It is because the body has the tendency to rotate. This situation demands another condition for equilibrium in addition to first condition of equilibrium.

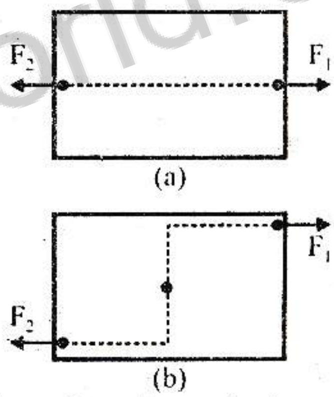


Figure 4.30: (a) Two equal and opposite forces acting along the same lines **(b)** Two equal and opposite forces acting along different lines.

Rotational acceleration

When the 2nd condition of equilibrium is satisfied, then no rotational acceleration is produced in the body.

States of Equilibrium

Q.No.9 Define and explain the three states of equilibrium.

Ans: There are three states of equilibrium:

(i) Stable equilibrium

(ii) Unstable equilibrium

(iii) Neutral equilibrium

Stable equilibrium

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

When body is in stable equilibrium, its centre of gravity is at the lowest position. When it is tilted, its centre of gravity rises. It returns to its stable state by lowering its centre of gravity. A body remains in stable equilibrium as long as the centre of gravity acts through the base of the body.

Example

Consider a block as shown in figure. When the block is tilted, its centre of gravity G rises. If the vertical line through G passes through its base in the tilted position, the block returns to its previous position. If the vertical line through G gets out its base, it does not return to its previous position.

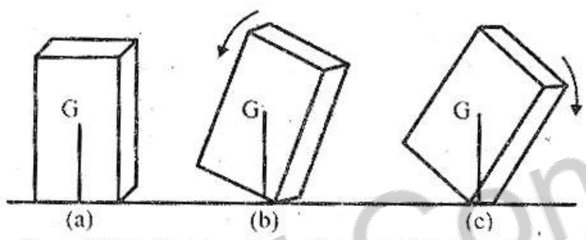


Figure 4.34 (a) Block in stable equilibrium **(b)** Slightly tilted block is returning to its previous position. **(c)** A more tilted block topples over its base and does not return to its previous position.

It topples over its base and moves to new stable equilibrium position. That is why a vehicle made heavy at its bottom to keep its centre of gravity as low as possible. A lower centre of gravity keeps it stable. Moreover, the base of the vehicle is made wide so that the vertical lien passing through the centre of gravity should not get out of its base during a turn.

More Examples

Table, chair, box and brick lying on a floor.

Unstable equilibrium

If a body does not returns to its previous position when sets after a slightest tilt is said to in unstable equilibrium.

The centre of gravity of the body is at its highest point in the state of unstable equilibrium. As the body topples over about its base, its centre of gravity moves towards its lower position and does not return to its previous position.

Example

A pencil is made to stand in equilibrium on its tip. When you leave it, the pencil topples over about its tip and falls down. The body may be made to stay only for a moment. Thus a body is unable to keep itself in the state of unstable equilibrium.

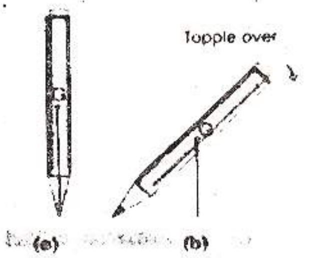


Figure 4.36: Unstable equilibrium (a) pencil just balanced at its tip with centre of gravity G at the highest position (b) Pencil topples over caused by the torque of its weight acting at G.

More Examples

- A stick standing vertically on the tip of a finger.
- A cone standing on the tip of a finger.

Neutral equilibrium

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

Example

A ball lying on a horizontal surface is shown in figure. Roll the ball over the surface and leave it after displacing from the previous position. It remains in its new position and does not return to its new position.

In neutral equilibrium, the centre of gravity of a body remains at the same height, irrespective of its new position.

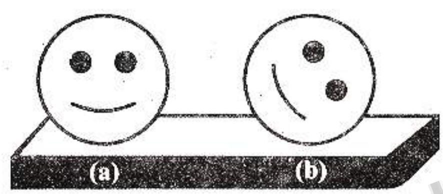


Figure 4.37: Neutral equilibrium (a) a ball is placed on a horizontal surface (b) the ball remains in its new displaced position.

More Examples

A pencil, a sphere, and cylinder, a roller, an egg lying horizontally on a flat surface.

4.9 STABILITY AND POSITION OF CENTRE OF MASS

Q.No.10 How Stability and Position of centre of mass are related to each other?

Ans: As we have learnt that position of centre of mass of an object plays an important role in their stability. To make them stable, their centre of mass must be kept as low as possible. It is due to the reason, racing cars are made heavy at the bottom and their height is kept to be minimum.

Examples

Here are few examples in which lowering of centre of mass makes the objects stable. These objects return to their stable states when disturbed. In each case centre of mass is vertically below their point of support. This makes their equilibrium stable.

- Circus artists such as tight rope walker use long poles to lower their centre of mass. In this way they are prevented from topple over.

- Figure shows a sewing needle fixed in a cork. The cork is balanced on the tip of the needle by hanging forks. The forks lower the centre of mass of the system.

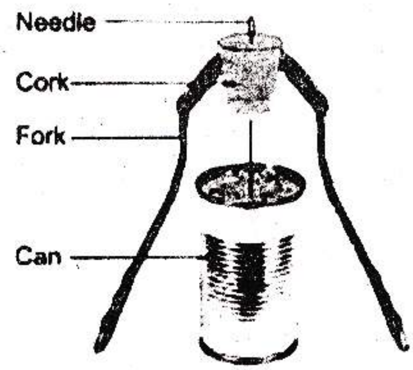


Figure 4.38: A needle is made to balance at its tip.

- Figure shows a perched parrot which is made heavy at its tall. Figure shows a toy that keeps itself upright when tilted. It has heavy semi spherical base. When it is tilted, its centre of mass rises. It returns to the upright position at which its centre of mass is at the lowest.

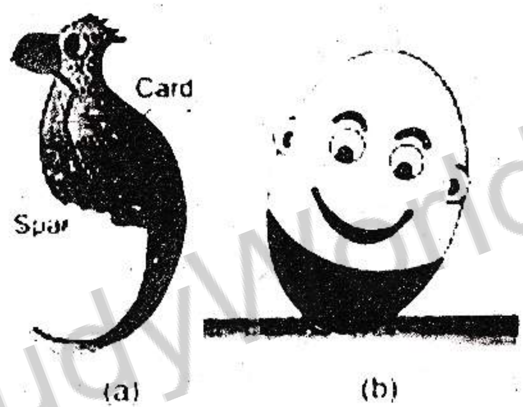


Figure 4.39 **(a)** A perched parrot
(b) A self righting toy

MINI EXERCISE

(1) In a right angled triangle length of base is 4 cm and its perpendicular is 3 m. Find

(i) length of hypotenuse (ii) sin θ (iii) cos θ (iv) tan θ

Ans: (i) We know that

$$(\text{Hypotenuse})^2 = (\text{Base})^2 + (\text{Perpendicular})^2$$
$$= (4)^2 + (3)^2$$
$$= 16 + 9$$
$$= 25$$

By taking square root on both sides

$$\text{Hypotenuse} = 5\text{cm}$$

(ii) As we know that

$$\sin\theta = \frac{\text{perpendicular}}{\text{hypotenuse}}$$

So $$\sin\theta = \frac{3}{5}$$

(iii) As we know

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

So $$\text{Cos}\theta = \frac{4}{5}$$

(iv) As we know that

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

So $$\tan\theta = \frac{3}{4}$$

(2) A force of 150 N can loosen a nut when applied at the end of a spanner 10cm long.

$$F = 150\text{ N}$$
$$L = 10\text{ cm}$$
$$= 0.1\text{ m}$$

So

$$\tau = F \times L$$
$$\tau = 150 \times 0.1$$
$$= 15\text{ Nm}$$

i. What should be the length of the spanner to loosen the same nut with a 60 N force?

Ans: As

$$\tau = F \times L$$
$$15 = 60 \times L$$
$$L = \frac{15}{60}$$
$$= 0.25\text{ m}$$
$$= 25\text{ cm}$$

ii. How much force would be sufficient to loosen it with a 6 cm long spanner?

Ans: As

$$L = 6\text{ cm}$$
$$= 0.06\text{ m}$$
$$\tau = F \times L$$
$$15 = F \times 0.06\text{ m}$$
$$L = \frac{15}{0.06}$$
$$= 250\text{ N}$$

(3) Can a small child play with a fat child on the see-saw? Explain how?

Ans: Yes, Fat child can play with small child by adjusting the moment arm.

(4) Two children are sitting on the see-saw, such that they can not swing. What is the net torque in this situation?

Ans: When two children are sitting on the see-saw, such that they cannot swing. In this case, net torque such that they can swing. In this case, net torque would be zero because second condition of equilibrium is satisfied.

(5) A ladder leaning at a wall as shown in figure 4.31 is in equilibrium. How?

Ans: Ladder is in equilibrium because its satisfies second condition of equilibrium.

Figure 4.31: A ladder leaning at a wall

(6) The weight of the ladder in figure 4.31 produces an anticlockwise torque. The wall pushes the ladder at its top end thus produces a clockwise torque. Does the ladder satisfy second condition for equilibrium?

Ans: Yes, its satisfies second condition of equilibrium because both torques are equal in magnitude what opposite in direction.

(7) Does the speed of a ceiling fan go on increasing all the time?

Ans: Speed of ceiling fan does not increase all the times. At acquiring maximum speed it moves with uniform speed.

(8) Does the fan satisfy second condition for equilibrium-when rotation with uniform speed?

Ans: No, it does not satisfy the second condition of equilibrium. Because it neither in the state of rest nor moving with uniform velocity.

TEXTBOOK EXERCISE QUESTIONS

4.1 Encircle the correct answer from the given choices.

i. Two equal but unlike parallel forces having different line of action produces:

a) Torque **b) couple** c) equilibrium d) neutral equilibrium

ii. The number of forces that can be added by head to tail rule are:

a) 2 b) 3 c) 4 **d) any number**

iii. The number of perpendicular components of forces are:

a) 1 **b) 2** c) 3 d) 4

iv. A force of 10 N is making an angle of 30° with the horizontal. Its horizontal component will be:

a) 4 N b) 5 N c) 7 N **d) 8.7 N**

v. A couple is formed by:

a) Two forces perpendicular to each other

b) Two like parallel forces

c) Two equal and opposite forces in the same line

d) Two equal and opposite forces not in the same line

vi. A body is in equilibrium when its:

a) Acceleration is uniform b) Speed is uniform

c) Speed and acceleration is uniform **d) Acceleration is zero**

vii. A body is in neutral equilibrium when its centre of gravity:

a) Is at its highest position b) Is at the lowest position

c) Keeps its height it displaced d) Is situated at its bottom

viii. Racing cars are made stable by:

a) Increasing their speed b) Decreasing their mass

c) Lowering their centre of gravity d) Decreasing their width

4.2 Define the following:

Ans:

(i) Resultant vector

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

(ii) Torque

The rotational effect of a force is measured by a quantity, known as torque.

(iii) Centre of mass

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

(iv) Centre of gravity

a point where the whole weight of the body appears to act vertically downward is called the centre of gravity of a body.

4.3 Differentiate the following.

Ans:

(i) Like and unlike parallel forces

Like Parallel Forces	Unlike Parallel Forces
Like parallel forces are the forces that are parallel to each other and have the same direction.	Unlike parallel forces are the forces that are parallel but have direction opposite to each other.

(ii) Torque and Couple

Torque	Couple
"The rotational effect of a force is measured by a quantity, known as torque".	A couple is formed by two unlike parallel forces of the same magnitude but not along the same line.

(iii) Stable and Neutral Equilibrium

Stable Equilibrium	Neutral Equilibrium
"A body is said to in stable equilibrium if after a slight tilt it returns to its previous position".	"If a body remains in its new position when disturbed from its previous position, it is said to be in a state of neutral equilibrium".

4.4 How head to tail rule helps to find the resultant of forces?

Ans: In head to tail rule, resultant force is found by joining the tail of the first force with heac of the last force.

4.5 How can a force be resolved into its rectangular components?

Ans: See Q. no.2 Long Question

4.6 When a body is said to be in equilibrium?

Ans: A body is said to be in equilibrium if no net force acts on it. A body in equilibrium remains at rest or moves with uniform velocity.

4.7 Explain the first condition for equilibrium.

Ans: See Q. no.8 Long Question

4.8 Whey there is need of second condition for equilibrium if a body satisfies first condition for equilibrium.

Ans: Two equal and opposite (unlike) force having their different lines of action form couple, which produce angular acceleration. Although first condition of equilibrium is being satisfied.

4.9 What is second condition of equilibrium?

Ans: A body satisfies second condition of equilibrium when the resultant torque acting on it is zero.

4.10 Give an example of a moving body which is in equilibrium.

Ans:

(i) A body with uniform velocity in straight line is in the equilibrium.

(ii) A paratrooper coming down with terminal velocity is in equilibrium.

4.11 Think of a body which is at rest but not in equilibrium.

Ans: A ball thrown upward becomes at rest at the top. At this state it is not in equilibrium although it is at rest.

4.12 When a body cannot be in equilibrium due to a single force on it?

Ans: A single force acting on a body is not balanced and produces acceleration. Therefore, in the presence of a single force body can not be in equilibrium.

4.13 Why the height of vehicles is kept as low as possible?

Ans: Vehicles are made heavy at the bottom. This lowers their centre of gravity and helps their stability and avoids the chance of toppling down.

4.14 Explain what is meant by stable, unstable, and neutral equilibrium. Give one example in each case.

Ans: See Q. no.9 Long Question

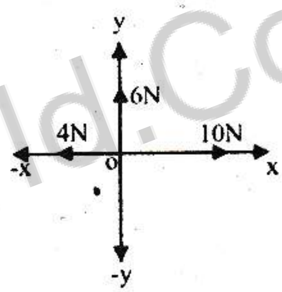
PROBLEMS

4.1 Find the resultant of the following forces.

(i) 10 N along x – axis

(ii) 6 N along y – axis

(iii) 4 N along negative x – axis



Solution

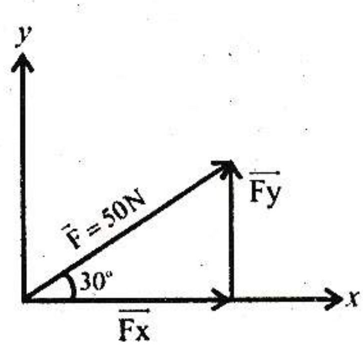
Scale 2N = 1cm

10N = 5cm

6N = 3cm

4N = 2cm

4.2 Find the rectangular components of a force of 50 N making an angle of 30^0 with x – axis.



Given Data

Force = F = 50 N

Angle = $\theta = 30^0$

Required

Horizontal component of force = F_x = ?

Vertical component of force = F_y = ?

Solution

As we know that

$$F_x = F\cos\theta$$

By putting the values, we have

$$F_x = 50 \times \cos 30^0$$
$$F_x = 50 \times 0.866$$
$$F_x = 43.3 \text{ N}$$

Also we know that

$$F_y = F \sin\theta$$
$$F_y = 50 \times \sin 30^0$$
$$F_y = 50 \times 0.5$$
$$F_y = 25 \text{ N}$$

Result

Horizontal component of force = F_x = 43.3 N
Vertical component of force = F_y = 25 N

4.3 Find the magnitude and direction of a force. If its x – component is 12 N and y component is 5 N.

Given Data

X – component of the force = F_x = 12N
Y – component of the force = F_y = 5N

Required

Magnitude of the resultant force = F =?
Direction of the resultant force = θ =?

Solution

According to Pythagoras theorem

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

By putting the values, we have

$$F = \sqrt{(13)^2 + (5)^2}$$
$$F = \sqrt{144 + 25}$$
$$F = \sqrt{169}$$
$$F = 13\text{N}$$

We also know that

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

By putting the values, we have

$$\theta = \tan^{-1} \frac{5}{13}$$
$$\theta = \tan^{-1} 0.38461$$
$$\theta = 22.6^o \text{ with x-axis}$$

Result

Magnitude of the resultant force = F = 13 N
Direction of the resultant force = θ = 22.6° with x-axis

4.4 A force of 100 N is applied perpendicularly on a spanner at a distance of 10 cm from a nut. Find torque produced by the force.

Given Data

Force acting on spanner = F = 100 N

Distant from nut = L = 10 cm = 0.1 m

Required

Torque produced by the force = τ = ?

Solution

As we know that

$$\tau = F \times L$$

By putting the values, we have

$$\tau = 100 \times 0.1$$

$$\tau = 10 \text{ Nm}$$

Result

Torque produced by the force = τ = 10 Nm

4.5 A force is acting on a body making an angle of 30^0 with the horizontal. The horizontal component of force is 20 N. Find the force.

Given Data

Horizontal component of the force = Fx = 20 N

Angle formed with the horizontal = $\theta = 30^0$

Required

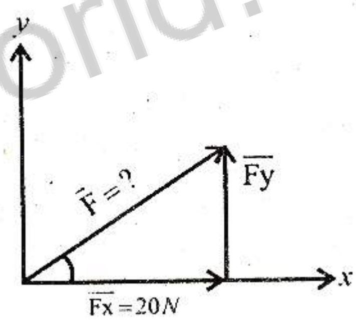
Force applied = F = ?

Solution

As we know that

$$F_x = F\cos\theta$$

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



By putting the values, we have

$$F = \frac{20}{\cos 30^0}$$

$$F = \frac{20}{0.866}$$

$$F = 23.09 \text{ N} = 23.1 \text{ N}$$

Result

Force applied = F = 23.1 N

4.6 The steering of a car has a radius 16 cm. Find the torque produced by a couple of 50 N.

Given Data

Force of the couple = F = 50 N

Radius of the steering = r = 16cm

Couple arm = d = AB = 32 cm = 0.32 m

Required

Torque produced by the couple = τ = ?

Solution

As we know that

$$\tau = F \times AB$$

By putting the values, we have

$$\tau = 50 \times 0.32$$
$$\tau = 16 \text{ Nm}$$

Result

Torque produced by the couple = τ = 16 Nm

4.7 A picture frame is hanging by two vertical strings. The tensions in the strings are 3.8 N and 4.4 N. Find the weight of the picture frame.

Given Data

Tension in the first string = T_1 = 3.8 N
Tension in the second string = T_2 = 4.4 N

Required

Weight of the picture frame = w = ?

Solution

From first condition of equilibrium, we have

$$\sum F_y = 0$$

OR Sum of downward forces = Sum of upward forces

$$w = T_1 + T_2$$

By putting the values, we have

$$w = 3.8 \text{ N} + 4.4 \text{ N}$$
$$w = 8.2 \text{ N}$$

Result

Weight of the picture frame = w = 8.2 N

4.8 Two blocks of 5 kg and 3 kg are suspended by the two strings are shown. Find the tension in each string.

Given Data

Mass of upper block = m_1 = 5 kg
Mass of below block = m_2 = 3 kg
Weight of the upper block = $w_1 = m_1g = 5 \times 10 = 50$ N
Weight of the below block = $w_2 = m_2g = 3 \times 10 = 30$ N

Required

Tension in upper string = T_1 = ?
Tension in lower string = T_2 = ?

Solution

From second condition of equilibrium, we have

$$\sum F_y = 0$$

OR Tension in the lower string = weight of the lower block

$$T_2 = w_2$$
$$T_2 = 30 \text{ N}$$

Tension in upper string = weight of lower block + weight of upper block

$$T_1 = w_1 + w_2$$
$$T_1 = 50 \text{ N} + 30 \text{ N}$$
$$T_1 = 80 \text{ N}$$

Result

Tension in upper string = T_1 = 80 N

Tension in lower string = T_2 = 30 N

4.9 A nut has been tightened by a force of 200 N using 10 cm long spanner. What length of spanned is required to loosen the same nut with 150 N force?

Given Data

Initial force = F_1 = 200 N

Initial moment arm = L_1 = 10 cm = 0.1 m

Second force = F_2 = 150 N

Required

Second moment arm = L_2 = ?

Solution

According to second condition of equilibrium, we have

$$\sum\tau = 0$$

OR Clockwise torque = Anticlockwise torque

$$F_2 \times L_2 = F_1 \times L_1$$

$$150 \times L_2 = 200 \times 0.1$$

$$L_2 = \frac{200\times0.1}{150}$$

$$L_2 = 0.133 \text{ m}$$

$$L_2 = 13.3 \text{ cm}$$

Result

Second moment arm = L_2 = 13.3 cm

4.10 A block of 10 kg is suspended at a distance of 20 cm from the centre of uniform bar 1m long. What force is required to balance it at its centre of gravity by applying the force at the other end of the bar?

Given Data

Mass of block = m = 10kg

Weight of the block = w = F_1= mg = 10 x 10 = 100 N

First moment arm = L_1 = 20 cm = 0.2 m

Second moment arm = L_2 = 50 cm = 0.5 m

Required

Second force = F_2 = ?

Solution

According to second condition of equilibrium, we have

$$\sum\tau = 0$$

OR Clockwise torque = Anticlockwise torque

$$F_2 \times L_2 = F_1 \times L_1$$

$$F_2 \times 0.5 = 100 \times 0.2$$

$$F_2 = \frac{100\times0.1}{0.50}$$

$$F_2 = 40 \text{ N}$$

Result

Second force = F_2 = 40 N