UNIT 4

TURNING EFFECT OF FORCE

4.1 LIKE AND UNLIKE PARALLEL FORCES

SHORT QUESTIONS

Q.1 What is meant by parallel forces? *(K.B)*

Ans: **PARALLEL FORCES**

Definition:

"In a plane, if number of forces act on a body such that their points of action are different but **their lines of action are parallel** to each other, then these forces are called parallel forces.**"**

Types of Parallel Forces:

There are two types of parallel forces:

- Like parallel forces
- Unlike parallel forces

Example:

Suppose an apple is suspended by a string. The string is stretched due to weight of the apple. The forces acting on it are; **weigh**t of the apple acting vertically downward and **tension** in the string pulling it vertically upward. The two forces are parallel but opposite to each other. These forces are called **unlike parallel forces** as shown in the figure below:

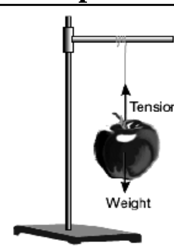


Figure: Like Parallel Forces

Q.2 What is meant by like and unlike parallel forces? Also give examples to differentiate them. *(K.B)* **(LHR 2011, 2014, 2015, 2017 GRW 2013)**

Ans: **LIKE PARALLEL FORCES**

Definition:

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

Example:

Consider a bag with apples in it. The weight of the bag is due to the weight of all the apples in it. Since the weight of every apple in the bag is the force of gravity acting on it vertically downwards, therefore, weights of apples are the parallel forces. All these forces are acting in the same direction. Such forces are called like parallel forces.

UNLIKE PARALLEL FORCES

Definition:

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

Example:

Suppose 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 downward and tension in the string pulling it vertically upward. The two forces are parallel but opposite to each other. These forces are called unlike parallel forces.

Example To Differentiate Parallel Forces:

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

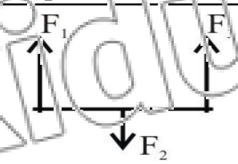


Figure: Like and unlike parallel forces

4.2 ADDITION OF FORCES

LONG QUESTIONS

Q.1 Which method is used for addition of forces? Explain with example.

(K.B+A.B+U.B)

Ans:

ADDITION OF FORCES

Force is a vector quantity. It has magnitude as well direction; therefore forces are not added by ordinary arithmetical rules. They are added by a method known as head to tail rule. By head to tail rule we get resultant force.

Resultant Force:

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

HEAD TO TAIL RULE

Definition:

"Graphical method of addition of vectors in which the representative lines of all the vector to be added are drawn in such a way that head of first vector coincides with the tail of second vector, and the head of second vector coincides with the tail of third vector and so on…the line obtained by joining the tail of first vector with the head of last vector represents resultant vector is called Head to Tail Rule.

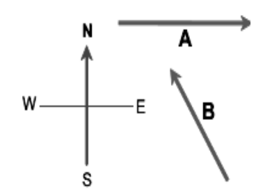


Figure: Frame of Reference and Representative Lines

Method:

Head to tail rule can be used to add any number of forces. The method of addition of two vectors is given below:

- Select the frame of reference and suitable scale and draw the representative lines of all the vectors 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

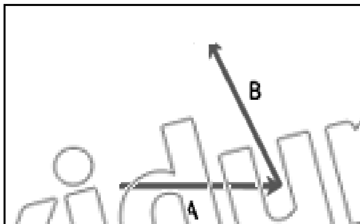


Figure: Coinciding Head to Tail

- 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**

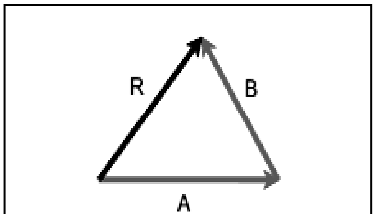


Figure: Resultant Vector " R"

- **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.

4.2 SHORT QUESTIONS

Q.1 Define Resultant Force. ***(K.B)***

Ans: *Given on page # 139*

EXAMPLE 4.1

Find the resultant of three forces 12 N along x-axis, 8 N making an angle of 45° with x- axis and 8 N along y-axis.

<u>Solution</u>:

<u>Given Data</u>:

First Force = F1 = 12 N along x-axis

Second Force =F2 = 8 N along 45° with x-axis

Third Force = F3 = 8 N along y-axis

Scale: 1 cm = 2 N

<u>Graphical Representation</u>:

- Represent the forces by vectors $\mathbf{F_1}$, $\mathbf{F_2}$ and F_3 according to the scale in the given direction.

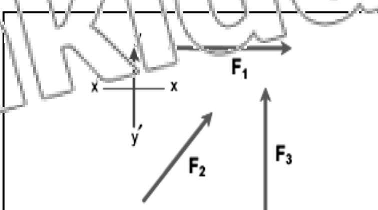


Figure: Representation of Forces

- Arrange these forces F_1, F_2 and F_3 such that the tail of force F_2 coincides with the head of force F_1 at point **B**. Similarly, the tail of force F_3 coincides with the head of force F_2 at point **C.**
- Join point **A** the tail of the force F_1 and point D the head of force F_3. Let **AD** represents force **F**. According to head to tail rule, force F represents the resultant force as shown in the figure.

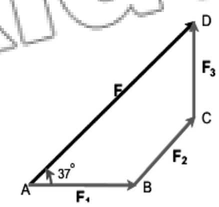


Figure: **Finding Resultant Force**

- Measure **AD** and multiply it by **2 cm** the scale to find the magnitude of the resultant force **F** in **(N).**
- Measure the angle **<DAB** using a protractor which the force **F** makes with **x-axis**. This gives the direction of the resultant force.

Result:

Hence, the resultant Force will be 9.6 N making 37° with x-axis.

4.1, 4.2 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 : *(K.B)*
(A) Same forces (B) Parallel forces
(C) Perpendicular forces (D) None of above

2. If the direction of parallel forces is the same, then these are called: *(K.B)*
(A) Same forces (B) Like Parallel forces
(C) Unlike Parallel forces (D) All of above

3. If the direction of parallel forces is the opposite, then these are called: *(K.B)*
(A) Same forces (B) Like Parallel forces
(C) Unlike Parallel forces (D) All of above

4. Addition of vectors are done by: *(K.B)*
(A) Head to tail rule (B) Left hand rule
(C) Right hand rule (D) None of above

4.3 RESOLUTION OF FORCES

LONG QUESTIONS

Q.1 Define and Explain Resolution of Forces *(K.B+U.B+A.B)*

Ans: **RESOLUTION OF FORCES**

Introduction:

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

Definition:

"Splitting up of a force into two mutually perpendicular components is called the resolution of that force.**"**

Explanation:

Consider 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 from **A** on x-axis as **AB** as shown in the figure:

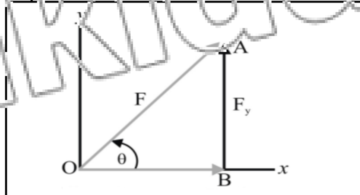


Figure: Resolution of a Force

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**.

According to head to tail rule, **OA** is the resultant vector of vectors represented by **OB** and **BA**.

So, **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 force **F.**

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:

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

Magnitudes of Rectangular Components:

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

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

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

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

Hence

Similarly,

$$\frac{F_Y}{F} = \frac{BA}{OA} = \sin\theta$$

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

Therefore,

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

Conclusion:

F_x and F_y are perpendicular components that are shown by the two sides of the right-angled triangle where as hypotenuse represents the magnitude of the actual vector

Q.2 Find the magnitude and direction of a vector whose rectangular components are given. ***(K.B+U.B+A.B)***

Ans: **DETERMINATION OF A FORCE FROM PERPENDICULAR COMPONENTS**

Introduction:

Since a force can be resolved into two perpendicular components. Its reverse is to determine the force knowing its perpendicular components.

Explanation:

Consider **Fx** and **Fy** as the perpendicular components of a force **F**. These perpendicular components **Fx** and **Fy** are represented by lines **OP** and **PR** respectively as shown in figure:

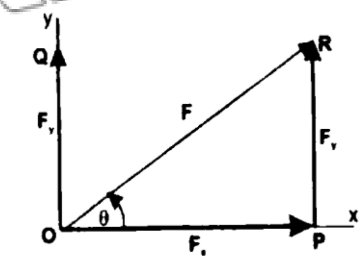


Figure: **Determination of a Force From its Perpendicular Components**

According to head to tail rule:

$$\mathbf{OR} = \mathbf{OP} + \mathbf{PR}$$

Thus **OR** will completely represent the force **F** where x and y-components are $\mathbf{F_x}$ and $\mathbf{F_y}$ respectively.

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

Magnitude of the Force:

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

According to Pythagoras Theorem

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

$$(OR)^2 = (OP)^2 + (PR)^2$$

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

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

Direction of the Force:

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.

Conclusion:

A Force can be found by its perpendicular components F_x and F_y by using Pythagoras Theorem and its direction can be found by using trigonometric ratio. $\tan\theta = \frac{\text{Perpendicular}}{\text{Base}}$

SHORT QUESTIONS

Q.1 Define Resolution of Forces. ***(K.B+U.B+A.B)*** **(LHR 2017)**

Ans: *Given on Page #* 142

Q.2 Define Trigonometric Ratios. Give Examples *(K.B)*

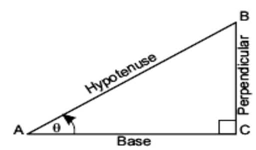
Ans: **TRIGONOMETRIC RATIOS**

Definition:

"The ratios between any of the two sides of a right angle triangle are called trigonometric ratios**"**

Examples:

Consider a right angled triangle **ABC** having angle **θ** at **A** as shown in the figure:



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

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

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

Figure: **Trigonometric Ratios**

Q.3 Define sin θ? *(K.B)*

Ans: **SIN θ**

Definition:

"For a right angled triangle the ratio between Perpendicular and Hypotenuse is called sin θ**"**

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

Q.4 Sketch values of Trigonometric values at different angles. *(K.B)*

Ans: **VALUES OF TRIGONOMETRIC RATIOS**

Some values of Trigonometric Ratios are given below:

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	∞

Figure: **Some Values of Trigonometric Ratios**

Table for MCQs

Q.5 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

(K.B+U.B+A.B) **(Mini Exercise Pg. # 89)**

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

Hypotenuse $= 5$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 $$\tan\theta = \frac{3}{4}$$

Q. 6 What is the advantages of resolution of force. (*C.B*)

Ans: In working out the effects of a force, it sometime helps to resolve the force into its components at right angle.

For example, when a helicopter tilts its main rotor, the force has vertical and horizontal component which lift the helicopter and move it forward.

Fy=Weight of helicopter

Fx=motion of helicopter in forward direction

EXAMPLE 4.2

A man is pulling a trolley on a horizontal road with a force of 200 N making 30° with the road. Find the horizontal and vertical components of its force. *(U.B+A.B)*

Solution:

Given Data:

Force applied on trolley = F = 200N

Angle of force with the road = $\theta = 30°$

To Find:

Horizontal Component of the force = $F_{x} = ?$

Vertical Component of the force = $F_{y} = ?$

Calculations:

We Know

$F_x = F\cos\theta$

Putting values

$F_x = 200\cos 30°$

$F_x = 200\,(0.866)$

$F_x = 173.2$ N

We Know

$F_y = F\sin\theta$

Putting values

$F_x = 200\sin 30°$

$F_x = 200\,(0.5)$

$F_x = 100$N

Result:

Hence, the horizontal and vertical components of the pulling force are 173.2 N and 100 N respectively.

4.3 MULTIPLE CHOICE QUESTIONS

1. **Component of a vector acting along the x – axis is called: *(K.B)***
   (A) x – component (B) Horizontal component
   (C) Vertical component (D) Both A and B
2. **Component of a vector acting along the y – axis is called: *(K.B)***
   (A) x – component (B) Horizontal component
   (C) Vertical component (D) Both A and B
3. **Value of sin 30^0: *(K.B)***
   (A) 0.5 (B) 0.866
   (C) 0.707 (D) None of them
4. **A force of 10 N is making an angle of 30^o with the horizontal. Its horizontal component will be: *(A.B)***
   (A) 4 N (B) 5 N
   (C) 7 N (D) 8.7 N

4.4 TORQUE OR MOMENT OF A FORCE
4.5 PRINCIPLE OF MOMENTS

Q.1 Define and Explain torque or moment of a force. *(K.B+A.B+U.B)*
(GRW 2011, LHR 2012, 2017)

Ans: **TORQUE**

Definition:

"The **turning effect** of a **force** is called torque. It is also called **Moment of Force".**

Formula:

Moment of Force (Torque) is denoted by Greek letter **"τ"** and its formula is given below:

Torque = Moment arm x Force

$$\boldsymbol{\tau = F \times L}$$

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.

$$\mathbf{1Nm = 1\ kgm^2s^{-2}}$$

Quantity:

Torque is a vector and derived quantity.

Examples:

Common examples of Torque are as follows:

- turning pencil in a sharpener
- turning stopcock of a water tap,
- turning doorknob
- opening or closing a nut by using spanner

Dependence of Torque:

Moment of force (torque) produced in a body depends on the following two factors:

- **Force (F)**
- **Moment arm (L)**

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.

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.

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.

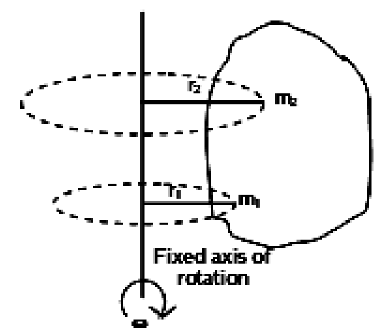


Figure: Axis of Rotation

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 **F.**

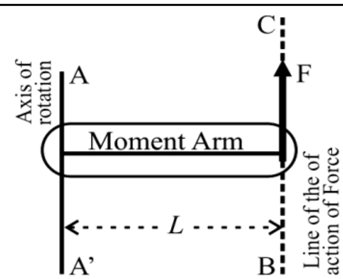


Figure: Important Terms Related to Torque

Moment Arm: **(LHR 2015)**

"The **perpendicular distance** between the **line of action of the force** and the **axis of rotation,** is known as moment arm". It is measured in **metres and centimetres**. 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 a force using a spanner of longer arm is greater than the torque produced by the same force but using a spanner of shorter arm.

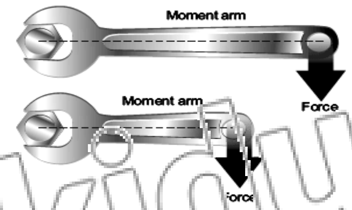


Figure: Greater the Moment Arm Greater will be the Torque

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.

4.4, 4.5 SHORT QUESTIONS

Q.1 Define Torque. Write its formula and unit? *(K.B+U.B+A.B)* **(GRW 2017)**

Ans: *Given on Page # 146*

Q.2 Write factors effecting Torque. *(K.B)*

Ans: *Given on Page # 146*

Q.3 Define Moment arm. *(K.B)*

Ans: *Given on Page # 147*

Q.4 Why do we prefer a spanner of longer arm for loosening or tightening a nut? *(U.B)*

Ans: **SPANNER OF LONGER ARM**

We Know

$$\tau = F \times L$$

Above formula shows that Moment of force (torque) produced in a body depends on the following two factors:

(i) Force
(ii) Moment arm

Longer is the moment arm greater is the moment of force (Torque)

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 a force using a spanner of longer arm is greater than the torque produced by the same force but using a spanner of shorter arm.

Q.5 Why do we put handle of the door at its extreme edge? *(K.B+U.B)*

Ans: **HANDLE OF THE DOOR**

We Know

$$\tau = F \times L$$

Above formula shows that Moment of force (torque) produced in a body depends on the following two factors:

- Force
- Moment arm

Longer is the moment arm greater is the moment of force (Torque), In order to increase moment arm we put handle of the door at its extreme edge. Hence 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. Thus, the location where the force is applied to turn a body is very important.

Q.6 How can we increase torque by keeping the force constant? (*U.B*)

Ans: **INCREASE IN TORQUE**

We Know

$$\tau = F \times L$$

Above formula shows that Moment of force (torque) produced in a body depends on the following two factors:

- Force
- Moment arm

We can increase the torque by increasing its moment arm while keeping the force constant.

Q.7 Define Rigid Body? (*K.B*) **(LHR 2012, 2014, GRW 2015)**

Ans: *Given on Page #* 147

Q.8 Define Axis of Rotation. **(LHR 2012, 2013, 2017, GRW 2011, 2013, 2015)**

Ans: *Given on Page #147*

Q.9 Differentiate between axis of rotation and point of rotation? *(K.B)*

Ans: **DIFFERENTIATION**

Axis of rotation and point of rotation can be differentiated as:

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

Q.10 Define types of moment. *(K.B)*

OR Define clockwise and anticlockwise moments.

Ans: **TYPES OF MOMENTS**

There are two types of moments:

- **Clockwise Moment:**

A force that **turns** a body in the **clockwise direction** is generally used to tighten a nut by a spanner. The torque or moment of the force so produced is called **clockwise moment**. According to Right Hand Rule clockwise moment is taken as **negative**.

- **Anticlockwise Moment:**

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

According to Right Hand Rule anticlockwise moment is taken as **positive.**

Q.11 What is meant by principle of moments? *(K.B)* **(GRW 2013, 2014)**

Ans: **PRINCIPLE OF MOMENT**

Introduction:

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.

Statement:

According to Principle of Moment:

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

Q.12 A force of 150 N can loosen a nut when applied at the end of a spanner 10cm long. Find its torque. *(U.B+A.B)* **(Mini Exercise Pg. # 92)**

Solution:

Given Data:

Force used to loosen a nut = F = 150 N

Length of spanner = L = 10 cm

= 0.1 m

To Find:

Torque = τ = ?

Calculations:

We know

$\tau = F \times L$

$\tau = 150 \times 0.1$

$= 15\ Nm$

Torque produced to loosen the nut is of 15Nm

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

As

$\tau = F \times L$

$15 = 60 \times L$

$L = \frac{15}{60}$

$= 0.25\ m$

$= 25\ cm$

The length should be of 25cm to loosen the nut with 60N force

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

As

$L = 6\ cm$

$= 0.06\ m$

$\tau = F \times L$

$15 = F \times 0.06\ m$

$L = \frac{15}{0.06}$

$= 250\ N$

The force required to loosen a nut with 6cm spanner is 250N

Result:

- **Torque produced to loosen the nut is of 15Nm**
- **The length should be of 25cm to loosen the nut with 60N force**
- **The force required to loosen a nut with 6cm spanner is 250N**

Q.13 Can a small child play with a fat child on the see-saw? Explain how? *(K.B)*

(Quick Quiz Pg. # 92)

Ans: **<u>SEE-SAW</u>**

Yes, Fat child can play with smart child by adjusting the moment arm, as shown in the figure:

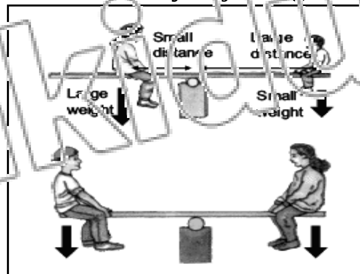


Figure: <u>Children on See-Saw</u>

Q.14 Two children are sitting on the see-saw, such that they cannot swing. What is the net torque in this situation? *(K.B)* **(Quick Quiz Pg. # 92)**

Ans: **<u>NET TORQUE ON SEE-SAW</u>**

In this case, net torque would be zero because clockwise torque is equal to anticlockwise torque.

EXAMPLE 4.3

A mechanic tightens the nut of a bicycle using a 15 cm long spanner by exerting a force of 200 N. Find the torque that has tightened it. *(U.B+A.B)*

<u>Solution</u>:

<u>Given Data</u>:

Length of spanner = L = 15cm = 0.15m

Force exerted by mechanic = F = 200N

<u>To Find</u>:

Torque used to tighten the nut = τ = ?

<u>Calculations</u>:

We know

$$\tau = F \times L$$

Putting values

$$\tau = 200 \times 0.15$$

$$\tau = 30Nm$$

<u>Result</u>:

Hence, the torque produced for tightening the nut will be 30Nm.

EXAMPLE 4.4

A metre rod is supported at its middle point O as shown in figure below. The block of weight 10 N is suspended at point B, 40 cm from O. Find the weight of the block that balances it at point A, 25 cm from O.

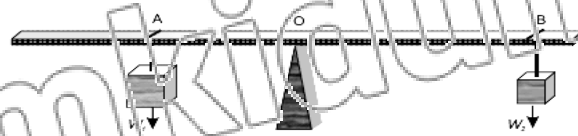


Figure: Balancing a Metre Rod on a Wedge

Solution:

Given Data:

Weight of the suspended block = w_2 = 10N
Moment arm of w_1 = OA = 25cm = 0.25 m
Moment arm of w_2 = OB = 40cm = 0.40 m

To Find:

Weight of the balancing block = w_1 = ?

Calculations:

We know that

Clockwise moments = Anticlockwise moments

$\therefore$ moment of w_2 = moment of w_1

Or $w_2 \times$ momentum arm of $w_2 = w_1 \times$ momentum arm of w_1

Putting values

$$10 \times 0.40 = w_1 \times 0.25$$

$$w_1 = \frac{10 \times 0.40}{0.25} = 16\text{N}$$

Result:

Hence, the weight of the block suspended at A will be 16N.

4.6 CENTRE OF MASS, CENTRE OF GRAVITY

Q.1 What is Centre of Mass? Explain its effect on rotation. ***(K.B+U.B+A.B)***

Ans:

CENTRE OF MASS

Definition:

"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

Example:

Consider a system of two particles **A** and **B** connected by a light rigid rod as shown in figure below:

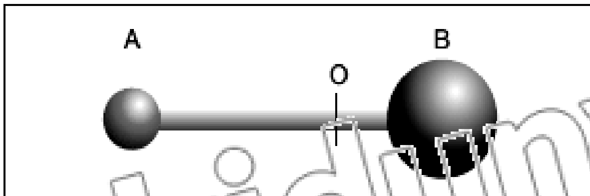


Figure: **Centre of Mass of Two Unequal Masses**

Let **O** is the point anywhere between A and **B** such that the force **F** is applied at point **O** as shown in figure above. if the system moves in the direction of force **F** without rotation, then point O is the centre of mass of the system.

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

- Let the force be applied near the lighter particle as shown in figure below. The system will move as well as rotate.

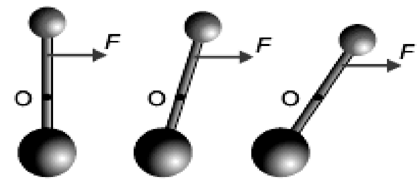


Figure: **The System Moves As well As Rotates When a Force is Applied Away From COM**

- Let the force be applied near the heavier near the heavier particle as shown in figure below, in this case, also the system moves as well as rotate.

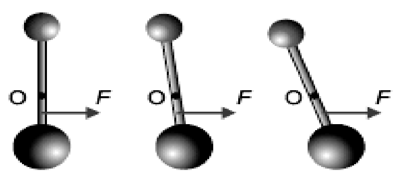
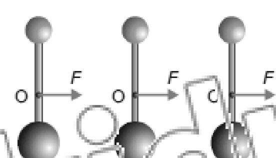


Figure: **The System Moves As well As Rotates When a Force is Applied Away From COM**

Conclusion:

A force applied at COM moves the system without rotation.



Q.2 Define and Explain Centre of gravity. ***(K.B+A.B+U.B)*** **(GRW 2014, LHR 2014)**

Ans: **CENTRE OG GRAVITY**

Definition:

"A point in a body where the **weight of the body** appears to **act vertically downward** is called the centre of gravity of a body"

Position of 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. A body is balanced when it is supported at its centre of gravity.

Explanation:

A body is made up of a large number of particles. 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** of the body.

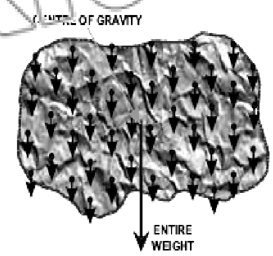


Figure: **Centre of Gravity of a Body is A Point Where its Entire Weight is Assumed to Act Vertically Downward**

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.

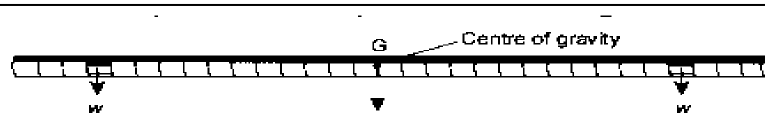


Figure: **Centre of Gravity of Uniform Rod**

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

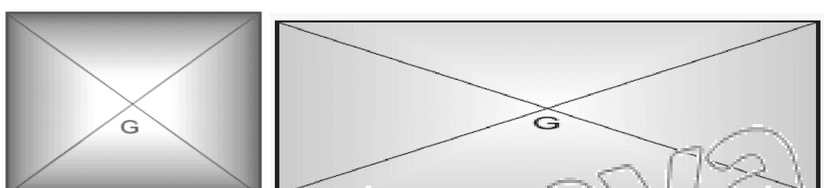


Figure: **Centre of Gravity of Rectangle and Square**

- The centre of gravity of a uniform circular disc is its centre. Similarly, centre of gravity of a solid sphere or hollow sphere is the centre of the spheres

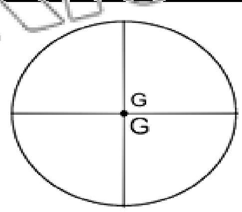


Figure: **Centre of Gravity of Sphere**

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

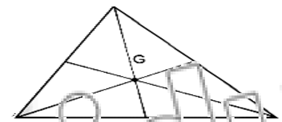


Figure: **Centre of Gravity of Triangular Shape**

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

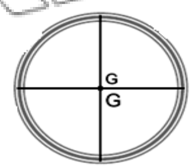


Figure: **Centre of Gravity of Uniform Circular Ring**

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

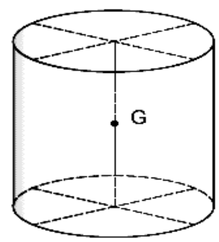


Figure: **Centre of Gravity of Uniform Hollow Cylinder**

Q.3 Write a method to find centre of gravity of an irregular shaped body. ***(K.B+A.B+U.B)***

Ans: **CENTRE OF GRAVITY OF AN IRREGULAR SHAPED BODY THIN LAMINA**

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

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.

Figure: **Plumb Line**

Experiment:

Following is the procedure for finding centre of gravity of an irregular shaped body called thin lamina.

- Take an irregular piece of cardboard.
- Make holes A, B and C as shown in the figure near its edge.

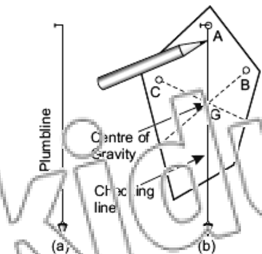


Figure: To Find Centre of Gravity of Thin Lamina

- 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.

Result:

Centre of gravity of an irregular shaped body will be at the point of intersection of vertical lines drawn with the help of plumb line.

4.6 SHORT QUESTIONS

Q.1 Define centre of Mass. *(K.B)*
Ans: *Given on page #152*

Q.2 Define centre of gravity.
Ans: *Given on page #153*

4.6 MULTIPLE CHOICE QUESTIONS

1. The force which is acting perpendicularly downwards towards the earth is called: *(K.B)*
(A) Torque (B) Weight
(C) Force of gravity (D) Both B & C

2. The point at which whole weight of the body appears to act is called: *(K.B)*
(A) Origin (B) Couple
(C) Centre of Gravity (D) Reference point

3. The position of the centre of gravity depends upon: *(K.B)*
(A) Size of the body (B) Shape of the body
(C) Weight of the body (D) Force of the body

4. The centre of gravity of parallelogram, rectangle, square is the: *(K.B)*
(A) Point of intersection of the medians (B) Central point of axis
(C) Point of intersection of the diagonals (D) Centre of parallelogram

5. The centre of gravity of a regular shaped body is always on its centre of: *(K.B)*
(A) Body (B) Symmetry
(C) Medians (D) Axis

6. The centre of gravity of triangle is the: ***(K.B)***
(A) Point of intersection of the medians (B) Central point of axis
(C) Point of intersection of the diagonals (D) Centre of parallelogram

7. The centre of gravity of cylinder is the: ***(K.B)***
(A) Point of intersection of the medians (B) Central point of axis
(C) Point of intersection of the diagonals (D) Centre of parallelogram

4.7 COUPLE

LONG QUESTIONS

Q.1 Define and explain couple with examples. ***(K.B+U.B+A.B)***

Ans: **COUPLE**

Introduction:
When a driver turns a vehicle, he applies forces that produce a torque. This car turns the steering wheel. These forces act on opposite sides of the steering and are equal in magnitude and opposite in direction as shown in the figure:

Figure: **It is easy to turn a steering wheel by applying a couple**

Definition:
"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.
- We apply couple while opening or closing a water tap.
- We apply couple 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:

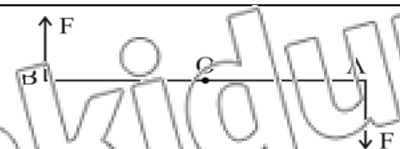


Figure: **Formation of Couple**

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.

Torque Due To Couple:

The torque 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**.

4.7 SHORT QUESTIONS

Q.1 Define couple with some examples. ***(K.B)***

Ans: *Given on page #157*

Q.2 Give an example of a case when the resultant force is zero but resultant torque is not zero. ***(K.B)***

Ans: **RESULTANT TORQUE IS NOT ZERO**

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.3 How does couple work when a cyclist pushes the pedals? ***(K.B)***

Ans: **COUPLE IN PEDLING**

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.

4.7 MULTIPLE CHOICE QUESTIONS

1. When two equal, opposite and parallel forces act at two points of the same body, they produce a: ***(K.B)***

(A) Torque (B) Moment of a couple
(C) Force (D) Couple

2. While opening or closing water tap, a lock, stopper of a bottle or jar we apply: ***(K.B)***

(A) Couple (B) Weight
(C) Single force (D) Mass

3. The perpendicular distance between the line of action of force and centre of rotation and denoted by 'r' is called: ***(K.B)***

(A) Centre of gravity (B) Moment arm
(C) Displacement (D) Force

4. The torque produced in a body due to a couple is equal to the product of one of the forces making couple and the: ***(K.B)***

(A) Couple (B) Force
(C) Like parallel force (D) Couple arm

4.8 EQUILIBRIUM
4.9 STABILITY AND POSITION OF CENTRE OF MASS

LONG QUESTIONS

Q.1 What is equilibrium? State and explain the conditions of equilibrium.
(K.B+U.B+A.B)

Ans: **EQUILIBRIUM**

Introduction:
Newton's first law of motion tells us that a body continues its **state of rest** or of **uniform motion** in a straight line if no **resultant** or net force acts on it. For example, a book lying on a table or a picture hanging on a wall, are at rest. The weight of the book acting downward is balanced by the upward reaction of the table. Consider a log of wood of weight w supported by ropes as shown in figure below:

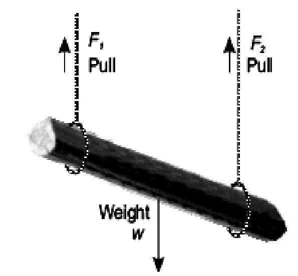


Figure: **The Forces Acting on The Log are; Upward Forces F_1, F_2 And Its Weight w In The Downward Direction**

Here the weight **w** is balanced by the forces $\mathbf{F_1}$ and $\mathbf{F_2}$ pulling the log upward. In case of objects moving with uniform velocity, the resultant force acting on them is zero. 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.

Definition:
"A body is said to be in **equilibrium** if no **net force** and no **net torque** acts on it.**"**

Mathematically:

$$\sum F = 0 \ldots\ldots\ldots\ldots\ldots \quad (1)$$
$$\sum \tau = 0 \ldots\ldots\ldots\ldots\ldots (2)$$

Types:
There are two types of equilibrium
- Static Equilibrium
- Dynamic Equilibrium

Static Equilibrium:
"If a **stationary body** is in the **state of equilibrium** then its equilibrium is called as Static Equilibrium.**"**

Example:
A book lying on a table and a picture hanging on a wall are in static equilibrium.

Dynamic Equilibrium:
"If a moving body is in the state of equilibrium then its equilibrium is called as Dynamic Equilibrium.**"**

Example:
A paratrooper coming down with terminal velocity (constant velocity) is in dynamic equilibrium.

Q.2 State and explain First Condition for equilibrium. ***(K.B)***

Ans:

FIRST CONDITION FOR EQUILIBRIUM

Statement:

According to first condition for equilibrium:

"There should be no net force acting on the body. It means a body will be in equilibrium if the **resultant of all the forces** acting on it is **zero"**

Mathematically:

$$\sum \mathbf{F} = \mathbf{0}$$

Explanation:

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

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

$$\sum \mathbf{F} = \mathbf{0}$$

The symbol $\sum$ **is a Greek letter** called **sigma used for summation**. The first condition of equilibrium can also be 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 $$\sum \mathbf{F_x} = \mathbf{0}$$

$$\sum \mathbf{F_y} = \mathbf{0}$$

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 because no net force is acting on them.

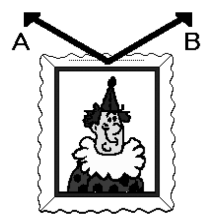


Figure: **An Example of Static Equilibrium**

- A paratrooper coming down with terminal velocity (constant velocity) experiences two forces
- His weight acts vertically downwards
- Up thrust of air (air resistance) acts vertically upwards

Both the forces cancel each other so no net force acts on paratrooper and he falls with constant velocity hence he follows First condition for equilibrium.

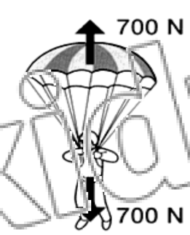


Figure: **An Example of Dynamics Equilibrium**

Conclusion:

When the 1st condition of equilibrium is satisfied, no linear acceleration is produced in the body. But still in some cases body may have tendency to rotate and can have rotational acceleration so we need Second Condition for equilibrium

Q.3 State and Explain Second Condition For Equilibrium. ***(K.B)***

Ans:

SECOND CONDITION FOR EQUILIBRIUM

Statement:

According to Second condition for equilibrium:

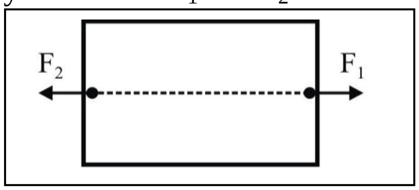
"There should be no net **torque acting on the body**. It means a body will be in **equilibrium** if the **resultant of all the torques acting on it is zero.**"

Mathematically:

$$\sum \tau = 0$$

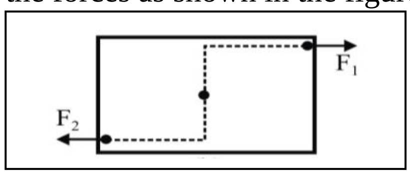
Explanation:

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.

Conclusion:

When the 1st condition of equilibrium is satisfied, no linear acceleration is produced in the body. But still in some cases body may have tendency to rotate and can have rotational acceleration so we need Second Condition for equilibrium. When the 2nd condition of equilibrium is satisfied, then no rotational acceleration is produced in the body.

Q.4 Define and explain the three states of equilibrium. ***(K.B+A.B+U.B)***

Ans:

STATES OF EQUILIBRIUM

There are three states of equilibrium:

- Stable equilibrium
- Unstable equilibrium
- Neutral equilibrium

STABLE EQUILIBRIUM

Definition:

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

Position of Centre of Gravity:

When body is in stable equilibrium, its centre of gravity is at the lowest position. When it is tilted, its centre of gravity rises. When applied force ceases to act the body 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, 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,

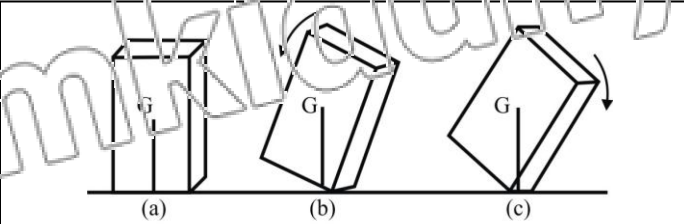


Figure: An Example of Stable Equilibrium

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

Examples:
Table, chair, box and brick lying on a floor are in stable equilibrium.

UNSTABLE EQUILIBRIUM

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

Position of Centre of Gravity:
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.

Explanation:
A pencil is made to stand in equilibrium on its tip as vertically upward on a table.
When it is set free, the pencil topples over about its tip and falls down. The body (Pencil) may be made to stay only for a moment. Thus a body is unable to keep itself in the state of unstable equilibrium.

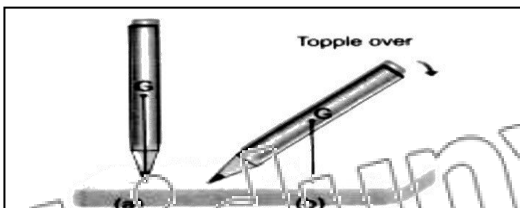


Figure: An Example of Unstable Equilibrium

Examples:
- A stick standing vertically on the tip of a finger and a cone standing on the tip of a finger are in unstable equilibrium

NEUTRAL EQUILIBRIUM

Definition:
"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."**

Position of Centre of Gravity:

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 a body remains at the same height, irrespective of its new position.

Explanation:

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 previous position.

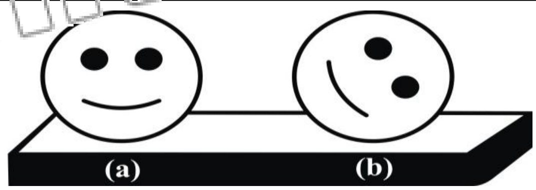


Figure: An Example of Neutral Equilibrium

Examples:

A pencil, a sphere, and cylinder, a roller, an egg lying horizontally on a flat surface are examples of neutral equilibrium

Q.5 How Stability and Position of centre of mass are related to each other?

(K.B+A.B+U.B)

Ans:

STABILITY

Definition:

"Stability refers to the **ability** of an object to **regain its original position** after it has been **tilted slightly**. **"**

Factors:

Within uniform gravitational field stability of a body or system depends upon:

- The position of its Centre of Mass or Centre of Gravity
- To make the objects stable, their Centre of mass or Centre of Gravity 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.

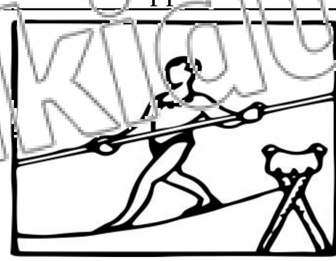


Figure: Role of Centre of Mass in Stability

- 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.

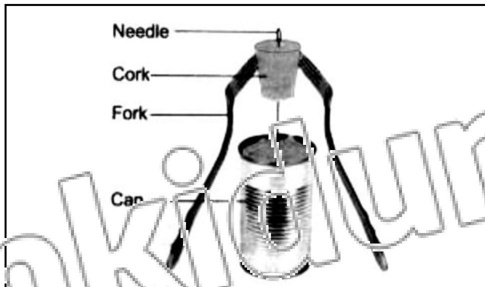


Figure: A Needle is Made to Balance at Tip

- Figure shows a perched parrot which is made heavy at its tail. 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.

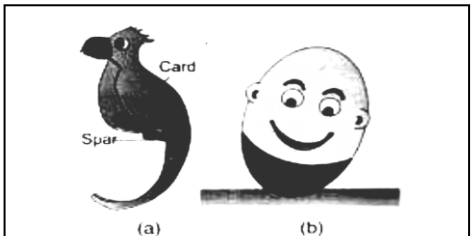


Figure: Stability of Different Objects

4.8, 4.9 SHORT QUESTIONS

Q.1 Can a moving body be in equilibrium? Explain. *(K.B)*

Ans: **A MOVING BODY IN EQUILIBRIUM**

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.

Dynamic Equilibrium:

"If a moving body is in the state of equilibrium then its equilibrium is called as Dynamic Equilibrium.**"**

Example:

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

Q.2 Can a body be in equilibrium if it is revolving clockwise under the action of a single force? *(K.B)*

Ans: **EQUILIBRIUM WHILE ROTATION**

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.3 How do we know whether a body is in a stable or unstable equilibrium due to position of its centre of gravity? *(K.B)*

Ans: **STATE OF EQUILIBRIUM**

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.

Q.4 Why are vehicle made heavy at the bottom? *(K.B)*

Ans: **HEAVY BOTTOM**

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

Q.5 (QUICK QUIZ PG#99)

1. A ladder leaning at a wall as shown in figure below is in equilibrium. How? *(K.B)*

Figure: **A Ladder Leaning *At Wall***

Ans: **LADDER IN EQUILIBRIUM**

Ladder is in equilibrium because it satisfies second condition of equilibrium.

2. The weight of the 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: **SECOND CONDITION**

Yes, it satisfies second condition of equilibrium because both torques are equal in magnitude but opposite in direction.

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

Ans: **CEILING FAN**

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

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

Ans: **SECOND CONDITION**

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

EXAMPLE 4.5

A block of weight 10 N is hanging through a cord as shown in figure below. Find the tension in the cord. *(U.B+A.B)*

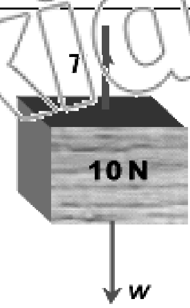


Figure: **Tension in the String**

Solution:

Given Data:

Weight of the block = w = 10N

To Find:

Tension in the cord = T =?

Calculations:

Applying first condition for equilibrium

$$\sum F_x = 0$$

There is no force acting along x-axis

$$\therefore \quad \sum F_y = 0$$

Or $T - w = 0$

$T = w$

Putting values

$$T = 10\text{ N}$$

Result:

Hence, the tension in the cord will be 10 N.

EXAMPLE 4.6

A uniform rod of length 1.5 m is placed over a wedge at 0.5 m from its one end. A force of 100 N is applied at one of its ends near the wedge to keep it horizontal. Find the weight of the rod and the reaction of the wedge. *(U.B+A.B)*

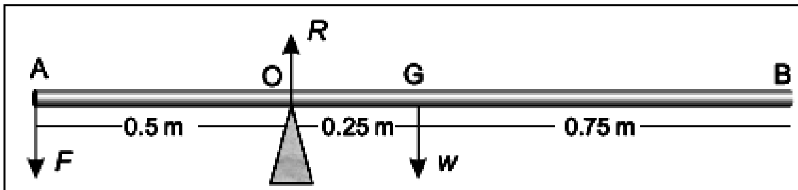


Figure: A Rod Balanced Over a Wedge

Solution:

Given Data:

Applied force on the rod = F = 10N

Moment arm of applied force = OA = 0.5m

AG=BG=0.75

Moment arm of weight of the rod =OG=0.75-0.5= 0.25 m

To Find:

Weight of the rod = w =?

Reaction of the wedge = R =?

Calculations:

From Figure above

Applying second condition for equilibrium, taking torques about O.

$$\Sigma\tau = 0$$

$$F \times AO + R \times 0 - w \times OG = 0$$

$$100N \times 0.5m - w \times 0.25m = 0$$

Or $w \times 0.25m = 100 \times 0.5m$

$$w = \frac{100N \times 0.5m}{0.25m}$$

$$w = 200N$$

Applying first condition for equilibrium

$$\sum F_y = 0$$

$$R - F - w = 0$$

$$R - 100N - 200N = 0$$

or $R = 300N$

Result:

Hence, the weight of the rod is 200 N and reaction of the wedge will be 300 N.

4.8,4.9 MULTIPLE CHOICE QUESTIONS

1. There are how many conditions of equilibrium? *(K.B)* **(LHR 2013)**
(A) 1 (B) 2
(C) 3 (D) 4

2. When the sum of all the force acting on a body is zero or the object is moving with uniform velocity then it will be in: *(K.B)*
(A) Rest (B) Motion
(C) Equilibrium (D) None of above

3. According to First condition of equilibrium, the sum of all the forces acting on the body should be: *(U.B)*
(A) Positive (B) Zero
(C) None (D) All of above

4. First condition of equilibrium is represented by: *(K.B)*
(A) $\sum F = 0$ (B) $\sum F_x = 0$
(C) $\sum F_y = 0$ (D) All of above

5. According to Second condition of equilibrium, the sum of all the torques acting on the body should be: *(U.B)*
(A) Positive (B) Zero
(C) None (D) All of above

6. Second condition of equilibrium is represented by: *(K.B)*
(A) $\sum \tau = 0$ (B) $\sum F = 0$
(C) Both a & b (D) All of above

7. Sigma ($\sum$) is the Greek letter which is used to represent: *(K.B)*
(A) Addition (B) Subtraction
(C) Multiplication (D) Division

8. There are how many states of equilibrium? *(K.B)*
(A) 1 (B) 2
(C) 3 (D) 4

9. The equilibrium in which the body comes back to its original condition when set free after slightly lifting from one side is: *(K.B)*
(A) Stable equilibrium (B) Unstable equilibrium
(C) Neutral equilibrium (D) None of above

10. The equilibrium in which the body does not come back to its original condition when set free after slightly lifting from one side is: *(K.B)*
(A) Stable equilibrium (B) Unstable equilibrium
(C) Neutral equilibrium (D) None of above

11. The type of equilibrium in which after disturbance, the body again comes to rest position and center of gravity remains unchanged: *(K.B)*
(A) Stable (B) Unstable
(C) Neutral (D) None of above

12. In Stable equilibrium, the centre of gravity than the original position is: *(K.B)*
(A) Raised (B) Lowered
(C) Remain same (D) All of above

13. In Unstable equilibrium, the centre of gravity than the original position is: *(K.B)*
(A) Raised (B) Lowered
(C) Remain same (D) All of above

14. In Neutral equilibrium, the centre of gravity than the original position is: *(K.B)*
(A) Raised (B) Lowered
(C) Remain same (D) All of above

15. When an object is resting on the smooth horizontal surface, the weight of the object is balanced by: *(K.B)*
(A) Normal Reaction (B) Torque
(C) Friction (D) Couple

16. A meter rod on a wedge is an example of: *(K.B)*
(A) Stable equilibrium (B) Unstable equilibrium
(C) Neutral equilibrium (D) None of above

17. A book lying on the table is an example of: *(K.B)*
(A) Stable equilibrium (B) Unstable equilibrium
(C) Neutral equilibrium (D) None of above

18. Motion of the football on the ground is an example of: *(K.B)*
(A) Stable equilibrium (B) Unstable equilibrium
(C) Neutral equilibrium (D) None of above

19. What is of a racing car is kept low to make its stable? *(K.B)*
(A) Width (B) Height
(C) Length (D) Weight

20. If the centre of gravity of the body is below the fulcrum then the body will be in: *(K.B)*
(A) Stable equilibrium (B) Unstable equilibrium
(C) Neutral equilibrium (D) None of above

21. The torque in ceiling fan rotating at constant speed is: *(K.B)*
(A) 1 (B) 2
(C) 0 (D) Maximum

MCQ'S ANSWER KEY (TOPIC WISE)

4.1 LIKE AND UNLIKE PARALLEL FORCES

4.2 ADDITION OF FORCES

1	2	3	4
B	B	C	A

4.3 RESOLUTION OF FORCES

1	2	3	4
D	C	A	B

4.4 TORQUE OR MOEMENT OF A FORCE

4.5 PRINCIPLE OF MOMENTS

1	2	3	4	5	6	7	8

4.6 CENTRE OF MASS, CENTRE OF GRAVITY

1	2	3	4	5	6	7
D	C	B	C	B	A	B

4.7 COUPLE

1	2	3	4
D	A	B	D

4.8 EQUILIBRIUM

4.9 STABILITY AND POSITION OF CENTRE OF MASS

1	2	3	4	5	6	7	8	9	10	11	12
B	C	B	D	B	A	A	C	A	B	C	A
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**			
B	C	A	B	A	C	B	A	C			

TEXT BOOK EXERCISE

MULTIPLE CHOICE QUESTIONS

4.1 Encircle the correct answer from the given choices.

i. Two equal but unlike parallel forces having different line of action produces: (K.B) **(GRW 2017)**

(a) Torque (b) couple
(c) Equilibrium (d) neutral equilibrium

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

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

iii. The number of perpendicular components of forces are: (K.B) **(LHR 2013)**

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

iv. A force of 10 N is making an angle of 30^o with the horizontal. Its horizontal component will be: (U.B+A.B)

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

v. A couple is formed by: (K.B) **(LHR 2017)**

(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: (K.B) **(LHR 2017)**

(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: (K.B)

(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: (K.B)

(a) increasing their speed (b) decreasing their mass
(c) lowering their centre of gravity (d) decreasing their width

ANSWER KEY

i	ii	iii	iv	v	vi	vii	viii
a	d	b	d	b	d	c	c

4.2 Define the following: (K.B)

Ans:

(i) Resultant vector

<u>RESULTANT FORCE</u>

<u>Definition:</u>

A resultant force can be defined as:

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

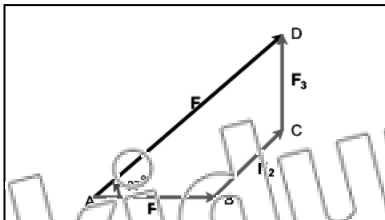


Figure: Finding Resultant Force

(ii) Torque(K.B + U.B)

TORQUE

Definition:

"The turning effect of a force is called torque. It is also called Moment of Force**"**.

Formula:

Moment of Force (Torque) is denoted by Greek letter **"τ"** and its formula is given below:

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.

$$1Nm = 1\ kgm^2s^{-2}$$

Quantity:

Torque is a vector and derived quantity.

Examples:

Common examples of Torque are as follows:

- Turning pencil in a sharpener
- turning stopcock of a water tap

(iii) Centre of mass(K.B)

Ans: **CENTRE OF MASS**

Definition:

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

Example:

Consider a system of two particles A and B connected by a light rigid rod as shown in figure below:

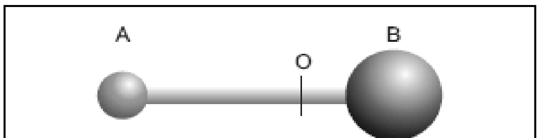


Figure: Centre of Mass of Two Unequal Masses

Let O is the point anywhere between A and B such that the force F is applied at point O as shown in figure above. if the system moves in the direction of force F without rotation, then point O is the centre of mass of the system.

(iv) Centre of Gravity (K.B)

Ans: **CENTRE OF GRAVITY**

Definition:

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

Position of 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. A body is balanced when it is supported at its centre of gravity.

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.

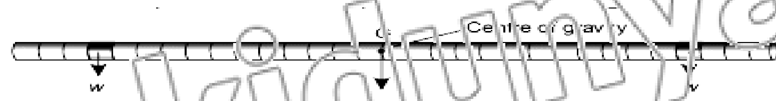


Figure: Centre of Gravity of Uniform Rod

4.3 Differentiate the following. (K.B) **(GRW 2017)**

(i) Like and unlike parallel forces

Ans: **DIFFFERENTIATION**

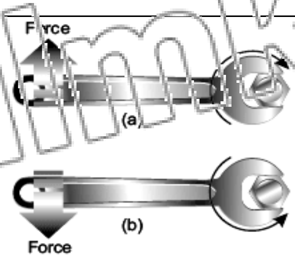
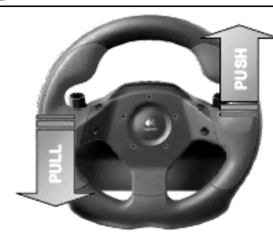
Like and unlike parallel forces can be differentiated as:

Like Parallel Forces	Unlike Parallel Forces
Definition	
• 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.
Example	
• Consider a bag with apples in it. The weight of the bag is due to the weight of all the apples in it. Since the weight of every apple in the bag is the force of gravity acting on it vertically downwards, therefore, weights of apples are the parallel forces. All these forces are acting in the same direction. Such forces are called like parallel forces.	• Suppose 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 downward and tension in the string pulling it vertically upward. The two forces are parallel but opposite to each other. These forces are called unlike parallel forces.

(ii) Torque and Couple (K.B)

Ans: **DIFFFERENTIATION**

Torque and couple can be differentiated as:

Torque	Couple
Definition	
• 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.
Unit	
• SI unit of torque is Nm	• SI unit of couple is newton (N)
Figure	
 **Figure: Torque in Spanner**	 **Figure: Couple on Steering**

(iii) Stable and Neutral Equilibrium

Ans: **DIFFEFERENTIATION**

Stable and neutral equilibrium can be differentiated as:

Stable Equilibrium	Neutral Equilibrium
Definition	
• 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.
Position of Centre of Gravity	
• When body is in stable equilibrium, its centre of gravity is at the lowest position. When it is tilted, its centre of gravity rises. When applied force ceases to act the body 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.	• In neutral equilibrium, the centre of gravity of a body remains at the same height, irrespective of its new position
Examples	
• Table, chair, box and brick lying on a floor are in stable equilibrium.	• A pencil, a sphere, and cylinder, a roller, an egg lying horizontally on a flat surface are examples of neutral equilibrium.

4.4 How head to tail rule helps to find the resultant of forces? (K.B + U.B)

Ans: **HEAD TO TAIL RULE**

Draw the representative lines of all the force to be added in such a way that head of first force coincides with the tail of second force, head of second force coincides with the tail of third force and so on. The line obtained by joining the tail of first force with the head of last force represent resultant force.

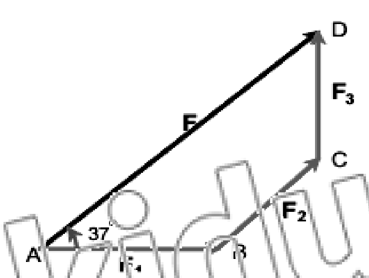


Figure: Finding Resultant Force

4.5 How can a force be resolved into its rectangular components? (K.B + U.B)

Ans: See Q. no.1 Long Question TOPIC 4.1

4.6 When a body is said to be in equilibrium? (K.B)

Ans: **EQUILIBRIUM**

Definition:

"A body is said to be in equilibrium if no net force and no net torque acts on it."

Mathematically:

$$\sum F = 0 \quad \ldots\ldots\ldots\ldots\ldots\ (1)$$
$$\sum \tau = 0 \quad \ldots\ldots\ldots\ldots\ldots\ (2)$$

Types:

There are two types of equilibrium

- Static Equilibrium
- Dynamic Equilibrium

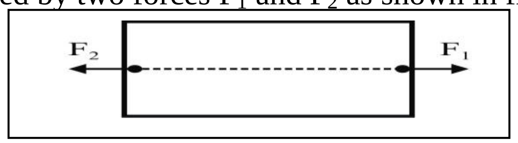
4.7 Explain the first condition for equilibrium. (K.B + U.B + A.B)

Ans: See Q. no.2 Long Question TOPIC 4.9

4.8 Why there is need of second condition for equilibrium if a body satisfies first condition for equilibrium. (K.B + U.B)

Ans: **NEED FOR SECOND CONDITION**

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.

Conclusion:

When the 1st condition of equilibrium is satisfied, no linear acceleration is produced in the body. But still in some cases body may have tendency to rotate and can have rotational acceleration so we need Second Condition for equilibrium. When the 2nd condition of equilibrium is satisfied, then no rotational acceleration is produced in the body.

4.9 What is second condition of equilibrium? (K.B + U.B)

Ans: **SECOND CONDITION FOR EQUILIBRIUM**

Statement:

According to Second condition for equilibrium:

"There should be no net torque acting on the body. It means a body will be in equilibrium if the resultant of all the torques acting on it is zero"

Mathematically:

$$\sum \tau = 0$$

4.10 Give an example of a moving body which is in equilibrium. (K.B)

Ans: **A MOVING BODY IN EQUILIBRIUM**

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.

Dynamic Equilibrium:

"If a moving body is in the state of equilibrium then its equilibrium is called as Dynamic Equilibrium."

Example:

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

4.11 Think of a body which is at rest but not in equilibrium. *(K.B)*

Ans: **BODY AT REST**

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?(K.B) **(LHR 2015)**

Ans: **THE ACTION OF SINGLE FORCE**

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.

4.13 Why the height of vehicles is kept as low as possible?(K.B)

Ans: **HEIGHT OF RACING CARS**

We know that smaller the height of centre of gravity of a body, greater will be its stability. The height of vehicles is kept low to lower their centre of gravity and as a result their stability increases.

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

Ans: See Q. no.4 Long Question TOPIC 4.8

NUMERICAL PROBLEMS (U.B + A.B)

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

Given Data:

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

F_y = Force along y-axis = 6 N

Required:

Magnitude of the resultant force = F = ?

Direction of the force = θ = ?

Solution:

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

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

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

$$= \sqrt{72} = 8.5\,N$$

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

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

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

$$\theta = 45^0$$

Result:

Hence, the resultant Force is

4.2 Find the rectangular components of a force of 50 N making an angle of 30^0 with x – axis.
(GRW 2015)

Solution:

Given Data:

Force = F = 50 N

Angle = θ = 30^0

To Find:

Horizontal component of force = F_x = ?

Vertical component of force = F_y = ?

Calculations:

As we know that

F_x = F cosθ

By putting the values, we have

F_x = 50 x cos 30^0

F_x = 50 x 0.866

$$\boxed{F_x = 43.3\text{ N}}$$

Also we know that

F_y = F sinθ

F_y = 50 x sin 30^0

F_y = 50 x 0.5

$$\boxed{F_y = 25\text{ N}}$$

Result:

Hence, the horizontal and vertical component of force

4.1 Find the magnitude and direction of a force. If its x – component is 12 N and y – component is 5 N. **(GRW 2013)**

Solution:

Given Data:

X – component of the force = F_x = 12N

Y – component of the force = F_y = 5N

To Find:

Magnitude of the resultant force = F =?

Direction of the resultant force = θ =?

Calculations:

According to Pythagoras theorem

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

By putting the values, we have

$$F = \sqrt{(12)^2 + (5)^2}$$
$$F = \sqrt{144 + 25}$$
$$F = \sqrt{169}$$
$$F = 13\ N$$

We also know that

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

By putting the values, we have

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

$$\theta = \tan^{-1} 0.4166$$

$$\theta = 22.6^o \text{ with x-axis}$$

Result:

Hence, the magnitude of the resultant force will be 13 N and direction of the resultant force will be 22.6° with x-axis

4.2 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.

Solution:

Given Data:

Force acting on spanner = F = 100 N

Distant from nut = L = 10 cm = 0.1 m

To Find:

Torque produced by the force = τ = ?

Calculations:

As we know that

τ = F x L

By putting the values, we have

τ = 100 x 0.1

τ = 10 Nm

Result:

Hence, the torque produced by the force will be 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.

Solution:

Given Data:

Horizontal component of the force = F_x = 20 N

Angle formed with the horizontal = θ = 30^0

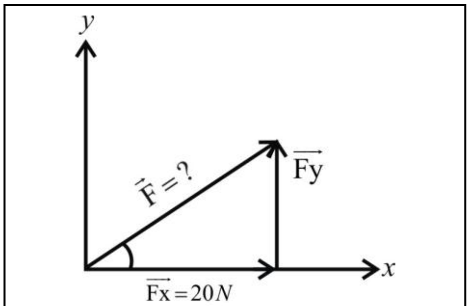


Figure: **Head To Tail Rule For Finding Resultant Force**

To Find:

Force applied = F = ?

Calculations:

As we know that

$F_x = F\cos\theta$

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

By putting the values, we have

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

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

F = 23.09 N = 23.1 N

Result:

Hence, the applied Force will be 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.

Solution:

Given Data:

Force of the couple = F = 50 N

Radius of the steering = r = 16cm

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

To Find:

Torque produced by the couple = τ = ?

Calculations:

As we know that

τ = F x AB

By putting the values, we have

τ = 50 x 0.32

τ = 16 Nm

Result:

Hence, torque produced by the couple will be 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.

Solution:

Given Data:

Tension in the first string = T_1 = 3.8 N

Tension in the second string = T_2 = 4.4 N

To Find:

Weight of the picture frame = w = ?

Calculations:

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:

Hence, weight of the picture frame will be 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.

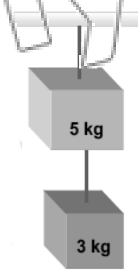


Figure: To Find Tension in the String

Solution:

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 x 10 = 50 N

Weight of the below block = $w_2 = m_2g$ = 3 x 10 = 30 N

To Find:

Tension in upper string = T_1 = ?

Tension in lower string = T_2 = ?

Calculations:

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:

Hence, the tension in upper string will be 80 N and tension in lower string will be 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?

Solution:

Given Data:

Initial force used for tightening = F_1 = 200 N

Initial moment arm of the force used for tightening = L_1 = 10 cm = 0.1 m

Second force used for loosen = F_2 = 150 N

To Find:

Second moment arm for loosen= L_2 = ?

Calculations:

According to second condition of equilibrium, we have

$\sum\tau = 0$

Or Clockwise torque = Anticlockwise torque

$F_2 \times L_2 = F_1 \times L_1$

$150 \times L_2 = 200 \times 0.1$

$$L_2 = \frac{200 \times 0.1}{150}$$

$L_2 = 0.133$ m

$L_2 = 13.3$ cm

Result:

Hence, the length of spanner to loosen the nut will be 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?

Solution:

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

To Find:

Second force = F_2 =?

Calculations:

According to second condition of equilibrium, we have

$\sum\tau = 0$

Or Clockwise torque = Anticlockwise torque

$F_2 \times L_2 = F_1 \times L_1$

$F_2 \times 0.5 = 100 \times 0.2$

$$F_2 = \frac{100 \times 0.1}{0.50}$$

$F_2 = 40$ N

Result:

Hence, the force required to balance uniform rod will be 40 N.

SELF TEST

Time: 40 min. **Marks: 25**

Q.1 Four possible answers (A), (B), (C) & (D) to each question are given, mark the correct answer. **(6×1=6)**

1. If the direction of parallel forces is same, then these are called:
(A) Same forces (B) Like Parallel forces
(C) Unlike Parallel forces (D) All of above

2. Turning effect of a force is called:
(A) Torque (B) Moment of a force
(C) Couple (D) Both (A) and (B)

3. The force which acts perpendicularly down towards the earth is called:
(A) Torque (B) Weight
(C) Force of gravity (D) Both B & C

4. When two equal, opposite and parallel forces act in the same line, they form a:
(A) Torque (B) Moment of a couple
(C) Force (D) Couple

5. 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

6. A pencil lying horizontally is in:
(A) Stable equilibrium (B) Unstable equilibrium
(C) Neutral equilibrium (D) None of above

Q.2 Give short answers to following questions. **(5×2=10)**

i. Differentiate like and unlike parallel forces.
ii. Find a force from its perpendicular components.
iii. Why handle of door is kept at its outer edge?
iv. State principle of moments.
v. Why do we need second condition for equilibrium?

Q.3 Answer the following questions in detail. **(4+5=9)**

a) Define and Explain Resolution of Forces
b) 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?

<u>Note</u>:
Parents or guardians can conduct this test in their supervision in order to check the skill of students.