3 EQUILIBRIUM OF FORCES

EQUILIBRIUM

OBJECTIVES

At the end of the topic, students should be able to:

- differentiate between resultant force and equilibrant force;
- explain the concept of equilibrium;
- differentiate between static and dynamic equilibrium; and
- state and explain the conditions of equilibrium of coplanar non parallel forces.

Dynamic and static equilibrium

A **body is in equilibrium if it is at rest or it moves with a constant velocity when many forces act on it.** The term *equilibrium* means that the resultant force acting on the body at any point is zero. A body moving in a straight line with a constant velocity or zero acceleration is in **dynamic equilibrium.** The two types of dynamic equilibrium are:

(i) Translational equilibrium: The forces acting on the body tend to cause translational motion.

(ii) Rotational equilibrium: The forces acting on the body tend to produce rotational motion.

If the resultant force on a body is zero and yet it does not move or turn about any point, it is in **static equilibrium.**

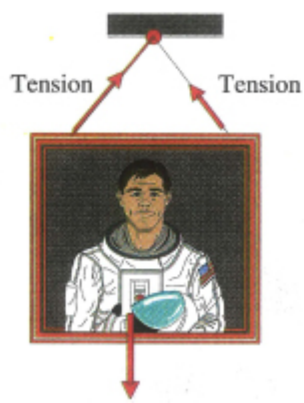


Figure 3.1: Weight

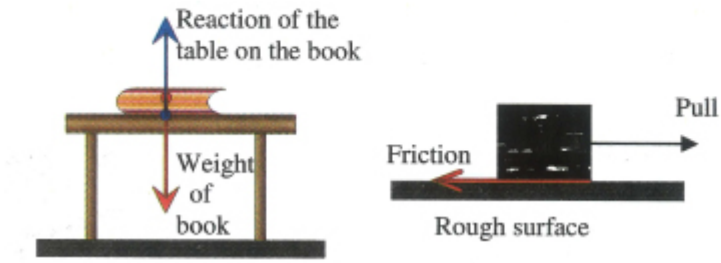


Figure 3.2: Forces in equilibrium

A frame hanging on the wall is in static equilibrium. Its weight pointing downward balances the tensions on the strings. Forces that support bridges, buildings, ceiling fans on the ceiling are in static equilibrium.

The best way to keep a body in equilibrium is to apply a force equal in size but opposite in direction to the resultant force acting on it.

A body with two parallel forces acting on it is in equilibrium if:

â€¢ the two forces are equal in size (magnitude);

â€¢ the two forces act on the body at the same point in the opposite directions.

Figure 3.2(a) illustrates the equilibrium of parallel forces. The weight of the book exerts a force on the table; the table supports the weight of the book by exerting an equal force in the opposite direction to keep the book in static equilibrium. When a push is given to a block of wood lying on a rough surface, friction between the surface and the wooden block resists the motion of the wooden block to keep it in static equilibrium, see figure 3.2(b) The frictional force is exactly equal to the pull but point in the opposite direction.

Equilibrium of three coplanar forces

Three coplanar forces T_1, T_2 and W are in static equilibrium if their point of intersection O is at rest. This occurs if the resultant of any two of the forces is balanced by the third force. For example, W balances the resultant of T_1 and T_2, T_1 balances the resultant of T_2 and W or T_2 balances the resultant of T_1 and W. When the effect of the forces acting at the point O is neutralized, the point O will not move or rotate; the system of forces T_1, T_2 and W is said to be in static equilibrium. The force, which acts in the direction opposite to the resultant to keep the system in static equilibrium, is called the e**quilibrant.**

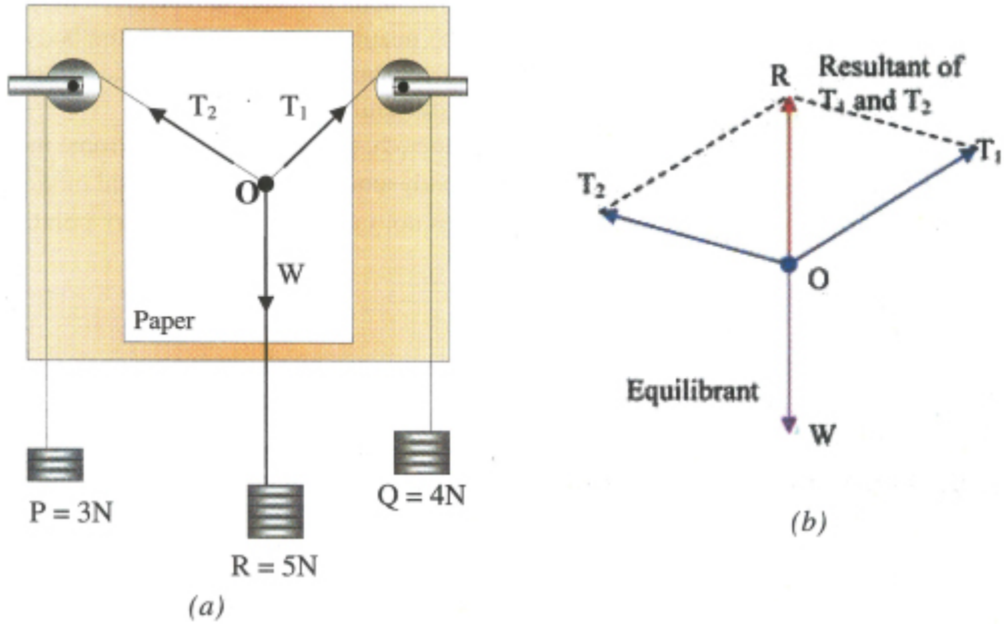


Figure 3.3

Equilibrant is equal to the **resultant** in magnitude but acts in the opposite direction.

Equilibrant is a force which is equal in magnitude to the resultant of two or more forces, but its direction is opposite to the direction of the resultant.

How to determine the equilibrant

(1) *Using parallelogram law of forces*

â€¢ The parallelogram law of vector addition is used to find resultant of any two forces.

â€¢ The equilibrant is drawn equal in magnitude to the resultant of the other forces such that its direction is opposite to the resultant. This is illustrated in figure 3.3(b)

(2) *Triangle of forces*

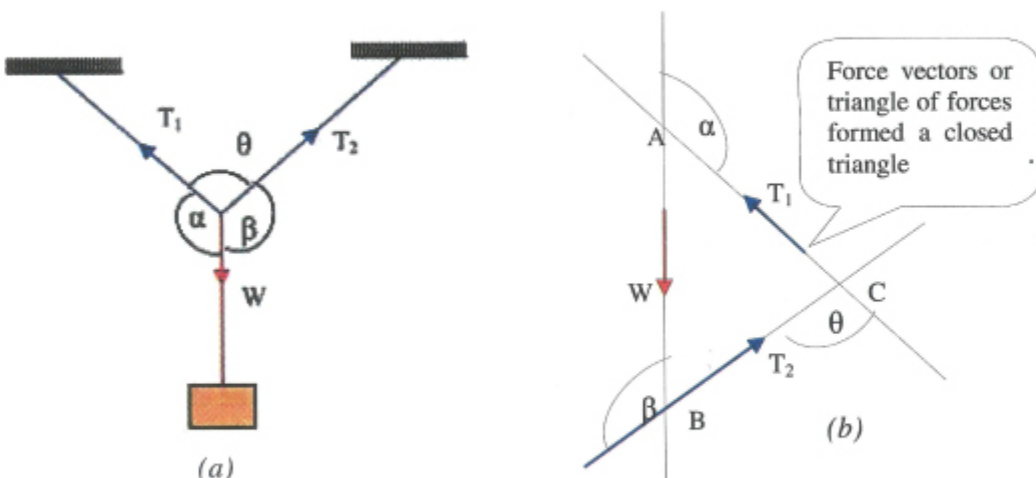


Figure 3.4 Triangle of forces

The easiest way to find the equilibrant of three coplanar forces acting simultaneously at the same point is to draw their **force vectors.** The force vectors representing their forces form a closed triangle called **triangle of forces.** The arrowheads representing the direction of the forces move round the triangle in the same clockwise or anticlockwise direction as if they are in equilibrium.

The triangle law of forces states that three forces acting simultaneously at a point are in equilibrium if their force vectors form a close triangle.

This can be stated in another way;

The triangle law of forces states that three forces acting at a point are in equilibrium if they can be represented in magnitude and direction by the sides of a triangle such that the arrowheads indicating the directions the forces move round the triangle in order.

Steps to sketch the triangle of forces

â€¢ Measure the angles Î±, Î² and Î¸ between any two the forces at the point of intersection. This is shown in figure 3.4(a)

â€¢ Draw AB, CA and BC to represent the magnitudes and directions of the forces W, T_1 and T_2 respectively. That is, AB is drawn to point in the direction of the force W, CA is drawn parallel to the force T_1 and BC is drawn parallel to the force T_2.

â€¢ On the force vectors or triangle of forces in figure 3.4(b), Î± is the external angle formed between the forces T_1 and W, Î² is the external angle formed between the forces T_2 and W while Î¸ is the external angle formed between the forces T_1 and T_2.

Close study of the force vectors shows that the arrowheads indicating the direction of the forces move round the triangle in the same direction, clockwise or anticlockwise. The magnitudes and directions of the forces can be calculated by applying sine rule to the force vectors triangle in Figure 3.4b.

$$\frac{T_1}{\sin B} = \frac{T_2}{\sin A} = \frac{W}{\sin C}$$

$$\frac{T_1}{\sin(180- \quad)} = \frac{T_2}{\sin(180- \quad)} = \frac{W}{\sin(180- \quad)}$$

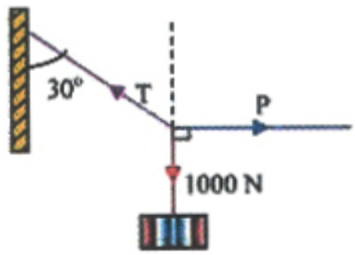
The Lamiâ€™s theorem is a short cut to bypass sketching the force-vector, triangle.

$$\frac{T_1}{\sin} = \frac{T_2}{\sin} = \frac{W}{\sin}$$

The theorem states that the ratio of any force to the sine of the angle directly opposite it is constant if three forces are in equilibrium.

Worked examples

1. A weight of 1000 N is suspended using a chain fixed on a vertical wall. The chain makes an angle of 30Â° with the wall when a horizontal force P is applied to the chain as shown below. Calculate the magnitudes of the tension T in the chain and the horizontal force P if the system is in equilibrium.



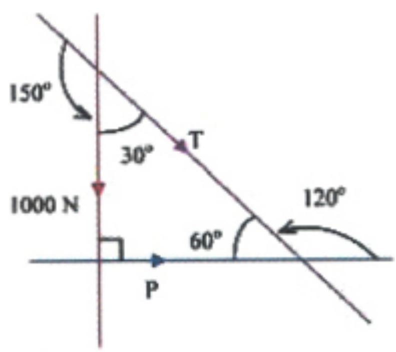
Solution

Method 1: Using force vectors triangle or triangle of forces.

$$\frac{P}{1000} = \tan 30^o \qquad \frac{1000}{T} = \sin 60^o$$

$$P = 1000 \tan 30^o \qquad T = \frac{1000}{\sin 60^o}$$

$$P = 577.4\ N \qquad T = 1154.7\ N$$



Solution

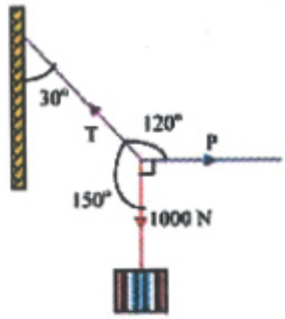
Method 2: Using Lamiâ€™s theorem.

$$\frac{T}{\sin 90^o} = \frac{P}{\sin 150^o} = \frac{1000}{\sin 120^o}$$

$$\frac{T}{\sin 90^o} = \frac{1000}{\sin 120^o} \Rightarrow T = \frac{1000 \sin 90^o}{\sin 120^o} = 1154.7\text{N}$$

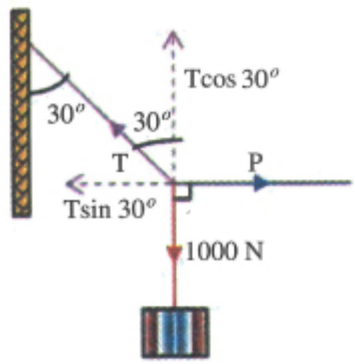
$$\frac{P}{\sin 150^o} = \frac{1000}{\sin 120^o} \Rightarrow P = \frac{1000 \sin 150^o}{\sin 120^o}$$

$$P = 577.4\ N$$



Solution

Method 3: Resolution of vectors



Since the three forces are in equilibrium, the vertical and horizontal resultants are zero.

$\therefore T\cos 30^o = 1000 \quad and \ P = T\sin 30^o$

$T = \dfrac{1000}{\cos 30^o}$ $\qquad$ $P = 1154.7\sin 30^o$

$T = 1154.7\ N$ $\qquad$ $P = 577.4\ N$

2. A frame portrait of weight 25 N is suspended on the ceiling by two supporting strings as shown in the diagram below. Calculate the tension on each string.

Solution

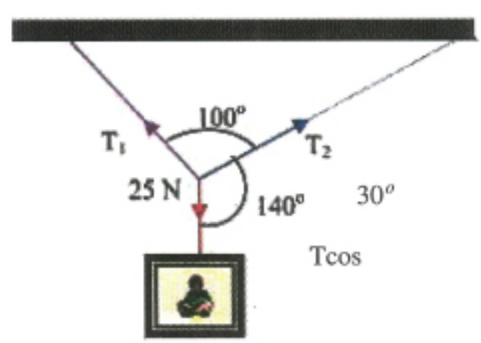
$$\frac{T_1}{\sin 140^o} = \frac{T_2}{\sin 120^o} = \frac{25}{\sin 100^o}$$

$$\frac{T_1}{\sin 140^o} = \frac{25}{\sin 100^o} \Rightarrow T_1 = \frac{25\sin 140^o}{\sin 100^o}$$

$T_1 = 16.3\ N$

$$\frac{T_2}{\sin 120^o} = \frac{25}{\sin 100^o} \Rightarrow T_2 = \frac{25\sin 120^o}{\sin 100^o}$$

$T_2 = 21.98\ N$



Summary

â€¢ A body is in **equilibrium** if it is at rest or it is with a constant velocity when many forces act on it. This happens if the resultant force on the body is zero.

â€¢ A body in **dynamic equilibrium** moves in a straight line or round a circle with a constant velocity or zero acceleration.

â€¢ A body is in **static equilibrium** if the resultant force on a body is zero and yet it does not move or turn about any point.

Equilibrant is a force which is equal in magnitude to the resultant of two or more forces, but its direction is opposite to the direction of the resultant.

â€¢ The **triangle law of forces** states that three forces acting at a point are in equilibrium if they can be represented in magnitude and direction by the sides of a triangle such that the arrow heads indicating the direction of the forces move round the triangle in order.

Practice questions 3a

1. (a) Explain the term *equilibrium.*

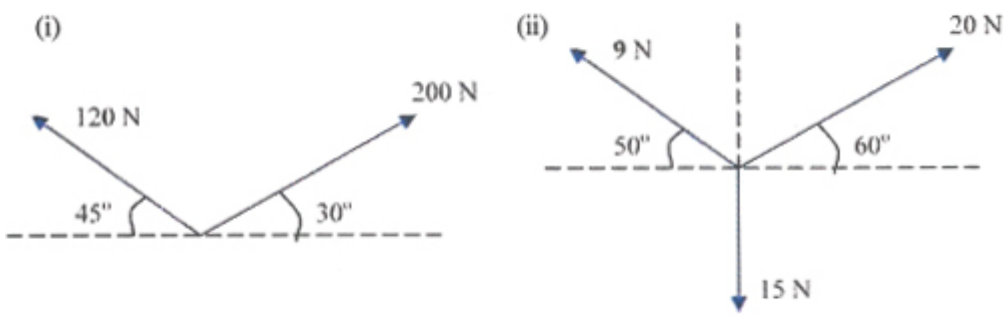
(b) Distinguish *static* and *dynamic equilibrium.*

The diagram above shows a force of 58 N applied to a box. If the box does not move, what is the direction and magnitude of the force needed to keep the body in equilibrium?

2. (a) What is an e*quilibrant?*

(b) Explain how to find the equilibrant of two or three forces acting at a point.

(c) Find the equilibrant of the following forces illustrated in the diagram below.

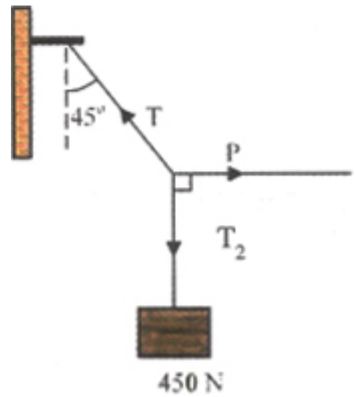


3. (a) State the triangle of forces.

(b) The forces shown in diagram below are in equilibrium:

(i) sketch the triangle of forces and use your sketches to find the forces labelled P and T.

(ii) Find the forces labelled T_1 and T_2 in the diagram below.



MOMENT OF A FORCE

OBJECTIVES

At the end of this topic, students should be able to:

- explain what is meant by the moment of a force;
- take moments about any given point and show the directions of the moments;
- state the conditions of equilibrium of a number of coplanar parallel forces; and
- solve simple problems on moments of forces.

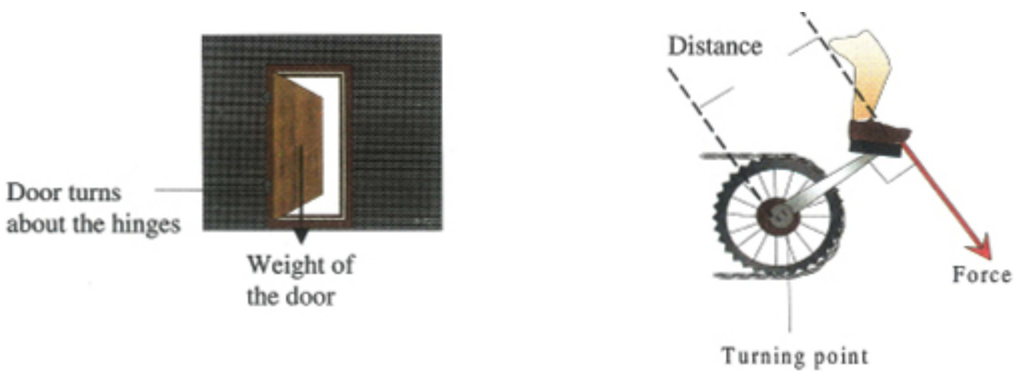


Figure 3.5 Moments of forces

A force has the ability to make objects turn about a point. **The turning effect of a force is called moment or torque.** When a door is opened, it turns about the hinges. The force exerted on the knob makes the door turn at the hinges. A cyclist moves a bicycle by pushing on the pedal of the bicycle. The force exerted by his push on the pedal turns the wheel of his bicycle. The above instances illustrated in Figure 3.5 are examples of moments.

The strength of moment of a force depends on:

â€¢ the size or magnitude of the force;

â€¢ the distance of the force from the turning point.

Moment of a force is the product of the size of the force and the perpendicular distance to the line of action of the force from the turning point.

Moment = Force Ã— Perpendicular distance to the line of action of *the force.*

M = F Ã— d

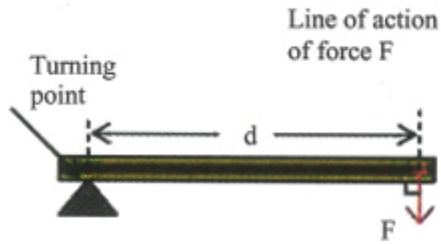


Figure 3.6

The force F produces a clockwise moment about the turning point. The unit of moment is Newton – metre (Nm).

Moment of an inclined force

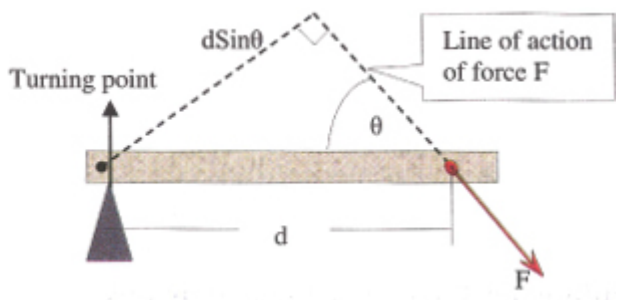


Figure 3.7: Moment of an inclined force

If the applied force F is inclined at an angle Î¸ (Î¸ must not be 90Â°) to the distance *d* from the turning point. The distance *d* is resolved into two perpendicular parts or components. The component perpendicular to the line of action of the force is used to compute the moment.

In Figure 3.7, *d* sin Î¸ is the component of the distance *d* perpendicular to the line of action of the force F.

Moment = F Ã— *d* sin Î¸ = Fdsin Î¸

Moments and directions

The direction of moment about any point can be clockwise or anticlockwise. If moments in the anticlockwise directions are assigned positive values, then the clockwise moments are taken as negative. When many forces act on a body, the direction the body turns will depend on the direction of the resultant moment on it. The body turns in the clockwise direction when the clockwise moments are greater than the anticlockwise moments.

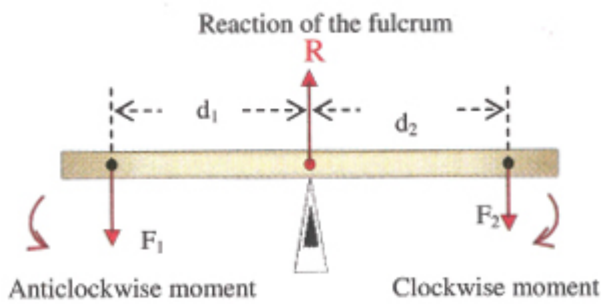


Figure 3.8: Moments and directions

The clockwise moment = F_2d_2 and the anticlockwise moment = F_1d_1 If the clockwise moment is greater than the anticlockwise moment, the body turns in the clockwise direction. Resultant moment = $F_2d_2 - F_1d_1$.

Moment and equilibrium

A body is in equilibrium if the sum of clockwise moments about any point is equal to the sum of anticlockwise moments about the same point. The resultant moment about the turning point is zero (Î£F_nd_n = 0).

The beam in Figure 3.8 is in equilibrium if;

$$F_2d_2 - F_1d_1 = 0 \text{ or } F_1d_1 = F_2d_2$$

The equation above is the principle of moment.

Principle of moment states that if many parallel forces act on a body, equilibrium is maintained if the sum of clockwise moments about any point is balanced by the sum of anticlockwise moments about the same point.

The principle of moment can be stated in another way:

A body is in equilibrium if the resultant moment about any point on the body is zero.

Conditions of equilibrium for parallel coplanar forces

A body acted upon by many parallel forces is in static equilibrium if:

(1) the resultant force acting on the body is zero (Î£ F = 0). That is the total forces acting in any direction is equal to the total forces acting in the opposite direction.

$$R = F_1 + F_2$$

(2) the resultant moment about the turning point is zero (Î£ F_nd_n = 0). That is the sum of clockwise moments about any point is equal to the sum of anticlockwise moments about the same point. See figure 3.8

$$F_2d_2 - F_1d_1 = 0 \text{ or } F_1d_1 = F_2d_2$$

The moment of R about the fulcrum or turning point is zero since it has zero distance perpendicular to the fulcrum.

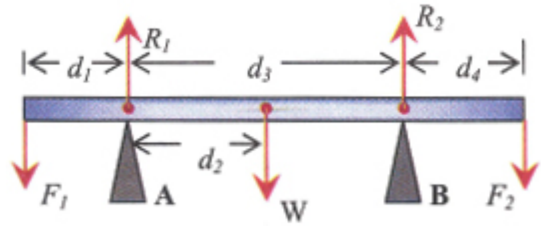


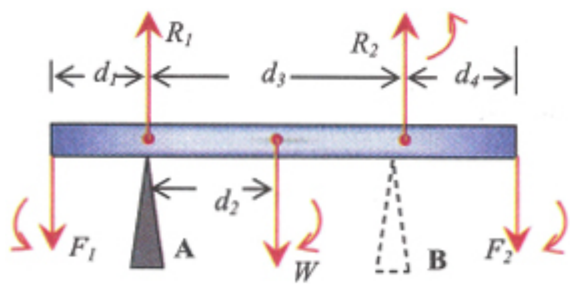
Figure 3.9: Beam balanced on two supports

A beam balanced on two supports A and B will be in equilibrium if:

â€¢ the sum of upward forces is equal to the sum of the downward forces.

$$R_1+R_2 = F_1 + W + F_2$$

â€¢ the sum of clockwise moments about any point is equal to the sum anticlockwise moments about the same point. If the fulcrum or support **B** is removed, the beam will turn about the fulcrum (**A**). The moment of R_1 is zero because it has no perpendicular distance from the fulcrum **A**.



Sum of clockwise moments = Wd_2 $+Fd_2(d_3+d_4)$
Sum of anticlockwise moments = $F_1d_1+R_2d_3$
Sum of clockwise moments = Sum of anticlockwise moments

$$Wd_2 +F_2\,(d_3+d_4) = F_1d_1+R_2d_3$$

Couple and torque

A couple comprises two parallel forces equal in magnitude and pointing in the opposite directions such that their lines of action do not meet

The moment of a couple is always pointing in the same direction; therefore, a couple always has a turning effect.

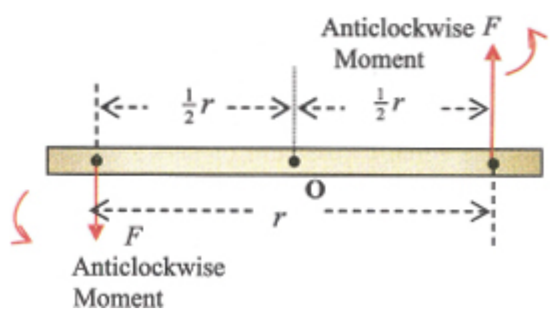


Figure 3.10 Couple

The moment of a couple is called **torque** (Î“). Torque is produced by forces which tend to turn the object in the same direction. Figure 3.10 shows two equal forces F, each producing a moment or torque in the anticlockwise direction. The resultant moment or torque is given by:

Torque about **O** = $F \times ½\, r + F \times ½\, r$

Torque about **O** = 2 ($F \times ½\, r$)

Î“ = *F* Ã— *r*

(*r* is the arm or length of the couple)

The moment of a couple or torque is the product of one force and the perpendicular distance (r) between the forces.

Torque = One force Ã— perpendicular distance between the forces

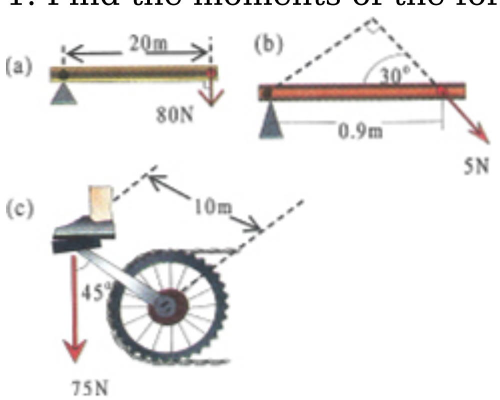
Î“ = *F* Ã— *r*

Balancing a couple

The resultant force of a couple is zero since the forces are equal in magnitude and point in the opposite directions but the resultant moment is not zero. A single force cannot be applied anywhere to balance a couple. It can only be balanced by another couple of equal strength whose torque is in the opposite direction to the given couple.

Worked examples

1. Find the moments of the forces shown in the diagrams below.



Solution

(a) Moment = force Ã— perpendicular distance.

Moment = 80 N Ã— 20 m = 1600 Nm.

(b) Moment = *Fd*sin Î¸

= 5N Ã— 0.9sin30Â° = 2.25 Nm.

(c) Moment = *Fd*sin Î¸

= 75 Ã— 10sin 45Â°

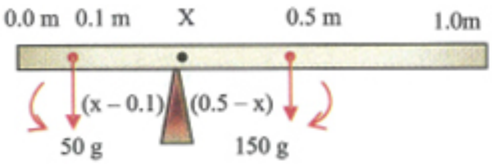
= 75 Ã— 10 Ã— 0.7071

= 530.3 Nm

3. A uniform metre rule of mass 150 g is balanced on a knife-edge at X m from a mass of 50 g suspended at the 0.1m mark. Find the position

(X) of the knife-edge.

Solution



Sum of clockwise moments = Sum of anticlockwise moments

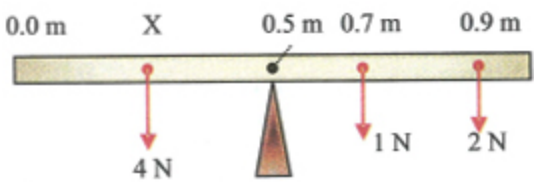
$50(x - 0.1) = 150(0.5 - x)$

$50x - 5 = 75 - 150x$

$200x = 80$

$$x = \frac{80}{200} = 0.4\ m$$

2. The diagram below shows a ruler balanced at the centre of gravity.
   (a) Calculate the value of (X) if the forces shown act upon the ruler.
   (b) What is the reaction at the fulcrum (support)?



Solution

(a) Taking moment about the fulcrum,

Sum of clockwise moments = Sum of anticlockwise moments

$4(0.5 - x) = 1(0.7 - 0.5) + 2(0.9 - 0.5)$

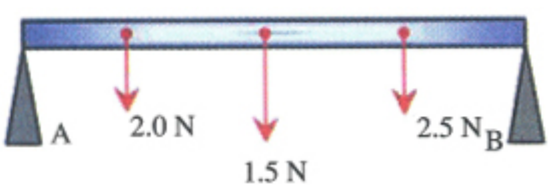
$4(0.5 - x) = 0.2 + 0.8 = 1$

$2 - 4x = 1$ or $4x = 1$ and $x = 0.25$m

(b) R = the reaction at the support

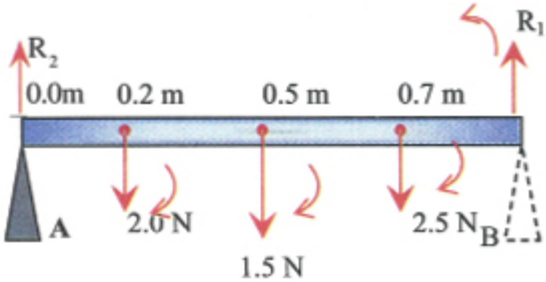
R = 4 N+1 N+2 N = 7 N

4. A uniform metre rule of weight 1.5 N is supported at the ends as shown below.



Calculate the reactions at the supports when the weights of 2N and 2.5N are placed at 0.2m and 0.7m marks respectively.

Solution



Removing the support B makes the ruler to turn about the point A the moment of R_1 =0

Sum of clockwise moments = Sum of anticlockwise moments

R_2 Ã— 1.0 = 2 Ã— 0.2 + 1.5 Ã— 0.5 + 0.7 Ã— 2.5

= 0.4 + 0.75 + 1.75 = 2.9 N

Total upward forces = Total downward forces

$R_1 + R_2 = 2.0 + 1.5 + 2.5$

$R_1 + 2.9 = 6.0$

R_1 = 6.0–2.9 = 3.1 N

Summary

â€¢ **Moment** is the turning effect of a force.

â€¢ **Moment of a force** is the product of the size of the force and the perpendicular distance to the line of action of the force from the turning point.

â€¢ **Moment** = Force Ã— perpendicular distance to the line of action of the force.

â€¢ **The unit of moment** is Newton metre (Nm).

â€¢ **Principle of moment** states that if many parallel forces act on a body, equilibrium is maintained if the sum of clockwise moments about any point is balanced by the sum of anticlockwise moments about the same point. The principle of moment can be stated in another way: A body is in equilibrium if the resultant moment about any point on the body is zero.

â€¢ **Two conditions for equilibrium of coplanar parallel forces** are;

(a) The resultant force acting on the body is zero (Î£ F = 0).

(b) **The resultant moment** about the turning point is zero.

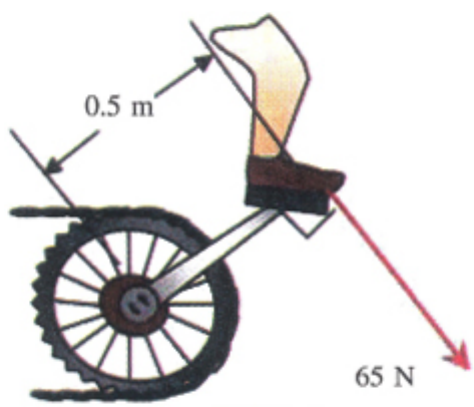
â€¢ **A couple** is two parallel forces which are equal in magnitude but pointing in opposite directions such that the lines of action do not meet.

â€¢ **The moment of a couple is called a torque** (Î“). The moment of a couple or a torque is the product of one force and the perpendicular distance between the forces.

â€¢ **Torque** = One force X perpendicular distance between the forces.

Practice questions 3b

1. (a) Explain the terms: (i) couple (ii) torque.
   (b) State the principle of moment.
   (c) A spanner of length 0.2 m is used to loosen a wheel nut of a car. If the torque produced by the spanner is 100 Nm, what is the maximum force applied at the end to loosen the nut?
2. (a) Explain the terms:
   (i) Equilibrant (ii) equilibrium
   (b) State the conditions for equilibrium for coplanar parallel forces.
   (c) A bus of total weight 20,000 N is packed 5m from one end of a bridge of uniform weight 60,000 N. If the length of the bridge is 20m, calculate the reactions at the supports.
3. (a) State the principle of moment.
   (b) Describe an experiment to determine the mass of metre rule using the principle of moments. State two precautions you should observes to ensure accurate result.
   (c) A non-uniform ladder PQ is 12m long and is balanced at 4m from the end P. When a load of 150 N is hanged at the end Q; the ladder balances at 6m from P. Calculate the weight of the ladder.
4. (a) Use diagrams to explain the moment of a force;
   (b) A boy pushes a bicycle pedal with a force of 65 N. If the force is perpendicular to the crank of length 0.5m, calculate the moment of the force he exerts on the pedal about the crank.



CENTRE OF GRAVITY AND STABILITY

OBJECTIVES

At the end of this topic, students should be able to:

- explain the meaning of centre of gravity of a body;
- determine the position of centre of gravity for objects with uniform shape;
- name and identify three types of equilibrium using stability of the body;
- and explain the effect of centre of gravity on the stability of a body.

Centre of gravity (G)

The weight of a rigid body is believed to act through a point called the **centre of gravity**. *A rigid body consists of billions of particles, each having a weight pulling it towards the centre of the earth.* The weights of these particles form a system of parallel forces as shown in Figure 3.11.

The resultant of these tiny parallel forces is the weight of the rigid body. The point G in the rigid body where the resultant weight **W** acts is the centre of gravity of the body.

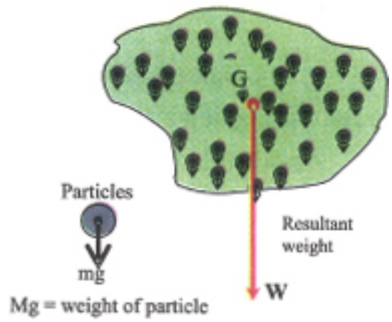


Figure 3.11: Centre of gravity of a rigid body

Centre of gravity is the point through which the weight of a rigid body appears to act.

Centre of gravity of objects with uniform shape

The position of centre of gravity depends on the shape or geometry of the body. *Objects with uniform shapes have their centre of gravity G at their centre or mid-point.*

- â€¢ Uniform beam rod and metre rule have their centres of gravity G at their centre. *The centre of gravity of uniform metre rule is at the 50 cm mark.*

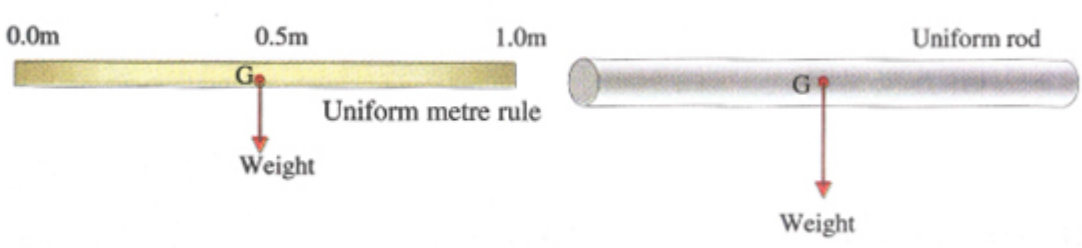


Figure 3.12a: Centres of gravity of a uniform metre rule and uniform rod

- â€¢ The centres of gravity of a uniform disc, a circular plate and a ring are at their centres.

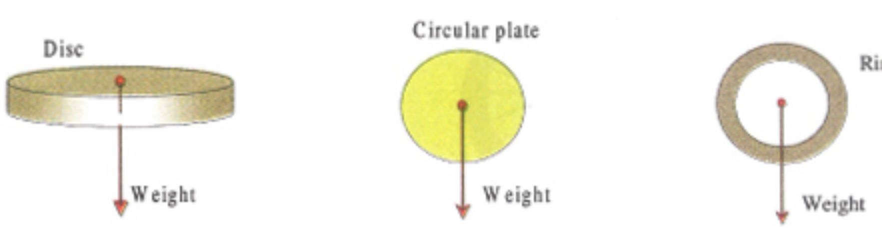


Figure 3.12b: Centres of gravity circular objects

â€¢ The centres of gravity of a square and a rectangle are at the points of intersection of their diagonals while that of a triangle is at the intersection of their altitudes.

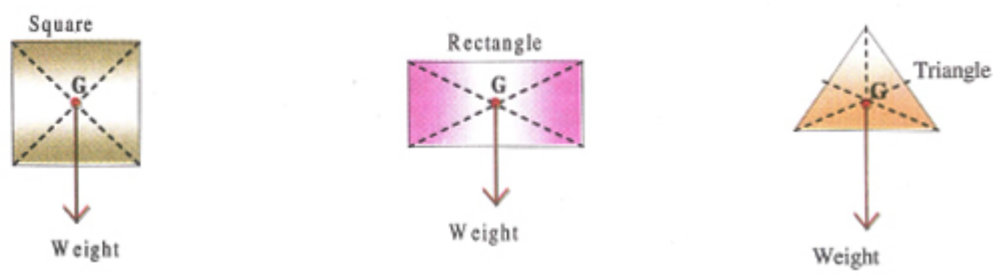


Figure 3.12c: Centres of gravity of two dimensional objects

â€¢ Cubes, cuboids, cylinders and spheres have their centres of gravity at their geometric centres.

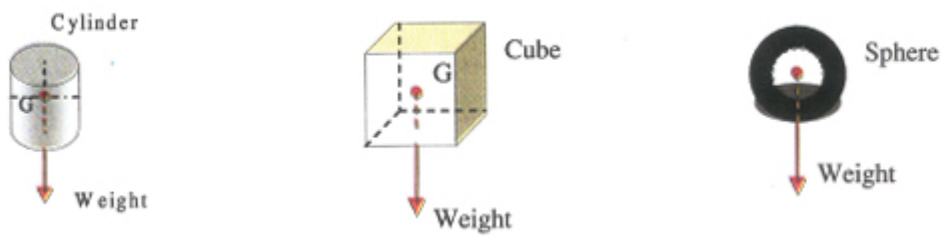


Figure 3.12d: Centres of gravity of two dimensional objects

Centre of gravity of non-uniform shape

The centre of gravity of objects with non-uniform shape is not at their centre. The position of the centre of gravity is the point where the mass of the body is concentrated. For cones and right pyramids, their centre of gravity is at Â¼ of its height measured from the base.

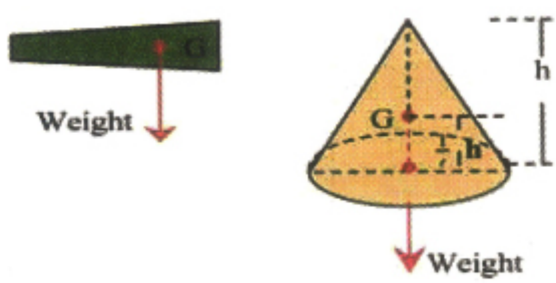


Figure 3.12e: Centres of gravity of non-uniform shapes

Determination of centre of gravity of a lamina

Apparatus: A lamina or flat plate, plumbline, retorts stand, pin and pencil.

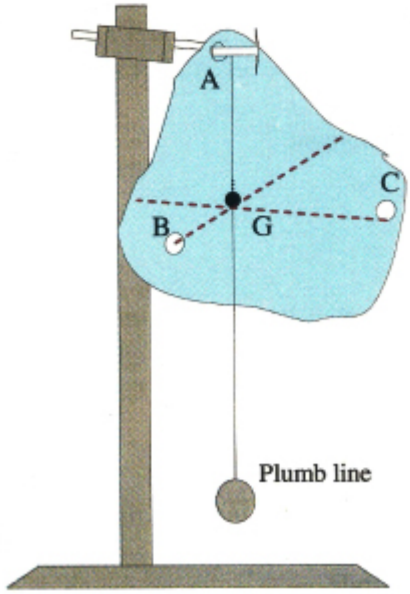


Figure 3.13: Determining centres of gravity of a lamina

Method

(i) Bore three holes A, B and C on the lamina at different positions.

(ii) Pass the pin through the first hole A on the lamina and hang the plumbline such that it is free to swing.

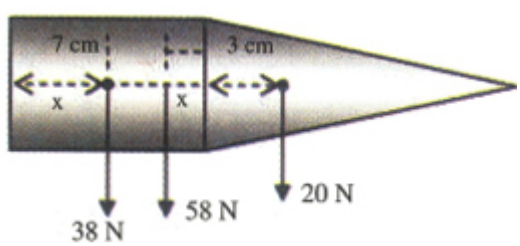
(iii) When the lamina stops swinging, use the pencil to mark two dots on the lamina along the line of the plumbline. Join the dots with a ruler. The centre of gravity G is along this line.

(iv) Repeat the procedure by suspending the lamina and the plumbline through the holes B and C. The point of intersection of the three lines is the centre of gravity G of the lamina. If the lamina is balanced at the centre of gravity G , it will be in equilibrium.

Worked examples

1. A composite shape is made up of a cylinder and a cone of total weight of 58 N and a total height of 26 cm. If the height and the weight of the cylinder are 14 cm and 38 N respectively, calculate the position of centre of gravity of the composite solid from the base of the cylinder.

Solution



Height of cone = 26 cm – 14 cm = 12 cm.

Weight of cone = 58 N – 38 N = 20 N.

Centre of gravity of cylinder G_1 = 14 cm from the base of the composite shape.

Centre of gravity of cone G_2 = Â¼ of height of the cone = 3 cm from the base of the cone.

Suppose the centre of gravity of the shape is at G, then taking moment about G, the moment of 58 N = 0.

Clockwise moment = Anticlockwise moment

20 (3+*x*) = 38(7 – *x*)

60+20*x* = 266 – 38*x*

58*x* = 306

x = 3.55 cm

Centre of gravity G is 14.0 cm – 3.55 cm = 10.80 cm from the base of the shape.

2. A uniform circular brass disc has a radius 7 cm. If a circle of radius 3 cm cut out the disc such that its centre is 4 cm from the centre of the disc. Calculate the new centre of gravity of the disc.

Solution

Weight of the brass disc is proportional to the area of the disc.

G = centre of gravity of the disc.

G_1 = centre of gravity of the cut out circle.

G_2 = centre of gravity of the remainder.

Taking moment about G, the moment of *W*= 0

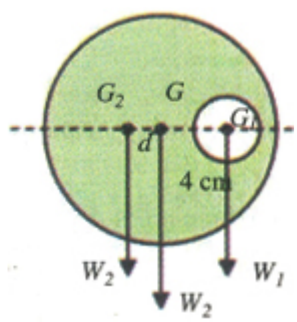
Clockwise moment = Anticlockwise moment

W_1 Ã— 4 = W_2 Ã— *d*

Ï€Ã—3^2 Ã— 4 = Ï€(7^2 – 3^2)*d*

36Ï€ = 40Ï€*d*

d = 0.9 cm



Stability

A stable body does not topple over if it is slightly displaced from its equilibrium position. Stability of a body depends on the position of the centre of gravity.

Stable equilibrium

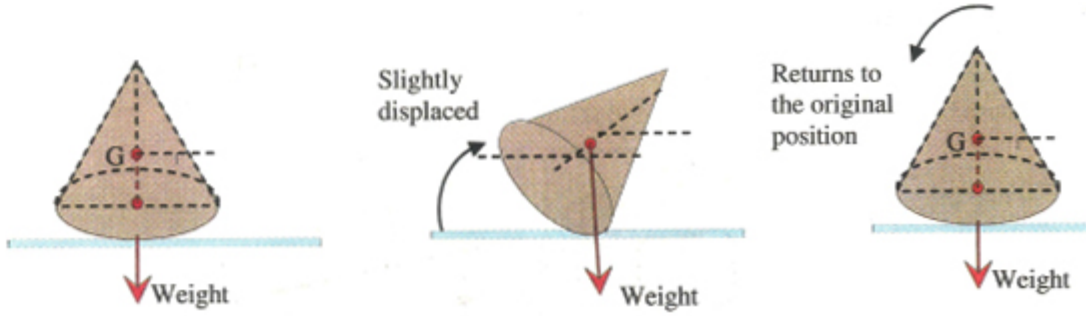


Figure 3.14a: Cone in stable equilibrium

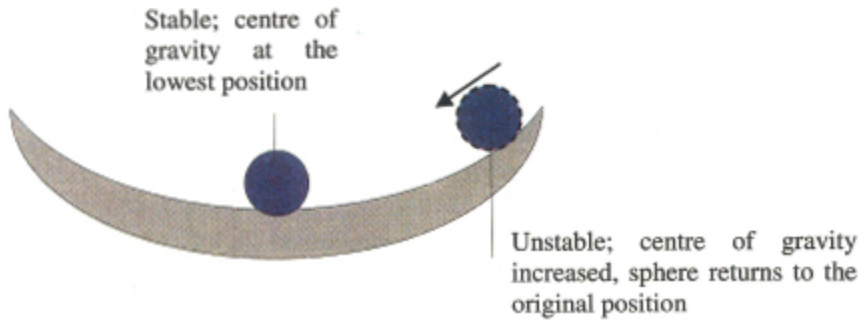


Figure 3.14b: Unstable to stable equilibrium for a sphere rolling in concave surface

Stable equilibrium is a term used to describe the state of equilibrium of a body with a low centre of gravity. This happens if the centre of gravity is very low and when displaced a little from its equilibrium position, it tends to return to its equilibrium position.

A body is in stable equilibrium if when it is slightly displaced from its rest position it does not topple over.

A body will be in stable equilibrium if:

â€¢ the position of centre of gravity is as low as possible.

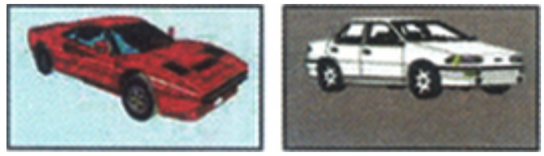
â€¢ it rests on a large base.

â€¢ the position of the centre of gravity is increased slightly when it is displaced a little from the equilibrium position.

â€¢ on slight displacement from the equilibrium position, the line of action of its weight passes through the base.

Figure 3.14c: Bunsen burner and drinking glass stands on a large base to remain stable

Racing cars and sports cars are built with heavy materials at the base to make the centre of gravity as low as possible. Vehicles with low centres of gravity are very stable. They are also designed with wide base and large tyres to increase their stability. This makes the racing car go round sharp bends at high speed without toppling over or skidding.



Cars like these ones have low centres of gravity to achieve stability. They do not topple over when negotiating bends at high speeds.

Unstable equilibrium

A body is in a state of unstable equilibrium if when displaced slightly from its rest position, it tends to seek for a new position where the centre of gravity is lowest.

The centre of gravity for a body in an unstable equilibrium is high. When the body is displaced slightly, the centre of gravity is raised making it to topple over.

A body is in an unstable equilibrium if:

â€¢ the position of centre of gravity is high.

â€¢ it lies on a small base.

â€¢ the position of the centre of gravity is decreased slightly when it is displaced a little from the equilibrium position.

â€¢ on slight displacement from the equilibrium position, the line of action of its weight falls outside the base.

â€¢ it tends to seek for a new position where the centre of gravity is lowest.

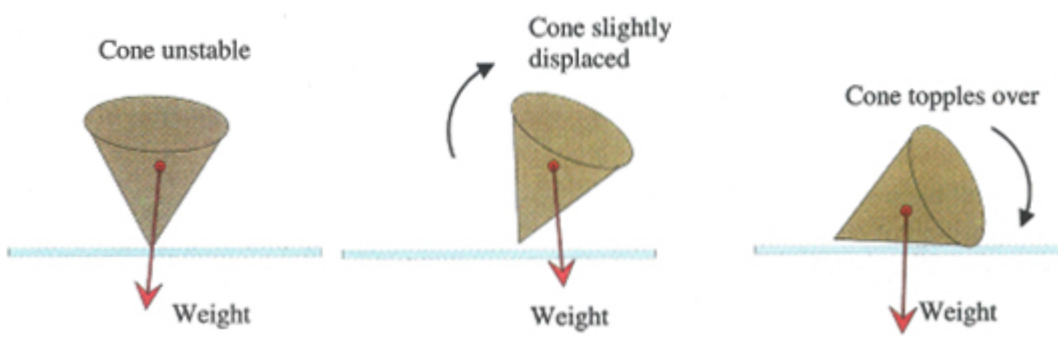


Figure 3.15: Cone in an unstable equilibrium

Loading a lorry with heavy materials at the top will increase its centre of gravity; the lorry stands the risk of toppling over when bending at high speed.

Neutral equilibrium

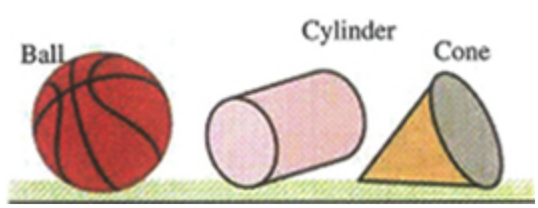


Figure 3.16: Objects in neutral equilibrium

A body is in neutral equilibrium if the position of centre of

gravity does not change when it is slightly displaced from its rest position.

A sphere, a cone lying on its slant side and a cylinder lying on its curved side are in neutral equilibrium. Changing the position of these objects does not change the position of the centre of gravity.

The new position of these objects cannot be distinguished from the old position.

Application of stability

(a) Racing cars, lorries and ships have very low centre of gravity to prevent the tendency of toppling when going round a sharp bend.

Figure 3.17: Objects with low centres of gravity

(b) Items like drinking glass, retort stand, Bunsen burners, and standing fans are built with large base to make them stable.

(c) Stable toys are weighted at the base to make them stable.

(d) Knowledge of stability is used in balancing objects which naturally are difficult to balance.

Summary

â€¢ Centre of gravity is the point through which the weight of a rigid body appears to act.

â€¢ Objects with uniform shapes have their centre of gravity G at their centre or mid-point.

â€¢ Three types of equilibrium are stable, unstable and neutral equilibriums.

â€¢ A body is in stable equilibrium if when it is slightly displaced from its rest position it does not topple over.

â€¢ A body is in a state of unstable equilibrium if when it is displaced slightly from its rest position, tends to seek for a new position where the centre of gravity is lowest.

â€¢ A body is in neutral equilibrium if the position of centre of gravity does not change when it is slightly displaced from its rest position.

Practice questions 3c

1. (a) Explain the following terms:
   (i) centre of gravity of a body;
   (ii) equilibrium.

   (b) How does the position of the centre of gravity determine the state of equilibrium of a rigid body?

(c) Show the position of the centre of gravity of the following shapes using simple sketches;
   (i) circular disc
   (ii) a uniform metre rule
   (iii) an equilateral triangle (iv) a ring

2. (a) Using the position of the centre of gravity, state three types of equilibrium.
   (b) State **two** characteristics of each type of equilibrium stated in (a);
   (c) Make a good sketch to illustrate the effect of small displacement on the position of centre of gravity of a rigid body.
3. Explain the following:
   (a) Sports cars are very low with large tyres;
   (b) It is risky to load lorries with heavy weights at the top.
   (c) Electric fans stand on a large base.
4. (a) State **four** characteristics of a body in stable equilibrium;
   (b) Using a cone or any other shapes, explain why an object in stable equilibrium does not topple over when it is slightly displaced from its rest position.
   (c) State **three** applications of stability.
5. (a) Define the centre of gravity of a body;
   (b) Describe an experiment to determine the centre of gravity of a lamina.

A uniform squared metal plate of sides 12 cm has a circular hole of area 4ð cm^2 punched out such that the centre of the hole is 3 cm from the centre of the plate. Calculate the new position of the centre of gravity of remainder.

FLOATING AND SINKING

Two forces act on a body immersed or floating in a liquid, the weight acting downwards and the upthrust acting upwards. The body floats in the liquid if the upthrust on it is equal to its weight and sinks if the weight is greater than the upthrust.

OBJECTIVE

At the end of this topic, students should be able to:

- identify the forces acting on a body fully immersed in a liquid;
- state the condition for a body to float in a liquid;
- explain why ship and hydrometer float in water;
- and use Archimedes principle to calculate relative density of solids and liquids.

Upthrust

Do you know that:

â€¢ pulling up a bucket of water is easier when it is fully immersed in water than when it is outside the water?
â€¢ some objects float in water while others sink in water?
â€¢ objects like iron which sinks normally in water can be shaped to float in water?

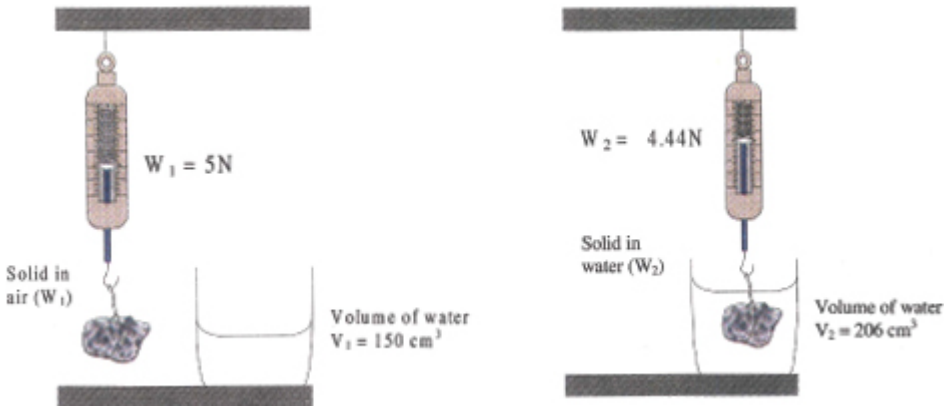


Figure 3.18: Objects totally immersed in liquid seem to lose weight

Try the following experiments to find out why objects appear to lose weight when immersed in water.

(i) Use a spring balance to weigh a small solid object in air and record its weight W_1.

(ii) Half fill the measuring cylinder with water and record its volume V_1.

(iii) Immerse the object in water gently and record the new volume of water V_2 in the measuring cylinder. Record also the reading of the spring balance W_2.

(iv) Find the difference between the final and initial reading of the spring balance.

(v) Find the difference between the final and initial volumes of the water in the measuring cylinder.

Observations

Weight of solid in air W_1 = 5.00 N

Weight of solid fully immersed in water

W_2 = 4.44 N

Initial volume of water V_1 = 150 cm^3;

Final volume of water V_2 = 206 cm^3.

Loss of weight of solid when fully immersed in water is called upthrust;

Apparent loss of weight (upthrust) = $W_1 - W_2$

= 5.00 N-4.44 N

= 0.56 N

The apparent loss of weight when a solid is completely or partly immersed in a liquid is the reason why objects weigh less (feel lighter) inside a liquid. Figure 3.18 shows that the spring balance reading is less when the solid is immersed in water. *The apparent loss of weight is* *called upthrust.*

Upthrust is the upward force which a fluid exerts on any object that is immersed partly or fully in it.

Upthrust or apparent loss of weight when a body is partly or fully immersed in a fluid (liquid or gas) is equal to the weight of the fluid displaced. Volume of displaced water = $V_2 – V_l$

Volume of displaced water = $V_2 – V_1$

= 206 cm^3 – 150 cm^3

= 56cm^3

The mass of 1 cm^3 of water = lg

The mass of 56 cm^3 of water = 56 g

Weight of displaced water = mass Ã— gravity

= 56 Ã— 10^{-3} Ã— 10

= 0.56 N

Upthrust =Weight of water displaced = 0.56 N

Observations from the experiment above show that upthrust of a liquid on a solid:

â€¢ is equal to the apparent loss of weight when a solid is partly or completely immersed in a fluid.

â€¢ is equal to the weight of fluid displaced.

Upthrust = Mass of displaced liquid Ã— gravity

Upthrust = ÏVg

Ï = density of displaced liquid

V = volume of displaced liquid

g = gravity

Upthrust:

â€¢ depends on the density of the liquid. The denser the liquid, the greater the upthrust it exerts on objects immersed in it. Mercury exerts more upthrust than water.

â€¢ depends on the volume of solid immersed. The bigger the volume of solid immersed the greater the upthrust on it.

â€¢ does not depend on the weight and density of the solid immersed. A cork and iron of the same volume will experience the same upthrust if completely immersed in water. The iron sinks because its weight is greater than the upthrust on it.

Archimedesâ€™ principle

The upthrust acting on a body fully or partly immersed in a fluid is equal to the weight of fluid displaced

Archimedes made this important discovery in the 3rd century BC. He celebrated it by shouting Eureka, which means, â€œI have found itâ€. He was faced with the challenge of finding out if the kingâ€™s crown was made of pure gold or not. This he must determine without melting the crown. Archimedes weighed the golden crown in air and weighed it again fully immersed in water. From his calculations, he discovered that the relative density of the crown is the same as that of pure gold.

Finding relative density of substances by Archimedesâ€™ principle

Relative density of a substance is the density of the substance compared to the density of water.

In Book 1, we showed that the relative density of a substance is given by:

$$R.D. = \frac{\text{Weight of substance}}{\text{weight of the same volume of water}}$$

An object completely immersed in water (liquid) displaces volume of water (liquid) equal to its own volume. The weight of water (liquid) displaced is equal to the upthrust pushing upward on the object.

$$\text{Relative density} = \frac{W_1}{W_1 - W_2}$$

W_1 = weight of solid in air, W_2 = weight of solid in water (liquid).

$W_1 - W_2$ = upthrust of water (liquid) on the solid = apparent loss in weight of body immersed in water (liquid).

1. Determination of relative density of solids by Archimedesâ€™ principle

Apparatus: A piece of stone, spring balance, a beaker of water and threads

Method

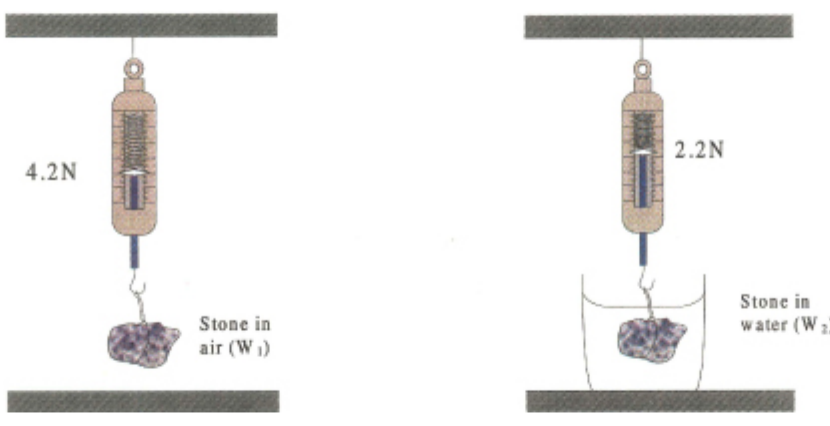


Figure 3.19a: Determining the relative density of solids by Archimedes

(i) Use the spring balance to weigh the stone in air and record its weight W_1.

(ii) Gently immerse the stone in water until it is completely covered with water. Record the weight W_2 of stone in water.

(iii) Work out the upthrust of water on the stone.

(iv) Work out the relative density using the formula;

$$\text{Relative density} = \frac{W_1}{W_1 - W_2}$$

Observations

Weight of stone in air W_1 = 4.2 N

Weight of stone fully immersed in water

$W_2 = 2.2\ N$

Upthrust = apparent loss of weight in water

= $W_1 - W_2$

= 4.2 N – 2.2 N = 2.0 N

$$\text{Relative density} = \frac{W_1}{W_1 - W_2} = \frac{4.2}{2.0} = 2.1$$

2. Determination of relative density of liquid by Archimedesâ€™ principle

Apparatus: Solid substance, liquid (oil), spring balance, a beaker of water and threads

Method

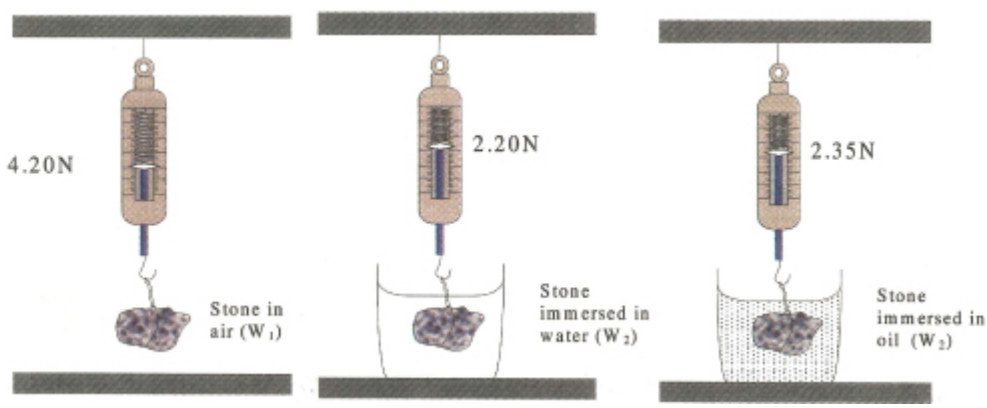


Figure 3.19b: Determination of relative density of oil by Archimedesâ€™ principle

(i) Use the spring balance to weigh the stone in air and record its weight W_1.

(ii) Gently immerse the stone in water until it is completely covered with water. Record the weight W_2 of stone in water.

(iii) Remove the stone from water, wipe out on the surface and completely immerse in oil. Record weight W_3 of the stone in oil.

(iv) Find the upthrust of water on the stone and the upthrust of oil on the stone.

(v) Calculate the relative density of oil using the formula:

$$\text{Relative density of oil} = \frac{W_1 - W_3}{W_1 - W_2}$$

$W_1 - W_3$ = upthrust of oil on the stone

$W_1 - W_2$ = upthrust of water on the stone

Observations

Weight of stone in air W_1 = 4.20 N

Weight of stone when fully immersed in water W_l = 2.20 N

Weight of stone when fully immersed in oil W_1 = 2.35N

Calculation

Upthrust of water on stone = 4.20 –2.20 = 2.0 N

Upthrust of oil on stone =4.20 –2.35= 1.85 N

$$\text{Relative density of oil} = \frac{W_1 - W_3}{W_1 - W_2}$$

$$\text{Relative density of oil} = \frac{4.20 - 2.35}{4.20 - 2.20}$$

$$= \frac{1.85}{2.0} = 0.925$$

3. Determination of relative density of solids and liquids by Archimedesâ€™ principle and principles of moment

Apparatus: Two solids substances labeled m_1 and m_2, kerosene, threads, a beaker of water and metre rule.

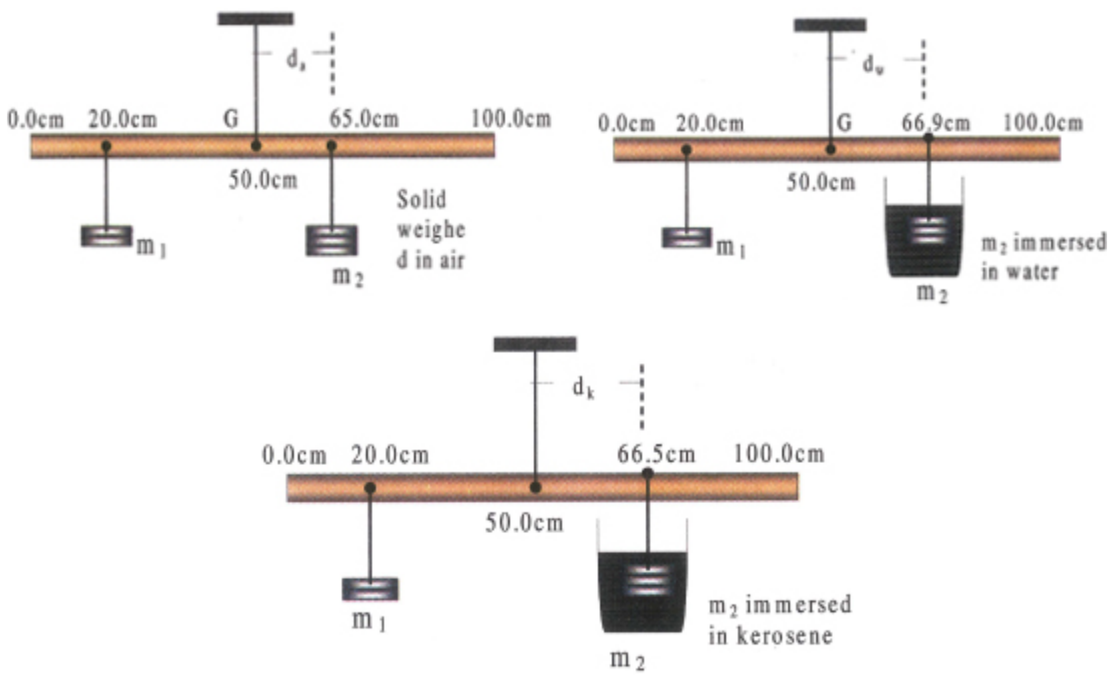


Figure 3.20: Determination of relative density by principle of moment and Archimedes

Method

(i) Use the thread to balance the metre rule horizontally, record the position G of the thread. This is the centre of gravity of the metre rule.

(ii) Hang the mass m_1 at the 20.0 cm mark. This distance should be kept constant throughout the experiment. Suspend the mass m_2 from the other end and adjust its position until the metre rule is balanced horizontally again. Record the distance d_a of m_2 from the thread.

(iii) Dip m_2 in water until it is completely covered and adjust its position until the metre rule is balanced horizontally. Record the distance d_w of m_2 from the thread.

(iv) Remove m_2 from water, wipe out any water on it and immerse in kerosene. Adjust the position of m_2 until the metre rule is balanced horizontally. Record the position d_k of m_2 from the thread.

Observations

Distance of m_2 in air from the thread

$d_a = 65.0$ cm.

Distance of m_2 in water from the thread

$d_w = 66.9$ cm

Distance of m_2 in kerosene from the thread

$d_k = 66.9$ cm

Calculation

Upthrust of water on $m_2 = d_w - d_a$

Upthrust of kerosene on $m_2 = d_k - d_a$

$$\text{Relative density of kerosene} = \frac{d_k - d_a}{d_w - d_a}$$

$$\text{Relative density of solid} = \frac{d_a}{d_w - d_a}$$

Do the following:

(a) Find the relative density of kerosene and m_2 using the readings in the observation above.

(b) Explain why d_w and d_k are greater than d_a.

(c) What precautions will you observe to obtain an accurate result?

Principle of flotation

Ice floats in water with 90% of its volume submerged. Cork and plastic also float in water but stone and iron sinks when dropped in water. Carry out the experiment in Figure 3.19 to find out why some objects float in a liquid while others sinks.

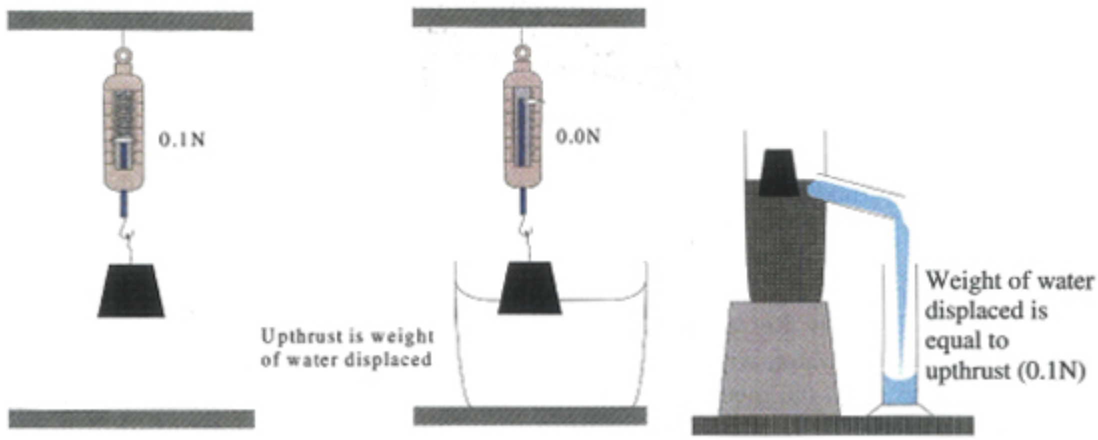


Figure 3.21

(i) Use the spring balance to weigh a piece of cork in air and record its weight.

(ii) Weigh the same cork when it floats on water.

(iii) Fill an overflow can with water and gently place the cork on the water. Collect the water displaced in a measuring cylinder.

(iv) Weigh the displaced water and record its weight.

Conclusion

â€¢ The weight of floating cork is equal to the weight of displaced water.

â€¢ Upthrust on the cork is equal to the weight of the floating cork.

The principle of flotation states that a body floats in a fluid when the upthrust of the fluid on it is equal to its own weight

A floating body will always displace a weight of liquid equal to its own weight.

Equilibrium of body in liquids: Normally, dense objects (objects with relative density greater than one) sink in water. They sink because their weight is greater than the upthrust of water on them. The resultant force on such a body is downward which makes them sink when released in water. The Upthrust increases as the object sinks deeper until a particular depth is reached where the resultant force on the object is zero (upthrust = weight), the object floats at that depth.

If a cork is submerged in water, the upthrust of water on it is greater than its weight; the resultant of the weight and upthrust act upwards and the cork rises to the surface where the upthrust on it is equal to its weight. This is the reason why a piece of cork floats on water.

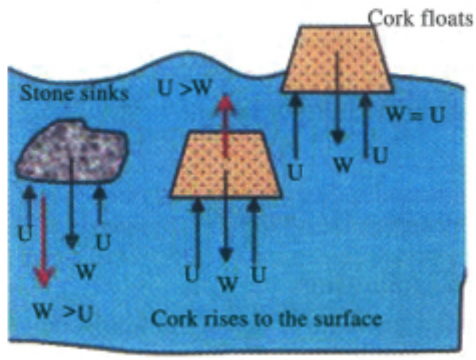


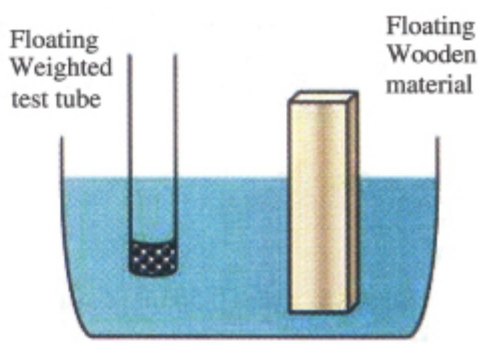
Figure 3.22: Equilibrium is maintained if upthrust = weight of a floating object

Making objects float in liquid

1. Ships

Any object can float in water if it is shaped to displace weight of water equal to its own weight. Ships are constructed with steels many times denser than water. The steel is shaped to enclose large volume of air such that the average density of the ship is less than the density of water. The ship displaces large volume of water; therefore, the upthrust of water on the ship is high enough to support its weight.

2. Floating bodies



Test tubes and other narrow tubes can float in water but they do not float upright. However if the end submerged in water is loaded, the test tube will float upright The depth to which the test tube sinks in a liquid depends on the density of the liquid. The denser the liquid, the less the test tube sinks; the test tube sinks more in a less dense liquid. *The length of the test tube submerged in a liquid is inversely proportional to the density of the liquid.*

$$h \propto \frac{1}{\rho}$$

The fraction of an object submerged in water is used to determine the density of the floating object.

The relative density a floating object is the fraction of its length submerged in water.

Ice floats with $\frac{9}{10}$ of its length submerged in water and only $\frac{1}{10}$ of its length outside water. The relative density of ice is 0.9 or the density of ice is 0.9 g cm^{-3}.

Relative density of a liquid is determined by measuring the length of an object submerged in water and the length of the same object submerged in the liquid.

Relative density of a liquid is the ratio of the fraction of its length submerged in water to the fraction of its length submerged in the liquid.

$$\text{Relative density} = \frac{h_w}{h_l}$$

h_w = fraction of length submerged in water;
h_1 = fraction of length submerged in liquid.

Worked examples

1. A long tube loaded at the base floats upright with $\frac{2}{3}$ rd of its length submerged in water.
   When it is placed in kerosene, it floats with $\frac{5}{6}$ th of its length submerged, calculate the relative densities of the material of the tube and kerosene.

Solution

(a) Relative densityof the tube = fraction of its length submerged in water

$$\text{Relative density} = \frac{2}{3} = 0.667.$$

(b) $$\text{Relative density} = \frac{h_w}{h_l}$$

h_w = fraction of length submerged in water;
h_l = fraction of length submerged in kerosene.

$$\text{Relative density} = \frac{\frac{2}{3}}{\frac{5}{6}} = \frac{2}{3} \times \frac{6}{5} = 0.8$$

2. A block of wood floating on water displaces 0.56 m^3 of water, calculate the:
   (a) mass of water displaced;
   (b) upthrust of water on the block.
   (c) what is the upthrust if it floats in a liquid of density 900 kg m^{-3}?
   {Density of water = 1000 kg m^{-3}, g =10 ms^{-2}}

Solution

(a) Mass of water = density Ã—

volume

= 1000 Ã— 0.56 = 560 kg.

(b) Weight of water = mass Ã— gravity

= 560 Ã— 10 = 5600 N

Or Upthrust = density Ã— volume Ã— gravity

= 1000 Ã— 0.56 Ã— 10 = 5600 N.

(c) Upthrust = density Ã— volume Ã— gravity

= 900 Ã— 0.56 Ã— 10 = 5040 N.

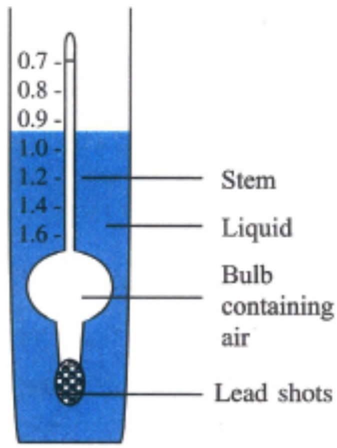


Figure 3.23: Hydrometer floats upright in liquids

A hydrometer is an instrument used to measure the density and relative density of a liquid. When a hydrometer is placed in a liquid, it sinks to different depths depending on the densities of the liquid. A practical hydrometer is designed to float upright in any liquid. Figure 3.23 is a hydrometer; it has the following essential parts:

3. Hydrometer

(i) A long narrow stem loaded at the base. The narrow stem makes the hydrometer detect small changes in densities when placed in different liquids; the loaded end helps to keep the hydrometer floating upright in the liquid.

(ii) A wide bulb with air inside it: the wide bulb makes the hydrometer displace more liquid thereby increasing the upthrust, which supports the weight of the floating hydrometer.

(iii) A scale to measure the density of the liquid directly. The depth to which the hydrometer sinks in a liquid is inversely proportional to the density of the liquid. A hydrometer is calibrated with lower densities towards the top and higher densities towards the base.

Summary

â€¢ Two forces act on a body immersed or floating in a liquid, the weight acting downwards and the upthrust acting upwards.

- â€¢ Upthrust is the upward force which a fluid exerts on any object that is immersed partly or fully in it.
- â€¢ The upthrust acting on a body fully or partly immersed in a fluid is equal to weight of fluid displaced.
- â€¢ When an object is immersed in water, the weight of water (liquid) displaced is equal to the upthrust pushing upwards on the object.
- â€¢ The principle of flotation states that a body floats in a fluid when the upthrust of the fluid on it is equal to its own weight
- â€¢ When an object floats in a liquid, the length of the object submerged in the liquid is inversely proportional to the density of the liquid
- â€¢ The relative density of a floating object is the fraction of its length submerged in water.
- â€¢ Relative density of a liquid is the ratio of the fraction of its length submerged in water to the fraction of its length submerged in the liquid.

Practice questions 3d

1. (a) State Archimedesâ€™ principle.
   (b) What is the condition for equilibrium if a body is immersed in a liquid which issteady?
   (c) A stone weighs 1.52 N in air, 0.90 N when fully immersed in water and 1.25 N in a liquid. Find: (i) the relative density of the stone;
   (ii) the relative density of the liquid.
2. A block of lead of relative density 11.2 weighs 28.4 N in air. When it is completely immersed in water calculate:
   (a) the upthrust of water on it;
   (b) the apparent weight of the lead block in water;
   (c) the mass of water displaced;
   (d) the volume of water displaced;
   (e) the volume of the lead block;
   (f) the upthrust on the lead block when it is fully immersed in oil of density 0.92 g/cm^3. {Density of water is 1.0 g cm^{-3}}.
3. (a) Name the forces acting on a body immersed in liquid. State the condition to be fulfilled before the body floats in the liquid.
   (b) State the principle of flotation.
   (c) A floating ship displaces 40,000m^3 of water. Calculate:
   (i) mass of water of displaced;
   (ii) weight of water displaced
   (iii) weight of the ship.

{Density of water is 1000 k/gm^3}

4. (a) State the Archimedesâ€™ principle and define the relative density of a substance.
   (b) Describe an experiment to determine the relative density of a liquid using Archimedesâ€™ principle.
   (c) A uniform metre rule supported at its centre of gravity G balances horizontally when a weight of 0.05 N is hanged at 20 cm marks and another weight of 0.1 N is placed Ã— cm from G. When the 0.1 N weight is completely immersed in water the metre rule balances horizontally when it is 16.5 cm from G and when it is fully immersed in a liquid the metre rule balanced horizontally when it is 17.2 cm from G. Calculate:
      (i) the value of x;
      (ii) the relative density of 0.1 N material.
      (iii) the relative density of the liquid.
5. Explain why:
   (a) a ship made of steel floats in water but a steel box sinks in the same water;
   (b) air ship rises in air even though it is made with a material denser than air.
   (c) stepping on sharp stones on sea shore becomes less painful as one enters the sea.
   (d) we feel lighter inside a swimming pool.
6. Make a label diagram of a hydrometer and explain why:
   (a) the base is loaded;
   (b) the stem is very narrow;
   (c) the scale is calibrated with the lower densities towards the top.
7. (a) State the principle of flotation.
   (b) A wooden cylinder of mass 1.2 kg and volume 0.0005 m^3 floats upright in water. Find the:
      (i) density of the wood;
      (ii) volume of the cylinder submerged in water;
      (iii) height of the cylinder below the water surface.

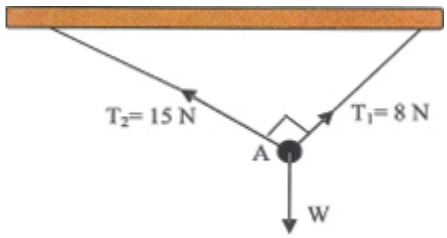
Past questions

1. An object is acted upon by a system of parallel forces causing the object to be in static equilibrium. Which of the following statements is not correct?
   A. The resultant of the parallel forces is zero.
   B. The algebraic sum of the moments of the forces is zero.
   C. All the parallel forces must be equal in magnitude and direction.

WASSCE

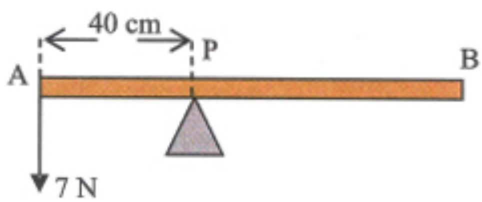
D. The sum of the forces in one direction must be equal to the sum of the forces in the opposite direction.

2. An object A is held in equilibrium as illustrated in the diagram above. Using the data on the diagram, determine the magnitude of W of the weight A.



A. 23 N
B. 17 N
C. 7 N
D. 5 N

WASSCE

3.


In the diagram below, AB represents a uniform rod of length 1.50 m which is in equilibrium on a pivot at P. If AP = 40 cm, calculate the mass of the rod. {g = 10 ms^{-2}}

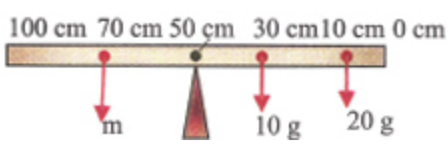
A. 0.280 kg
B. 0.400 kg
C. 0.613 kg
D. 0.800 kg

WASSCE

4. The equilibrant of a system of forces is

A. equal and opposite to the resultant of the forces.
B. the force which has the same effect as the system.
C. equal to the resultant of the system.
D. the force that makes the system unstable.

WASSCE

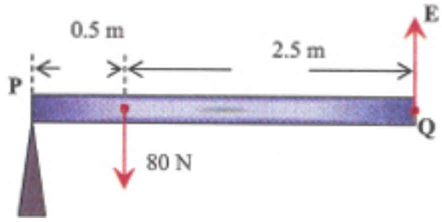
5.


A uniform meter rule has masses 20 g and 10 g hang at 10cm and 30cm marks respectively as illustrated in the diagram above. Calculate the value of m required to balance the horizontally.

A. 30 g
B. 40 g
C. 45 g

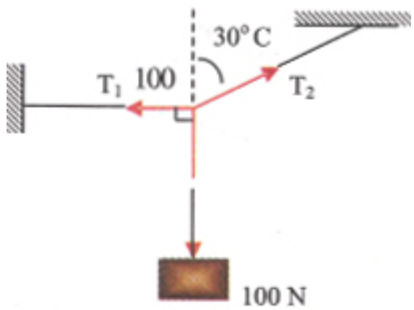
WASSCE

D. 50 g

6. 

A beam PQ pivoted at P carries a load of 80N as shown above. Calculate the effort E required to keep it horizontally. {Neglect the weight of the beam}

A. 32.0 N
B. 26.7 N
C. 16.0 N
D. 13.3 N **WASSCE**

7. 

The diagram above illustrates three forces T_1, T_2 and 100 N in equilibrium. Determine the magnitude of T_1.

A. 100tan 30Â°
B. $\frac{100}{cos\ 30^o}$
C. 200*sin* 30Â°
D. $\frac{100}{\tan 30^o}$ **WASSCE**

8. Two forces forming a couple are separated by a distance of 25 cm, if one of the forces equal 40 N, what is the moment of the couple?

A. 1000N m
B. 500 N m
C. 10 N m
D. 5Nm
E. 1.6 N m **NECO**

9. When a lever is in equilibrium under the action of two or more forces, the algebraic sum of the moments of the forces about the point of support is

A. anticlockwise
B. clockwise
C. equal to the product of the forces
D. numerically equal to the total forces acting

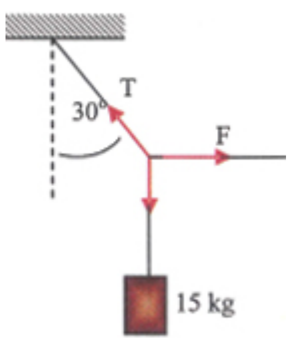
E. equal to zero.

NECO

10. Three forces that can be represented in magnitude and direction by the three sides of a triangle taken in order must
    I. have their lines of action passing through a common point.
    II. be acting in the same plane.
    III. have any one of them as an equilibrant of the other two.
    Which of the statements above are correct?
    A. I and II only
    B. I and III only
    C. II and III only
    D. I, II and III.

WASSCE

11. A 15 kg mass, suspended from a ceiling is pulled aside with a horizontal force, F, as shown in the diagram below. Calculate the value of the tension T. {$g = 10ms^{-2}$}



A. 300.0 N
B. 173.2 N
C. 30.0 N
D. 17.3 N

WASSCE

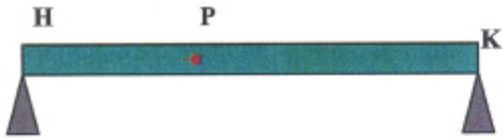
12. A force of 250 N is applied at the free end of a 25 cm long spanner to remove a nut. Calculate the moment of the force.
    A. 62.5 N m
    B. 40.0 N m
    C. 34.2 N m
    D. 14.8 N m
    E. 10.0 N m

WASSCE

13. The term torque means
    A. the moment of a couple about an axis.
    B. the resultant of several forces acting on a body in equilibrium.
    C. two equal and opposite forces whose line of actions do not coincide.
    D. two coplanar forces at right angles to each other.

WASSCE

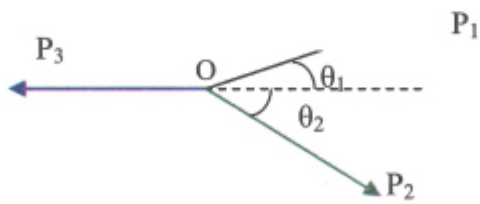
14. A uniform beam HK of length 10 m and weighing 200 N is supported at both ends as shown above. A man weighing 1000 N stands at a point P on the beam. If the reactions at Î— and Îš are respectively 800N and 400 N, then the distance HP is



A. 4 m
B. $3\frac{1}{3}$ m
C. 3 m
D. $6\frac{2}{3}$ m
E. 7 m

JAMB

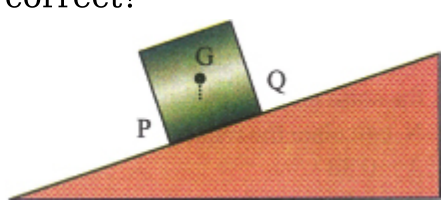
15. Consider the three forces acting at a point O and is in equilibrium as shown above. Which of the equations is/are correct?



I $P_1 cos \ _1 = P_1 cos \ _2$
II $P_3 = P_1 cos \ _1 + P_2 cos \ _2$
III $P_1 sin \ _1 + P_2 sin \ _2$
A. I only
B. II only
C. III only
D. II and III only
E. I and III only.

JAMB

16. The diagram above shows a solid figure with base PQ and centre of gravity G on an inclined plane. Which of the following statements is correct?

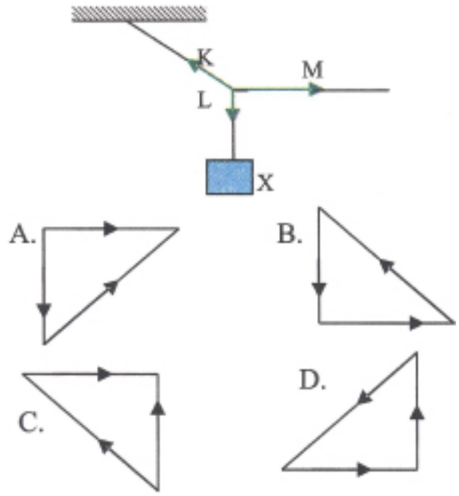


A. The solid will fall over if the vertical line through G lies outside the base.
B. The solid will fall over if the vertical line through G lies inside the base.
C. The solid will not fall over if the vertical line through G lies outside the base.

D. The solid can never fall over.

JAMB

17. In the figure above the weight X is held in position by pulling the rope KLM in the direction LM. Which of the following diagrams shows the force acting at the point L?



JAMB 1993

18. Which of the following actions will increase the stability of a body?
    I. Increasing the area of the body.
    II. Raising the centre of gravity of the body.
    III. Lowering the centre of gravity of the body.
    A. I and II only
    B. I and III only
    C. II and III only
    D. I, II and III

WASSCE

19. The weight of a solid in air is 45 N. When the solid is immersed in water, it weighs 15 N, calculate the relative density of the solid.
    A. 0.33
    B. 0.50
    C. 1.50
    D. 3.00

WASSCE

20. A piece of metal of relative density 5.0 weighs 60N in air. Calculate its weight when fully immersed in water.
    A. 4 N
    B. 5N
    C. 48 N
    D. 60 N

WASSCE

21. An object weighing 8 N in air is partially immersed in water. It displaces water of mass 0.3 kg. What is the upthrust on the body? {g= 10 ms^{-2}}

A. 11.0 N
B. 8.0 N
C. 5.0 N
D. 3.0 N
E. 2.7 N

NECO

22. A copper cube weighs 0.25 N in air, 0.17 N when completely immersed in paraffin oil and 0.15 N when completely immersed in water. The ratio of upthrust in oil to upthrust in water is

A. 4:5
B. 3:5
C. 13:10
D. 7:10

JAMB

23. Which of the following statements is **not** correct about an object floating in a liquid? The

A. density of the object must be less than that of the liquid.
B. object is in equilibrium.
C. density of the object must be greater than that of the liquid.
D. object displaces its own weight of the liquid.

WASSCE

24. An object of weight 10 N immersed in a liquid displaces a quantity of the liquid. If the liquid displaced weighs 6 N, determine the upthrust on the object.

A. 20 N
B. 10 N
C. 6 N
D. 4 N

WASSCE

25. The apparent weight of a body fully immersed in water is 32 N and its weight in air is 96 N. Calculate the volume of the body.
{Density of water = 1000 kgm^{-3}, g = 10 ms^{-2}}

A. 8.9 Ã— 10^{-3} m^{-3}
B. 6.4 Ã— $10^{-3}m^{-3}$
C. 3.2 Ã— $10^{-3}m^{-3}$
D. 3.0 Ã— $10^{-3}m^{-3}$

WASSCE

26. If a plastic sphere floats in water {density = 1000 kg m^{-3}} with 0.5 of its volume submerged and floats in oil with 0.4 of its volume submerged, the density of the oil is

A. 800 kgm^{-3}
B. 1200 kgm^{-3}
C. 1250 kgm^{-3}
D. 2000 kg m^{-3}

JAMB

27. An object of mass 400 g and density 600 kg m^{-3} is suspended with a string so that half of it is immersed in paraffin of density 900kg m^{-3}. The tension in the string is

A. 1.0 N

B. 3.0 N

C. 4.0 N

D. 5.0

JAMB

28. A cube of sides 0.1 m hangs freely from a string. What is the upthrust on the cube when it is immersed in water? {Density of water is 1000 kg m^{-3}, g = 10 ms^{-2}}

A. 1000 N

B. 700 N

C. 110 N

D. 10 N.

JAMB

29. (a) What is meant by equilibrium? How does the position of the centre of gravity of a body determine its state of equilibrium?

(b) A uniform half metre rule AB is balanced horizontally on a knife edge placed 15 cm from A with a mass of 30 g at A. What is the:

(i) mass of the rule?

(ii) force exerted on the rule by the knife edge?

WAEC

30. (a) Explain with aid of a diagram what is meant by the moment of a force about a point?

(b) State the conditions of equilibrium for a number of coplanar parallel forces.

(c) A meter rule is found to balance at the 48 cm mark. When a body of mass 60g is suspended at the 6 cm mark, the balance point is found to be at the 30 cm mark.

Calculate the:

(i) mass of the rule,

(ii) the distance of the balance point from the zero end if the body were moved to the 13 cm mark.

WAEC

31. (a) (i) Define the centre of gravity of a body.

(ii) State how it is related to the stability of a body.

(b) Describe how you will determine the centre of gravity of a body of an irregularly shaped thin lamina.

(c) A uniform disc of diameter 1m has a circular piece, diameter 0.2 m cut from it.The centre of the circular piece is 0.26 m from the edge. Find the new centre of gravity of the disc.

NECO

32. (a) Define the moment of a force about a point;

(b) Explain the meaning of:

(i) centre of gravity;

(ii) stable equilibrium;

(iii) unstable equilibrium.

(c) A uniform square plate of sides 20cm has a square of sides 4cm cut out of it. If the centre of the cut out square is 6cm from the centre of the square plate, find the new position of the centre of gravity of the plate.

33. (a) State the principle of Archimedes;

(b) Describe an experiment to verify the principle of Archimedes.

(c) A solid of mass 1.3 kg, suspended by a string, is completely immersed in water. If the tension in the string is 6.0 N, calculate:

(i) the upthrust on the body;

(ii) the volume of the solid;

(iii) its density.

{Density of water 10^3 kg m^{-3}, g = 10 ms^{-2}} **NECO**

34. (a) (i) State the principle of Archimedes.

(ii) Describe an experiment to verify it.

(b) A piece of metal of density 3.9Ã—10^3 kg m^{-3} weighs 10 N in air. Calculate the apparent weight of the metal when completely immersed in a liquid of density 4.1Ã—10^2 kg m^{-3}. [g = 10 ms^{-2}]

(c) Explain why a ship made of steel floats on water whereas a piece of solid steel sinks. **NECO**