UNIT # 4
TURNING EFFECT OF FORCES

Q1. Can the nut of the axle of a bike be loosened with hand why we use a spanner for this purpose?

we can lose a nut with a spanner

Ans: No, we cannot loosen the nut of the excel of a bike. Normally we use a spanner because a spanner increases the turning effect of the force which easily loosened the nut of excel of a bike.

Q2. What is the joker doing in the figure?

Ans: He is trying to balance himself on a wooden plank which is placed over a cylindrical pipe. Due to open the arms he is doing its centre of mass as low as possible to make him stable.

Q3. Women and children in the villages often carry pitchers with water on their heads how this is possible?


Children carrying pitchers on their heads

Ans: Woman and children keep itself upright when carry pitchers on their heads. Pitcher has a heavy semi-spherical base. When it is tilted, its centre of mass rises. It returns to its upright position at which its centre of mass is at the lowest.

That is why Women and children in the villages often carry pitchers with water on their heads.

Q4. With a little effort we can learn to balance a stick vertically up on our finger tip how this is possible.

Ans: In order to balance something, all you need to do is make sure that the center of gravity of the object is either directly above or directly below the pivot point. An example would be balancing the stick on the end of a finger with the stick pointing vertically up. If you do this you will find that the stick wants to fall over, and you need to keep moving your finger around to keep this from happening.

Q5. What is meant by parallel forces?

Ans: Parallel Forces:

In a plane, 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 called parallel forces.

Q6. What is the difference between like and unlike parallel force?

OR

Define like and unlike parallel force?

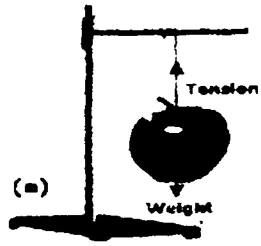
Ans: See Q # 4.3 (i) from Exercise.

Q7. Many people push a bus to start it why all of them push it in the same direction?

Ans: Like parallel forces acting in the same direction increases the resultant force which moves the bus easily.

Q8. Explain the unlike parallel forces in the given figure?

Ans: An apple is suspended by a string. The string is stretched due to weight of the apple. The forces acting on it are; weight of the apple acting vertically downwards and tension in the string pulling it vertically upwards. The two forces are parallel but opposite to each other. These forces are called unlike parallel forces.



Q9. Explain the unlike parallel forces in the given figure?

Ans: In figure, forces F_1 and F_2 *are* also unlike parallel forces, because they are parallel and opposite to each other. But F_1 and F_2 are not acting along the same line and hence they are capable to rotate the body.

Q10. Define resultant vector?

Ans: Resultant Vector:

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

OR

The sum of two or more vector is a single vector which has the same effect as the combined effect of all the vectors to be added. This single vector is called resultant vector.

Q11. How head to tail rule helps to find the resultant of forces?

Ans: See Q # 4.4 from Exercise

Q12. What is meant by trigonometry? Give some important trigonometric ratios.

Ans: Trigonometry:

Trigonometry is that branch of mathematics which deals with the properties of a right angled triangle.

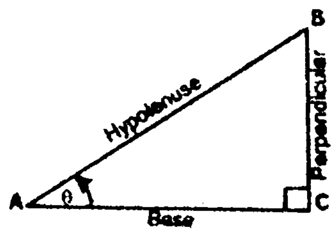
Trigonometric ratios:

Consider a right angled triangle ΔABC having angle θ at A.

$$\sin\theta = \frac{\text{Prependicular}}{\text{Hypotenuse}} = \frac{BC}{AB}$$

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

$$\tan\theta = \frac{\text{Prependicular}}{\text{Base}} = \frac{BC}{AC}$$



Note:

To remember trigonometric ratios use the following sentence:

"Some people have - Curly brown hair -Through proper brushing".

Pythagoras theorem:

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

Q13. How can a force be resolved into its rectangular components?

OR

Explain the resolution of vector?

Ans: See Q # 4.5 from Exercise.

Trigonometric Table

Ratio/θ	0°	30°	45°	60°	90°
sin θ	0	0.5	0.707	0.866	1
cos θ	1	0.866	0.707	0.5	0
tan θ	0	0.577	1	1.732	∞

Mini Exercise

In a right angled triangle length of base is 4 cm and its perpendicular is 3 cm. Find:

(i) Length of hypotenuse **(ii) sin θ**

(iii) cos θ **(iv) tan θ**

Solution:

(i) Length of hypotenuse:

Pythagoras theorem:

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

$(\text{Hypotenuse})^2 = (4)^2 + (3)^2$

$(\text{Hypotenuse})^2 = 16 + 9$

$(\text{Hypotenuse})^2 = 25$ by taking square root on both sides

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

(ii) sin θ:

$$\sin\theta = \frac{\text{Prependicular}}{\text{Hypotenuse}} = \frac{3}{5}$$

(iii) cos θ:

$$\cos\theta = \frac{\text{Base}}{\text{Hypotenuse}} = \frac{4}{5}$$

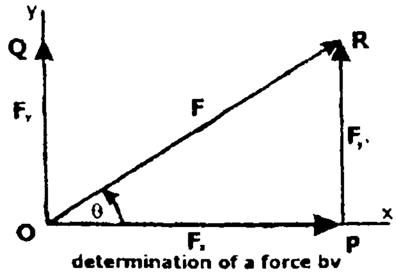
(iv) tan θ:

$$\tan\theta = \frac{\text{Prependicular}}{\text{Base}} = \frac{3}{4}$$

Q14. Briefly explain determination of a force from its perpendicular components?

Ans: Determination of a Force or a vector from its Perpendicular Components:

Consider F_x and F_y as the perpendicular components of a force $\mathbf{F}$. These perpendicular components F_x and F_y are represented by lines **OP** and **PR** respectively.



determination of a force by perpendicular components

According to head to tail rule:

$$OR = OP + PR$$

Thus **OR** will completely represent the force **F** whose x and y-components are F_x and F_y respectively. That is

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

Magnitude of resultant force/Magnitude of resultant 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 $$F = \sqrt{F_x^2 + F_y^2} \qquad \text{(i)}$$

Direction of the resultant force/Direction of the resultant vector:

The direction of force **F** with x-axis is given by

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

$$\theta = \tan^{-1}\frac{F_y}{F_x} \qquad \text{(ii)}$$

Q15. Why it is easy to open and close the door by pulling or pushing it at its handle?

Ans: We open or close a door by pushing or pulling it. Here push or pull turn the door about its hinge or **axis of rotation**. The door is opened or closed due to the **turning effect** of the force acting on it.

Q16. What do you mean by a rigid body?

Ans: Rigid body:

A body is composed of large number of small particles. If the distances between all pairs of particles of the body do not change by applying a force then it is called a rigid body. In other words, a rigid body is the one that is not deformed by force or forces acting on it.

Q17. What do you mean by axis of rotation?

Ans: Axis of rotation:

Consider a rigid body rotating about a line. The particles of the body move in circles with their centres all lying on this line. This line is called the axis of rotation of the body.

Q18. Name some objects that work by the turning effects of forces.

Ans: Turning pencil in a sharpener, turning stopcock of a water tap, turning doorknob and so on are some of the examples where a force produces turning effect.

QUICK QUIZ

1. Name some more objects that work by the turning effects of forces.

Ans: **(i)** Torque is produced when a force is applied to paddle of a bicycle. Because by applying force its wheels experience the rotational effect (torque).

(ii) Torque is produced when a force is applied to the door to open.

Q19. Define torque. What is its unit? On what factors torque (moment of a force) depends?

Ans: **Torque (moment of a force):**

The turning effect of a force is called torque or moment of the force.

Torque $\tau = F \times L$

Torque is a vector quantity and its direction can be found by using the right hand rule.

Unit of torque:

Unit of torque is Nm.

Torque depends upon two factors.

The torque or moment of a force depends upon the force F and the moment arm *L* of the force.

i. Magnitude of the force (F)

Greater is a force, greater is the moment of the force.

$\tau \propto F$ ....(i)

ii. Moment arm:-

Similarly, longer is the moment arm greater is the moment of the force.

$\tau \propto L$ ....(ii)

Q20. Why the handle of a door is fixed near the outer edge of a door?

OR

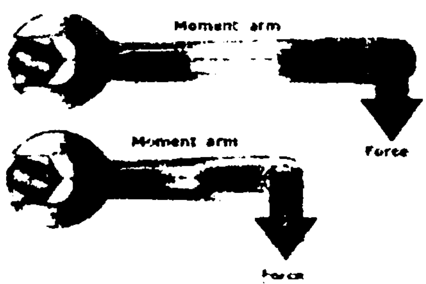
Why door handles usually on the opposite edge of the door from the hinge?

Ans: We can open or close a door more easily by applying a force at the outer edge of a door rather than near the hinge.

The moment produced by a force using a greater moment arm is greater than the torque produced by the same force using by shorter moment arm. Therefore the handle of a door is fixed near the outer edge of a door. ($\tau \propto L$)

Q21. Why it is easy to tighten a nut using a spanner of longer arm than a spanner of shorter arm

Ans: A spanner having long arm helps to loosen or tighten a nut or a bolt with greater ease than the one having short arm. It is because the turning effect (torque) of the force increases. ($\tau \propto L$)

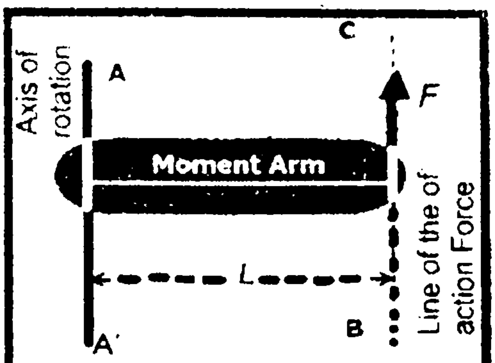


It is easy to tighten a nut using a spanner of longer arm than a shorter arm

Q22. What do you mean by line of action of a force?

Ans: Line of action of a force:

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

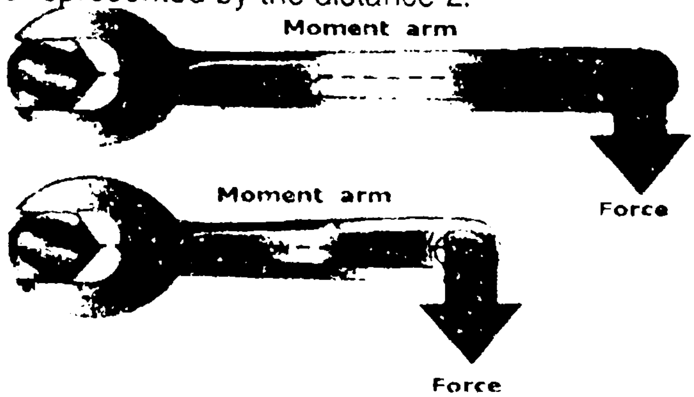


Factors affecting the moment of a force

Q23. Define moment arm.

Ans: Moment arm:

The perpendicular distance between the axis of rotation and the line of action of the force is called the moment arm of the force. It is represented by the distance L.



It is easy to tighten a nut using a spanner of lo
than a shorter arm

Q24. What do you mean by newton-metre (Nm)?

Ans: SI unit of torque is newton-metre (Nm).

newton-metre (Nm):

A torque of 1 N m is caused by a force of 1 N acting perpendicular to the moment arm 1 m long.

Mini Exercise

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

Solution: $F = 150$ N

$L = 10 \text{ cm} = \frac{10}{100} = 0.1 \text{ m}$

Torque $\tau = ?$

$\tau = F \times L$

$\tau = 150 \text{ N} \times 0.1 \text{ m}$

$\tau = 15 \text{ Nm}$

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

Solution: $F = 60$ N

$\tau = 15$ Nm

$L = ?$

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

$$L = \frac{15}{60} = 0.25 \text{ m}$$

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

Solution: $L = 6cm = \frac{6}{100} = 0.06\ m$

$\tau = 15\ Nm$

$F = ?$

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

$$F = \frac{15}{0.06} = 250\ N$$

Q25. Describe principle of moment?

Ans: Principle of moments:

According to the principle of moments:

A body is balanced if the sum clockwise moments acting on the body is equal to the sum of anticlockwise moments acting on it

Explanation:

Clockwise moment:

A force that turns a spanner in the clockwise direction is generally used to tighten a nut. The torque or moment of the force so produced is called **clockwise moment**.

Anticlockwise moment:

On the other hand, to loosen a nut, the force is applied such that it turns the nut in the anticlockwise direction. The torque or moment of the force so produced is called **anticlockwise moment**.

(a) to tighten, nut is turned clockwise (b) to loosen, nut is turned anticlock

Note:

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.

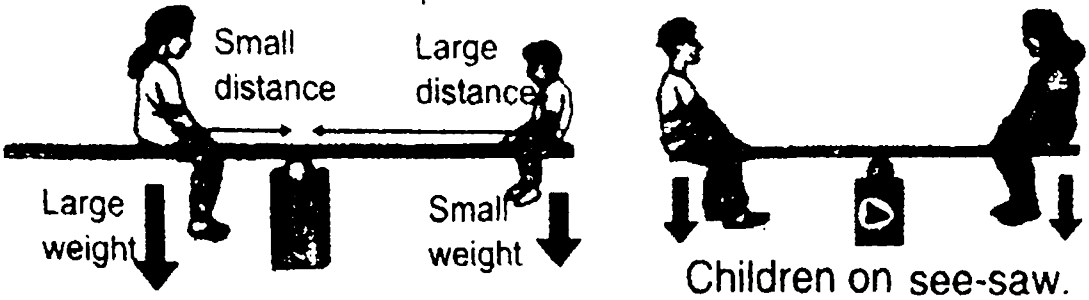
QUICK QUIZ

1. **Can a small child play with a fat child on the seesaw? Explain how?**

Ans: Yes, they can play on see saw, the fat child has larger weight that's mean larger force and smaller child has smaller weight and smaller force. So in order to play, larger weight should be at smaller distance from the centre of the see saw and the smaller weight should be at larger distance from the centre of the see saw. In another situation a fat child cannot play with a „ small child if they have equal distances from the centre see-saw.

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

Ans: Net torque in this situation is zero. Because clockwise torque will cancel the effect of anticlockwise torque.



Children on see-saw.

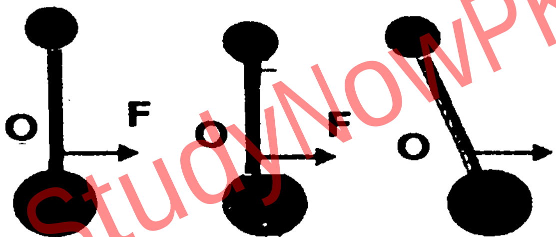
Q26. Explain how center of mass helps the system to move as well as rotate?

Ans: Centre of mass:

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 moves as if its entire mass is confined at 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.



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

Q27. Define centre of gravity?

Ans: Centre of gravity:

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

Note:

It is useful to know the location of the centre of gravity of a body in problems dealing with equilibrium.

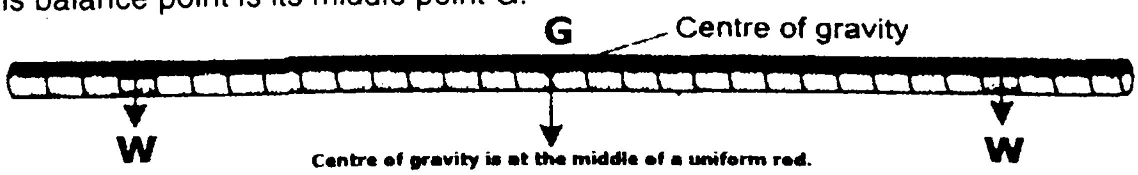
Q28. List the centre of gravity of some symmetrical objects?

Ans: Centre of gravity of symmetrical objects:

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

The centre of gravity of a uniform rod:

The centre of gravity of a uniform rod lies at a point where it is balanced. This balance point is its middle point G.



centre of gravity is at the middle of a uniform rod

Centre of a gravity of a uniform square or a rectangular sheet:

The centre of a gravity of a uniform square or a rectangular sheet is the point of intersection of its diagonals.

Centre of gravity of a uniform circular disc:

The centre of gravity of a uniform circular disc is its centre.

Gravity of a solid sphere or hollow sphere:

Similarly, the centre of gravity of a solid sphere or hollow sphere is the centre of the spheres.

Centre of gravity of a uniform triangular sheet:

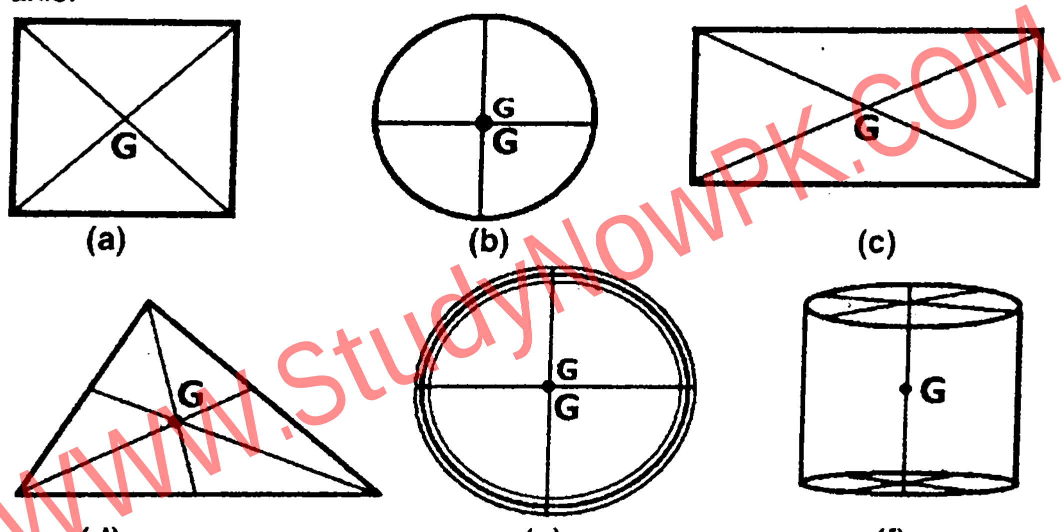
The centre of gravity of a uniform triangular sheet is the point of intersection of its medians.

Centre of gravity of a uniform circular ring:

The centre of gravity of a uniform circular ring is the centre of the ring.

Centre of gravity of a uniform solid or hollow cylinder:

The centre of gravity of a uniform solid or hollow cylinder is the middle point on its axis.



Centre of gravity of some symmetrical objects

No.	Object	Centre of gravity
1	Uniform rod	Centre of the rod
2.	Round plate	Centre of the plate
3.	Sphere	Centre of the sphere
4.	Triangular plate	Point of intersection of the medians
5.	Cylinder	Central point of axis
6.	Square, Rectangle, parallelogram	Point of intersection of the diagonals

Q29. Explain an experiment to find the centre of gravity of a four-sided plate of uniform thickness. How can you verify your answer by using geometry?

OR

Explain an experiment to find the centre of gravity of a an irragullar shaped thin lamina?

Ans: Centre of gravity of an irregular shaped thin lamina:

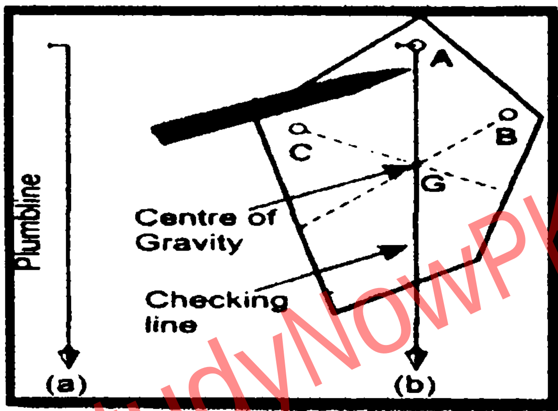
A simple method to find the centre of gravity of a body is by the use of a plumbline.

Plumbline:

A plumbline consists of a small metal bob (lead or brass) supported by a string. When the bob is suspended freely by the string, it rests along the vertical direction due to its weight acting vertically downward. 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 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 plumbline hung from the nail. Mark the line on the cardboard behind the plumbline.



(a) Plumbline (b) Locating the centre of gravity of a pace of cardboard by using plumbline.

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.

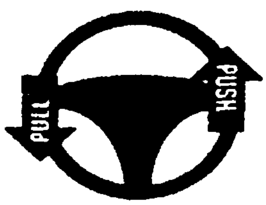
Q30. Define couple. Describe its role in steering wheel double arm spanner?

Ans: Couple:

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

Role of couple in steering wheel:

When a driver turns a vehicle, he applies forces that produce a torque. This torque turns the steering wheel. These forces act on opposite sides of the steering wheel and are equal in magnitude but opposite in direction. These two forces form a couple.



It is easy to turn a steering wheel by applying a couple.

Role of couple in double arm spanner:

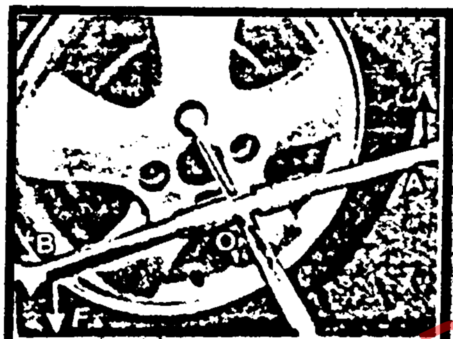
A double arm spanner is used to open a nut. Equal forces each of magnitude F are applied on ends A and B of a spanner in opposite direction. These forces form a couple that turns the spanner about point O. The torques produced by both the forces of a couple have the same direction. Thus, the total torque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

Total torque of the couple $= F \times OA + F \times OB$

$= F(OA + OB)$

Torque of the couple $= F \times AB$ .... (i)

Equation (i) gives the torque produced by a couple of forces F and F separated by distance AB.



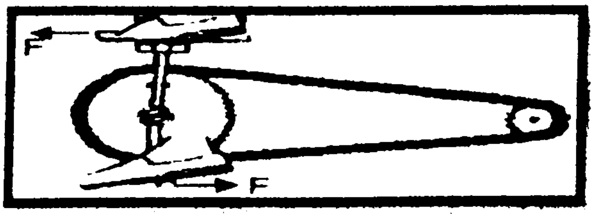
A double arm spanner

Torque of a couple:

The torque of a couple is given by the product of one of the two forces and the perpendicular distance between them.

DO YOU KNOW?

A cyclist pushes the pedals of a bicycle. This forms a couple that acts on the pedals. The pedals cause the toothed wheel to turn making the rear wheel of the bicycle to rotate.



Q31. When a body is said to be in equilibrium?

OR

Define equilibrium.

Ans: See Q # 4.6 from Exercise.

Q32. Explain the first condition for equilibrium.

Ans: See Q # 4.7 from Exercise.

Q33. What is second condition for equilibrium?

Ans: See Q # 4.9 from Exercise.

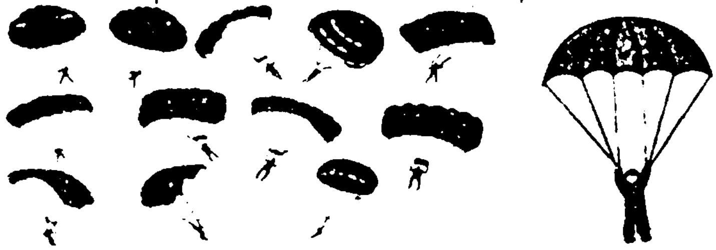
Q34. Why there is a need of second condition for equilibrium if a body satisfies first condition for equilibrium?

Ans: See Q # 4.8 from Exercise.

Q35. How does a paratrooper come down?

Ans: A paratrooper comes down with terminal velocity is in equilibrium.

A paratrooper coming down with terminal velocity (constant velocity) also satisfies first condition for equilibrium and is thus in equilibrium.



Q36. Define terminal velocity?

Ans: Terminal velocity:

The maximum and constant velocity of an object falling vertically downward is called terminal velocity.

$$Terminal\ velocity = V_t = \frac{2gr^2\rho}{9\eta}$$

Where g = acceleration due to gravity, r = radius, ρ = density, η = viscosity

QUICK QUIZ

1. A ladder leaning at a wall as shown in figure is in equilibrium. How?

Ans: In this case three forces involved are:

(a) The weight of the ladder

(b) The reaction at the wall (R_1) – at right angles because the wall is smooth

(c) The reaction at the ground (R_2) - not at right angles.

As the ground is rough and all the forces pass through the same point.

The vector diagram for the three forces will cancel the effect of each other therefore ladder leaning at a wall will be in equilibrium.

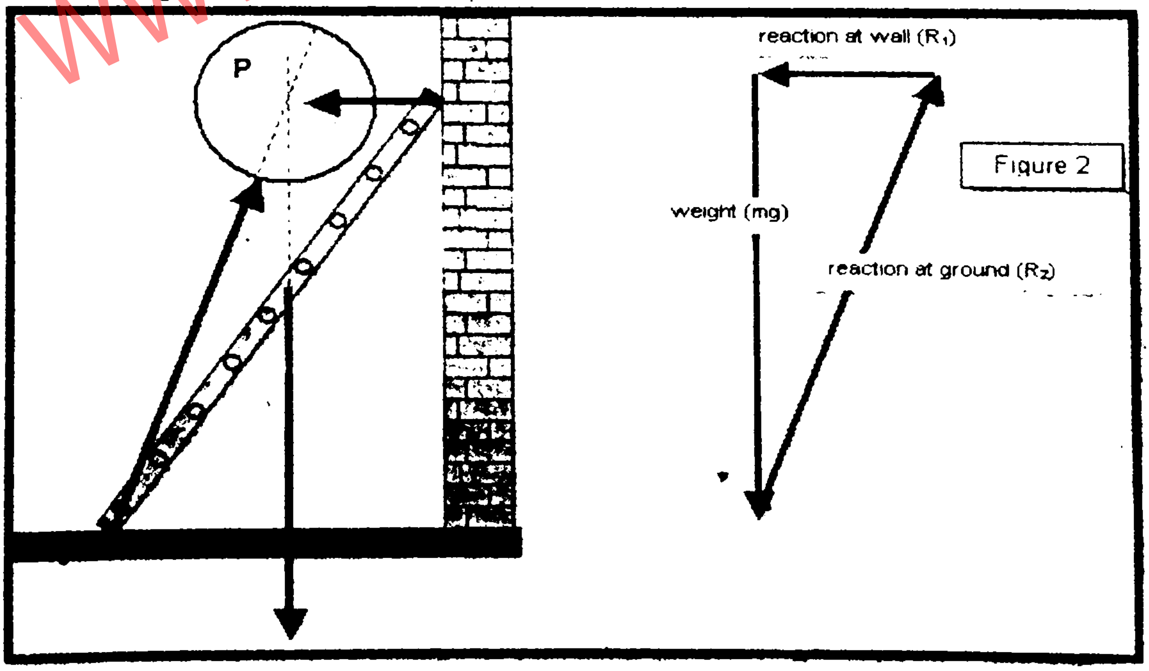
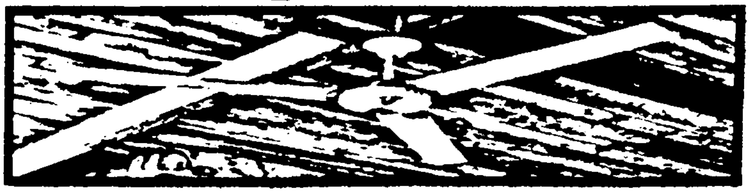


Figure 2

2. The weight of the ladder in figure 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 the ladder satisfies second condition for equilibrium because the clockwise torque will cancel the effect of anticlockwise torque. So the resultant torque acting in this situation is zero.

$$\sum \tau = 0$$



A ceiling fan rotating at constant speed is in equilibrium as net torque acting on it is zero.

$$\sum \tau = 0$$

3. Does the speed of a ceiling fan go on increasing all the time?

Ans: No, the speed of a ceiling fan does not go on increasing all the time. Fan will move with constant speed.

4. Does the fan satisfy second condition for equilibrium when rotating with uniform speed?

Ans: Yes, a rotating ceiling fan satisfy second condition for equilibrium. Because ceiling fan rotating at constant speed is in equilibrium as net torque acting on it is zero.

$$\sum \tau = 0$$

Q37. Explain what is meant by stable, unstable and neutral equilibrium. Give one example in each case.

OR

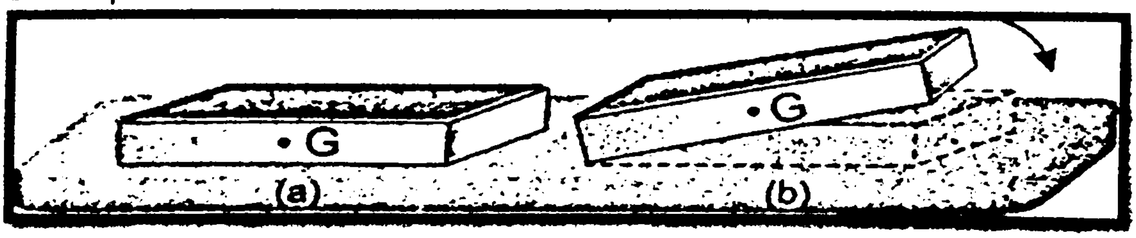
Briefly explain the states of equilibrium?

Ans: States of Equilibrium:

There are three states of equilibrium; stable equilibrium, unstable equilibrium and neutral equilibrium.

i. Stable equilibrium:

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



Stable equilibrium (a) A book is lying on a table (b) The book returns to its previous position when let free after a slight tilt.

Example:

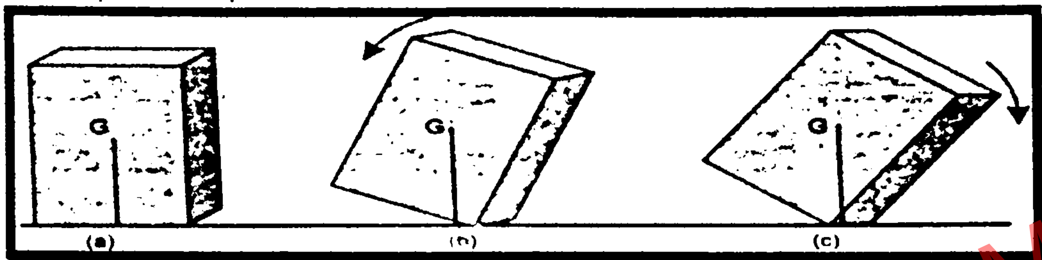
Consider a book lying on the table. Tilt the book slightly about its one edge by lifting it from the opposite side as shown in figure. It returns to its previous position when sets free. Such a state of the body is called stable equilibrium.

Features of stable equilibrium:

When a 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.

Explanation:

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 as shown in figure (b), the block returns to its previous position. If the vertical line through G gets out of its base as shown in figure (c), the block does not return to its previous position.



(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.

Unstable equilibrium:

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

Example:

Take a pencil and try to keep it in the vertical position on its tip as shown in figure. Whenever you leave it, the pencil topples over about its tip and falls down. This is called the **unstable equilibrium**. In unstable equilibrium, a body may be made to stay only for a moment. Thus a body is unable to keep itself in the state of unstable equilibrium.

Features of unstable equilibrium:

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

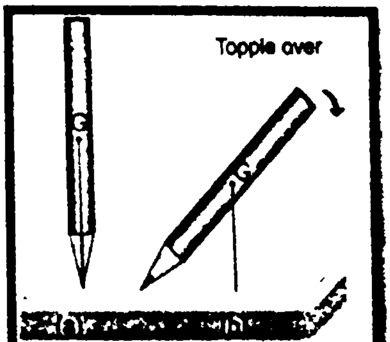


Figure: Unstable equilibrium (a) pencil just balanced at its tip with centre of gravity G at the highest position. (b) Pencil topples over caused by the torque of its weight acting at G.

DO YOU KNOW?

Vehicles are made heavy at the bottom. This lowers their centre of gravity and helps to increase their stability.

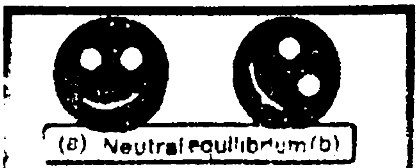
iii. Neutral equilibrium:

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:

Take a ball and place it on a horizontal surface as shown in figure. Roll the ball over the surface and leave it after displacing from its previous position. It remains in its new position and does not return to its previous position, this is called neutral equilibrium.

There are various objects which have neutral equilibrium such as a ball, a sphere, a roller, a pencil lying horizontally, an egg lying horizontally on a flat surface etc.



(a) a ball is placed on a horizontal surface (b) the ball remains in its new displaced position

Features of neutral equilibrium:

In neutral equilibrium, all the new states in which a body is moved, are the stable states and the body, remains in its new state. In neutral equilibrium, the centre of gravity of the body remains at the same height, irrespective to its new position.

Q38. Discuss stability and position of centre of mass with the reference of example?

OR

Give few examples in which lowering of centre of mass make the objects stable?

Ans: Stability and position of centre of mass:

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.

Examples:

i. Height of vehicles (racing car) is kept low:

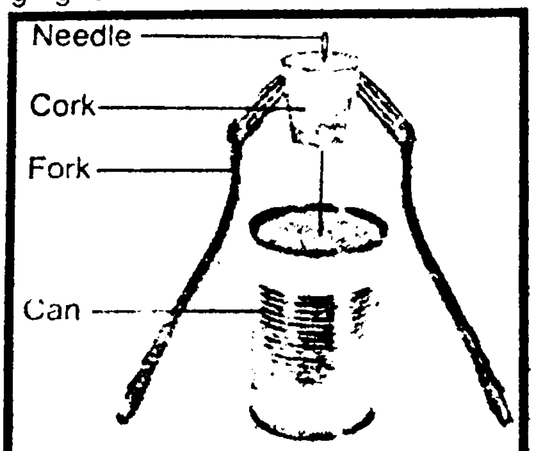
It is due to this reason, racing cars are made heavy at the bottom and their height is kept to be minimum.

ii. Walking of circus artists on tight rope:

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

iii. Sewing needle fixed in a cork:

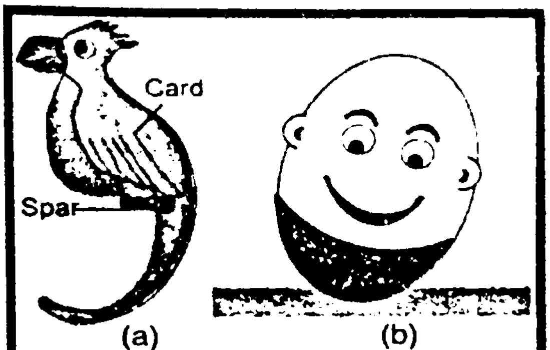
Figure shows a sewing needle fixed in a cork. The cork is balanced on the tip of the needle by hanging forks. The forks lower the centre of mass of the system.



A needle is made to balance at its tip

iv. Perch parrot:

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



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

Q39. Why a vehicle is made heavy at its bottom?

Ans: A vehicle is 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 a vehicle is made wide so that the vertical line passing through its centre of gravity should not get out of its base during a turn.

SUMMARY

1. **Parallel forces:** Parallel forces have their lines of action parallel to each other.
2. **Like parallel forces:** If the direction of parallel forces is the same, they are called like parallel forces.

   Unlike parallel forces: If two parallel forces are in opposite direction to each other, then they are called unlike parallel forces.
3. **Resultant force:** The sum of two or more forces is called the resultant force.
4. **Head to tail rule:** A graphical method used to find the resultant of two or more forces is called head to tail rule.
5. **Resolution of that force:** Splitting up a force into two components perpendicular to each other is called resolution of that force. These components are:

   $$F_x = F\cos\theta \quad , \quad F_y = F\sin\theta$$
6. A force can be determined from its perpendicular components as

   $$F = \sqrt{F_x^2 + F_y^2} \quad , \quad \theta = \tan^{-1}\frac{F_y}{F_x}$$
7. **Torque or moment:** Torque or moment of a force is the turning effect of the force. Torque of a force is equal to the product of force and moment arm of the force.

8. **Principle of moment:** According to the principle of moments, the sum of clockwise moments acting on a body in equilibrium is equal to the sum of anticlockwise moments acting on it.
9. **Centre of mass:** Centre of mass of a body is such a point where a net force causes it to move without rotation
10. **Centre of gravity:** The centre of gravity of a body is a point where the whole weight of a body acts vertically downward
11. A couple is formed by two parallel forces of the same magnitude but acting in opposite direction along different lines of action.
12. A body is in equilibrium if net force acting on it is zero. A body in equilibrium either remains at rest or moves with a uniform velocity.
13. A body is said to satisfy second condition for equilibrium if the resultant torque acting on it is zero.
14. A body is said to be in stable equilibrium if after a slight tilt it returns to its previous position.
15. **Unstable equilibrium:** If a body does not return to its previous position when sets free after slightly tilt is said to be in unstable equilibrium.
16. **Neutral equilibrium:** A body that remains in its new position when disturbed from its previous position is said to be in a state of neutral equilibrium.

QUESTIONS

4.1 Encircle the correct answers from the given choices:

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

A. a torque | B. a 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 a force 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 are 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 if 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

Answers

i. B	**ii. D**	**iii. B**	**iv. D**
v. D	**vi. D**	**vii. C**	**viii. C**

4.2 Define the following:
(i) resultant vector **(ii) torque**
(iii) centre of mass **(iv) centre of gravity**

Ans: (i) resultant vector

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

OR

The sum of two or more vector is a single vector which has the same effect as the combined effect of all the vectors to be added. This single vector is called resultant vector.

(ii) torque

The turning effect of a force is called torque or moment of the force.

$$\text{Torque } \tau = F \times L$$

Torque is a vector quantity and its direction can be found by using the right hand rule.

Unit of torque: Unit of torque is Nm.

(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 centre of gravity of a body.

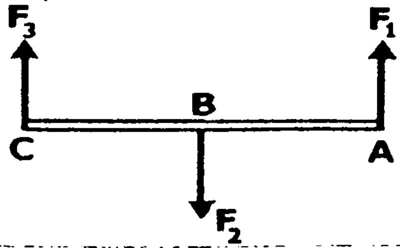
4.3 Differentiate the following:
(i) like and unlike forces **(ii) torque and couple**
(iii) stable and neutral equilibrium

Ans: (i) Difference between like and unlike forces

Like parallel force	**Unlike parallel force**
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 directions opposite to each other.

Explanation:
The forces F_1, F_2 and F_3 are acting at points A, B and C respectively.

Since the direction of the applied forces F_1 and F_3 is the same, so these are like parallel forces. The applied forces F_1, F_2 and F_2, F_3 are acting in the opposite direction, so these are unlike parallel forces.



(ii) Difference between torque and couple

Torque is a special kind of force that has the capacity to rotate an object about an axis. While a force is described as a push or a pull, it is better to think of torques as a twist.

In a special case when applied force vectors add to zero, then the force is called a couple and their moment is called a torque. Thus the rotational force that produces no moment is called a couple.

When a driver turns a steering wheel, he exerts two equal but opposite forces on it. The two forces form a couple. The turning effect of a couple is the sum of moment of the two forces. The moment of a couple is called a torque.

(iii) Difference between stable and neutral equilibrium

States of equilibrium:

There are three states of equilibrium:

- ❖ Stable equilibrium
- ❖ Unstable equilibrium
- ❖ Neutral equilibrium

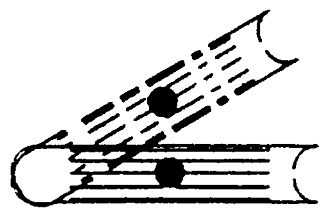
❖ Stable equilibrium:

When the center of gravity of a body lies below point of suspension or support, the body is said to be in STABLE EQUILIBRIUM. For example a book lying on a table is in stable equilibrium.

Explanation:

A book lying on a horizontal surface is an example of stable equilibrium. If the book is lifted from one edge and then allowed to fall, it will come back to its original position. Other examples of stable equilibrium are bodies lying on the floor such as chair, table etc.

Reason of stability:



When the book is lifted its center of gravity is raised. The line of action of weight passes through the base of the book. A torque due to weight of the book brings it back to the original position.

❖ Unstable equilibrium:

When the center of gravity of a body lies above the point of suspension or support, the body is said to be in unstable equilibrium

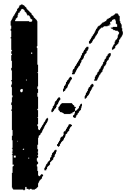
Example pencil standing on its point or a stick in vertically standing position.

Explanation:

If thin rod standing vertically is slightly disturbed from its position it will not come back to its original position. This type of equilibrium is called unstable

equilibrium, other example of unstable equilibrium are vertically standing cylinder and funnel etc.

Reason of instability:



When the rod is slightly disturbed its center of gravity is lowered. The line of action of its weight lies outside the base of rod. The torque due to weight of the rod toppled it down.

❖ Neutral equilibrium

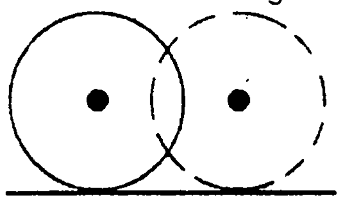
When the center of gravity of a body lies at the point of suspension or support, the body is said to be in neutral equilibrium. Example rolling ball.

Explanation:

If a ball is pushed slightly to roll, it will neither come back to its original nor it will roll forward rather it will remain at rest. This type of equilibrium is called NEUTRAL EQUILIBRIUM.

Reason of neutral equilibrium:

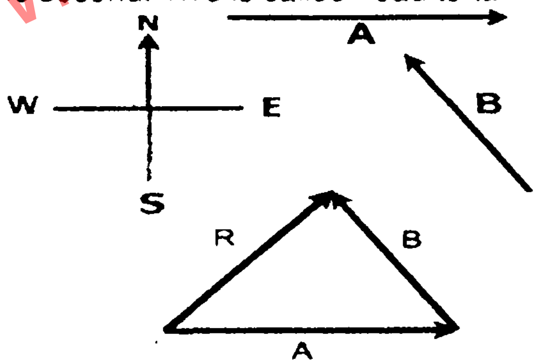
If the ball is rolled, its center of gravity is neither raised nor lowered. This means that its center of gravity is at the same height as before.



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

Ans: Addition of Vectors by head to tail rule:

To add the vectors, draw the representative lines of these vectors in such a way that the head of the first vector coincides with the tail of the second. The line joining the tail of the first vector with the head of the second vector represents the resultant vector. The direction of the resultant vector is from the tail of the first vector towards the head of the second. This is called head to tail rule.



Adding vectors by head to tail rule

Note:

It should be noted that head to tail rule can be used to add any number of forces. The vector representing resultant force gives the magnitude and direction of the resultant force.

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

Ans: Resolution of Forces/Resolution of vectors:

The process of splitting up vectors (forces) into their component forces is called resolution of forces.

OR

Splitting up of a force into two mutually perpendicular components is called the resolution of that force. Resolution of vectors is the reverse of vector addition.

Perpendicular component/Rectangular components:

If a force is formed from two mutually perpendicular components then such components are called its **perpendicular components**.

Explanation:

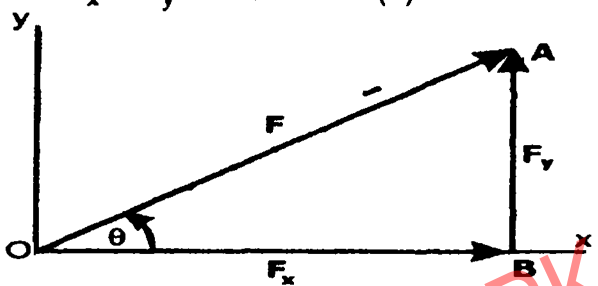
Consider a force **F** represented by line **OA** making an angle θ with x-axis.

Draw a perpendicular **AB** on x-axis from A. According to head to tail rule, **OA** is the resultant of vectors represented by **OB** and **BA**.

Thus $\quad \mathbf{OA} = \mathbf{OB} + \mathbf{BA}$ .... (1)

From figure

$\mathbf{F} = \mathbf{F_x} + \mathbf{F_y}$ .... (2)



Resolution of a force

Magnitude of horizontal component (F_x):

In right angled triangle OBA

$$\cos\theta = \frac{\text{Base}}{\text{Hypotenuse}} = \frac{OB}{OA}$$

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

$$F_x = F\cos\theta \qquad (3)$$

Magnitude of vertical component (F_y):

$$\sin\theta = \frac{\text{Prependicular}}{\text{Hypotenuse}} = \frac{BA}{OA}$$

$$\frac{F_y}{F} = \sin\theta$$

$$F_y = F\sin\theta \quad \text{...............} \quad (4)$$

Equations (3) and (4) give the magnitude of perpendicular components F_x and F_y respectively.

4.6 When a body is said to be in equilibrium?

Ans: Equilibrium:

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

Examples:

A car moving with uniform velocity on a levelled road and an aeroplane flying in the air with uniform velocity are the examples of bodies in equilibrium.

Conditions for equilibrium:

In the above examples, we see that a body at rest or in uniform motion is in equilibrium if the resultant force acting on it is zero. For a body in equilibrium, it must satisfy certain conditions. There are two conditions for a body to be in equilibrium.

4.7 Explain the first condition for equilibrium.

Ans: First condition for equilibrium:

A body is said to satisfy first condition for equilibrium if the resultant of all the forçes acting on it is zero.

Explanation:

Let n number of forces $\mathbf{F_1}, \mathbf{F_2}, \mathbf{F_3}, \dots, \mathbf{F_n}$ are acting on a body such that

$$\mathbf{F_1} + \mathbf{F_2} + \mathbf{F_3} + \dots\dots + \mathbf{F_n} = 0$$

or $$\sum \mathbf{F} = 0 \quad \dots\dots\dots \text{(i)}$$

The symbol Σ is a Greek letter called sigma used for summation. Equation (i) is called the first condition for equilibrium.

The first condition for equilibrium can also be stated in terms of x and y-components of the forces acting on the body as:

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

and $$\mathbf{F_{1y}} + \mathbf{F_{2y}} + \mathbf{F_{3y}} + \cdots + \mathbf{F_{ny}} = 0$$

or $$\sum \mathbf{F_x} = 0 \qquad \text{(ii)}$$

and $$\sum \mathbf{F_y} = 0 \qquad \text{(iii)}$$

Examples:

A book lying on a table or a picture hanging on a wall, are at rest and thus satisfy first condition for equilibrium.

A paratrooper coming down with terminal velocity (constant velocity) also satisfies first condition for equilibrium and is thus in equilibrium.

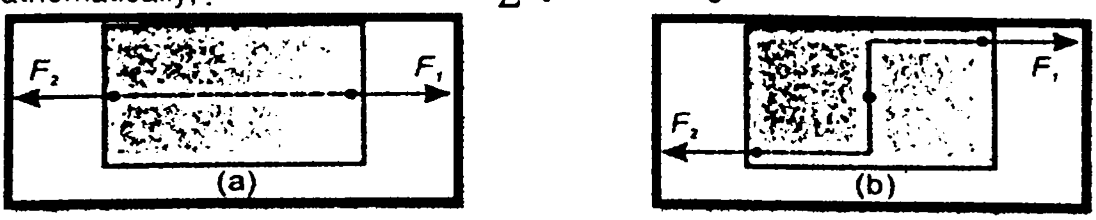
4.8 Why there is a need of second condition for equilibrium if a body satisfies first condition for equilibrium?

Ans: Case I:

First condition for equilibrium does not ensure that a body is in equilibrium. Consider a body pulled by the forces F_1 and F_2. 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 the first condition, the body will be in equilibrium.

Case II:

Now shift the location of the forces as shown in figure. In this situation, the body is not in equilibrium although the first condition for equilibrium is still satisfied. It is because the body has the tendency to rotate. This situation demands another condition for equilibrium in addition to the first condition for equilibrium. This is called **second condition for equilibrium**. According to this, a body satisfies second condition for equilibrium when the resultant torque acting on it is zero. Mathematically, $\sum \boldsymbol{\tau} = 0$



(a) Two equal and opposite forces acting along the same lines (b) Two equal and opposite forces acting along different lines

4.9 What is second condition for equilibrium?

Ans: Second condition for equilibrium:

A body satisfies second condition for equilibrium when the resultant torque acting on it is zero. Mathematically, $\sum \tau = 0$

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

Ans: A car moving with uniform velocity on a levelled road and an aeroplane flying in the air with uniform velocity are the examples of bodies in equilibrium.

A paratrooper coming down with terminal velocity (constant velocity) also satisfies first condition for equilibrium and is thus in equilibrium.

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

Ans: Rest implies stationary, equilibrium implies a resultant force of zero. Therefore, a body in equilibrium could be moving, for example a sky diver at terminal velocity, where resistive forces are equal to the force of gravity. This means that a body can be in equilibrium and not at rest, but a body at rest must be in equilibrium, otherwise it would move. So, to answer the question is: It's impossible.

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

Ans: No, with only a single force present, the body would accelerate infinitely in the direction of that force.

Because the force which is alone applied will have some direction and the object will try to move in this direction under it's influence. However, if two opposite and equal forces take part it, gives rise to a null vector force. The body can be in rotational equilibrium under the impact of a single force.

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

Ans: As the whole weight of a body acts on centre of gravity so, in case of racing car centre of gravity must be close to the earth so that there are less chances of overturning of the car.

If the car is high, it is easy to produce the torque in car due to large moment arm, and the car can takes the somersault (forward roll).

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

Ans: See Q # 4.3 (iii) from Exercise.

PROBLEMS

4.1 Find the resultant of the following forces:

(i) 10 N along x-axis (ii) 6 N along y-axis and

(iii) 4 N along negative x-axis. (8.5 N making 45° with x-axis)

Solution: F_x = Net force along x-axis = 10 - 4 = 6 N

F_y = Force along y-axis = 5 N

Magnitude of the resultant force = F = ?

Direction of the force = θ = ?

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

$$F = \sqrt{(6)^2 + (6)^2}$$

$$F = \sqrt{36 + 36}$$

$= \sqrt{72} = 8.5$ N

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

$\theta = \tan^{-1}\frac{6}{6}$

$\theta = \tan^{-1}(1)$

$\theta = 45°$ with x-axis

4.2 Find the perpendicular components of a force of 50 N making an angle of 30° with x axis. (43.3 N, 25 N)

Solution: Force F = 50N

Angle $\theta = 30°$

$F_x = ?$ and $F_y = ?$

$F_x = F\cos\theta$

$F_x = 50 \times \cos 30°$

$= 50N \times 0.866$ $(\because \cos 30° = 0.866)$

$F_x = 43.3N$

Similarly, $F_y = F\sin\theta$

$F_y = 50 \times 0.5$ $(\because \sin 30° = 0.5)$

$F_y = 25N$

4.3 Find the magnitude and direction of a force, if its x-component is 12 N and y- component is 5N. (13 N making 22.6° with x-axis)

Solution: $F_x = 12N$

$F_y = 5N$

(i) Magnitude of the force = F = ?

(ii) Direction of the force = θ = ?

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

$F = \sqrt{(12)^2 + (5)^2}$

$F = \sqrt{144 + 25}$

$= \sqrt{169}$

F = 13 N

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

$\theta = \tan^{-1}\frac{12}{5}$

$\theta = \tan^{-1}(2.4)$

$\theta = 22.6°$ 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 the torque produced by the force. (10 Nm)

Solution: Force = F = 100 N

Distance = L = 10 cm = 0.1 m

Torque = τ = ?

$\tau = F \times L$

$\tau = 100 \times 0.1$

$= 100 \times \frac{1}{10} = 10$ Nm

4.5 A force is acting on a body making an angle of 30° with the horizontal. The horizontal component of the force is 20 N. Find the force. (23.1 N)

Solution: Angle $\theta = 30°$ (with x-axis)

Horizontal component of force $F_x = 20N$

Force $F = ?$

$F_x = F\cos\theta$

$20N = F\cos 30°$

or $20N = F \times 0.866$ $(\because \cos 30° = 0.866)$

or $F = \frac{20N}{0.866} = 23.09$

$F = 23.1N$

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

Solution: Radius $= r = L = 16\text{ cm} = \frac{16}{100}\text{ m} = 0.16\text{m}$

Couple arm $= L = 16\text{ cm} = \frac{16}{100}\text{ m} = 0.16\text{m}$

Force $= F = 50$ N

Torque $= \tau = ?$

$\tau = F \times L$

$\tau = 50 \times (2 \times 0.16) = 16$ 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. (8.2 N)

Solution: Tension $T_1 = 3.8N$

Tension $T_2 = 4.4N$

Weight of the picture frame $= w = ?$

When the picture frame is in equilibrium, then

$\Sigma F_x = 0$ and $\Sigma F_y = 0$

Therefore $T - w = 0$

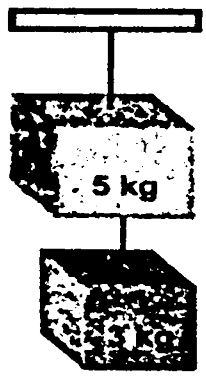
or $(T_1 + T_2) - w = 0$

$T_1 + T_2 = w$

$3.8 + 4.4 = w$

$w = 8.2$ N

4.8 Two blocks of masses 5 kg and 3 kg are suspended by the two strings as shown. Find the tension in each string. (80 N, 30 N)



Solution: Mass of large block $= M = 5$ kg

Mass of small block $= m = 3$ kg

Tension produced in each string $= T_1 = ?$ and $T_2 = ?$

$T_1 = w_1 + w_2$

$T_1 = mg + Mg$

$T_1 = (m + M)g$

$T_1 = (3 + 5) \times 10$

$= 8 \times 10$

$= 80$ N

Also, $T_2 = mg$

$T_2 = 3 \times 10 = 30$ N

4.9 A nut has been tightened by a force of 200 N using 10 cm long spanner. What length of a spanner is required to loosen the same nut with 150 N force? (13.3 cm)

Solution: Force = F_1 = 200 N

Length = L_1 = 10 cm = $\frac{10}{100}$ = 0.1 m

Length of the spanner to tighten the same nut:

Force = F_2 = 150 N

Length = L_2 = ?

Since $\tau_1 = \tau_2$

$F_1 \times L_1 = F_2 \times L_2$

$200 \times 0.1 = 150 \times L_2$

$20 = 150 \times L_2$

$L_2 = \frac{20}{150} = 0.133\,m = 0.133 \times 100 = 13.3\,cm$

4.10 A block of mass 10 kg is suspended at a distance of 20 cm from the centre of a uniform bar 1 m long. What force is required to balance it at its centre of gravity by applying the force at the other end of the bar? (40 N)

Solution: Mass of the block = m = 10 kg

Length of the bar = l = 1 m

Moment arm of w_1 = L_1 = 20 cm = 0.2 m

Moment arm of w_2 = L_2 = 50 cm = 0.5 m

Force required to balance the bar F_2 = ?

By applying principle of moments:

Clockwise moments = Anticlockwise moments

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

$mg \times L_1 = F_2 \times L_2$

$(10 \times 10) \times 0.2 = F_2 \times 0.5$

$20 = F_2 \times 0.5$

$F_2 = \frac{20}{0.5} = \frac{200}{5} = 40$ N