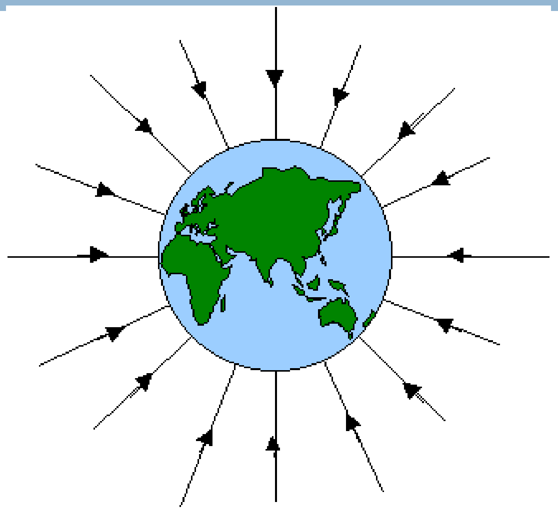
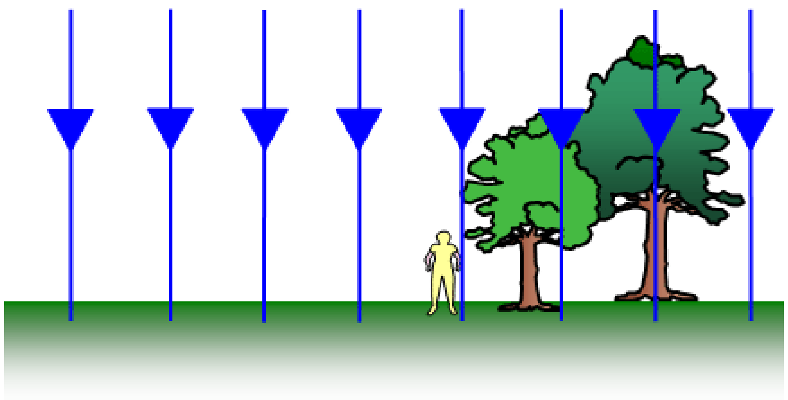
Chapter 5:Forces

i. Forces
   i. Uniform gravitational field
ii. Equilibrium of forces
iii. Centre of gravity
iv. Turning effects of forces

Force act on mass in uniform gravitational fields



- Outside or far from earth surface, earth gravitational field strength, g is not constant.
- The field strength become constant near the Earth surface. Here, g is equal to 9.81 Nkg^{-1}
- Constant g on Earth is also known as acceleration of free fall (9.81 ms^{-2})



An object with mass, m

Force of gravity, F_g act on m in this uniform gravitational field strength is called weight, W

$$F = mg = W$$

Forces in equilibrium

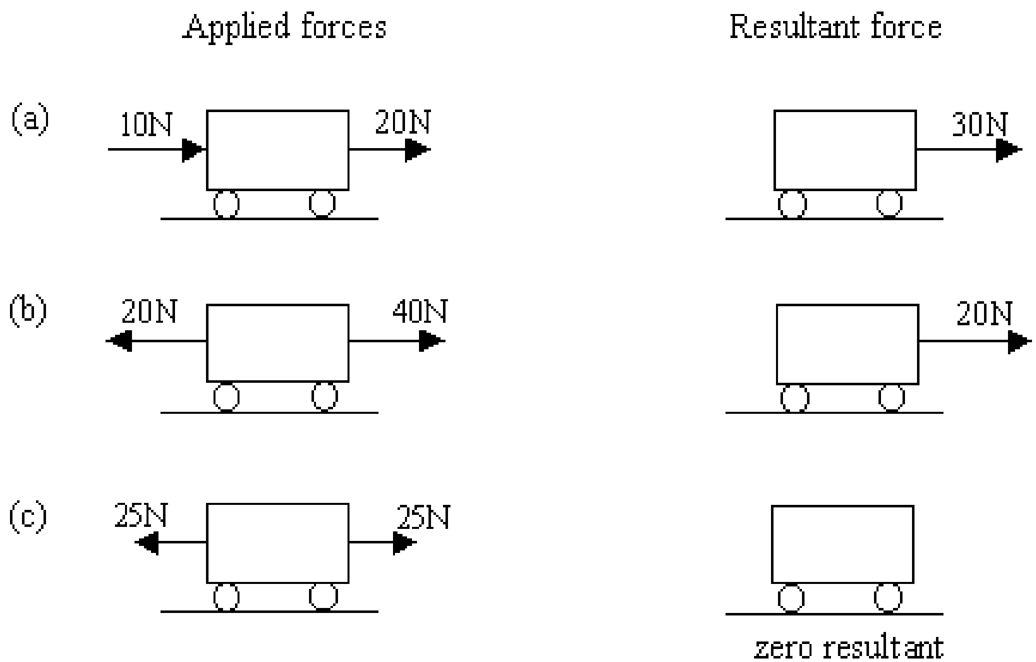
Balanced and unbalanced force

- If forces act on an object is balanced, it means
  - Net force, $F_{net} = 0$
  - $\sum F$ vertical = 0
  - $\sum F$ horizontal = 0
- And according to Newton's first law, the object may be
  - stay at rest (if initially it is at rest) or
  - the object may in uniform motion (same speed, same direction) if it is initially in uniform motion

Combining forces

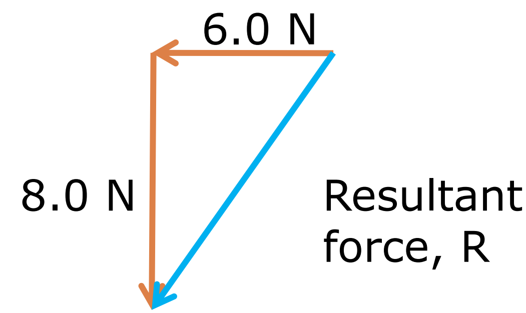
- Add two / more coplanar forces in more complex situation
  - Forces in the same straight line
  - Forces at right angles
  - Three or more forces
    - Balanced force (Object in equilibrium) (net force= 0)
    - Unbalanced force (net force≠0)
  - Forces of object at slope

Forces act in same straight line



- We can directly sum up total forces act in the same straight line
- But remember force is a vector, so, direction must be taken into consideration
- Forces act in different direction on the same straight line will cause net force decrease.

Forces at right angle

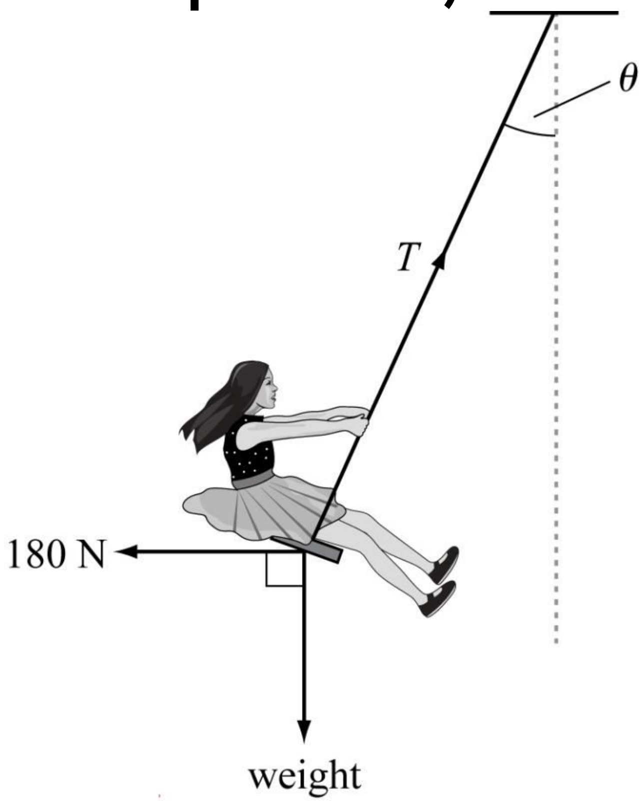


- A shuttlecock falling on a windy day.
  - There are two forces act on the shuttlecock; its weight which is 8.0 N and horizontal push of the wind of 6.0 N
- Calculate the resultant force acting on this shuttlecock

- Draw free body diagram of forces
- Connect the forces tip to tail
- Find resultant force using Phythagoras theorem
- R = 10 N
- $\theta = \tan^{-1}(6/8) = 53^{o}$ to vertical

Three or more forces

1. **Balanced forces (object in equilibrium)**



- A child of mass 35 kg on a swing is pulled to one side.
  The diagram shows the forces acting on the seat of the swing when it is in equilibrium.

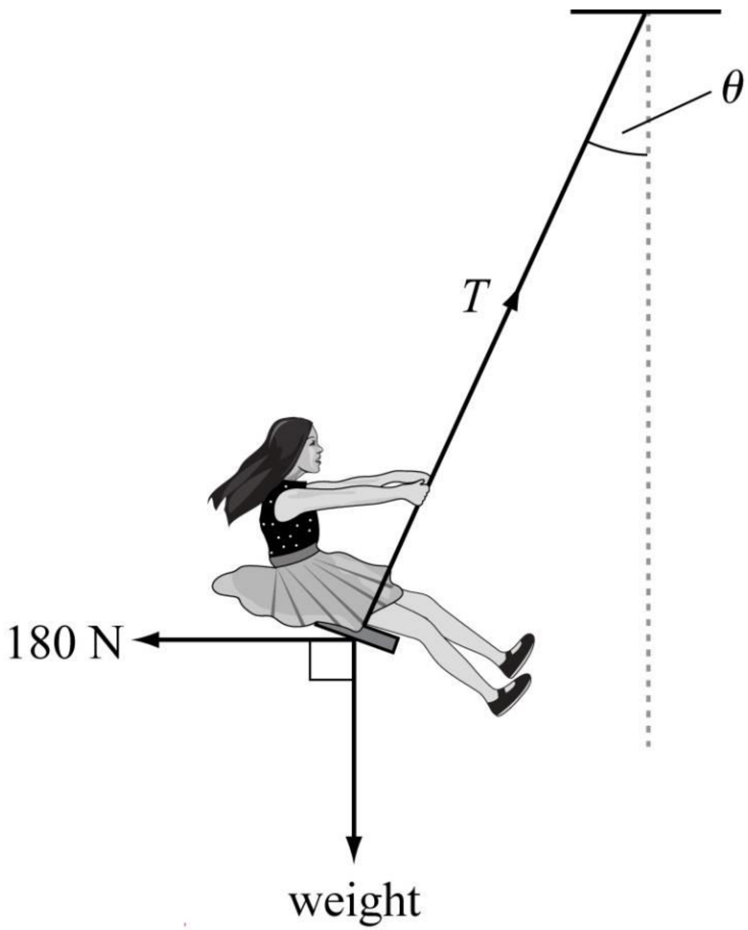
  a. What is the net force on the seat?

  b. Draw a **triangle of forces.** Hence determine:

     a. the tension T in the rope

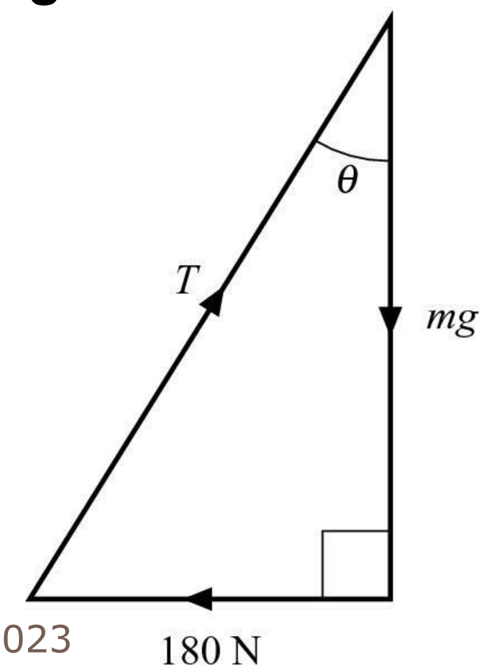
     b. the angle θ made by the rope with the vertical.

Three or more forces



a. The net force is zero because the seat is in equilibrium.

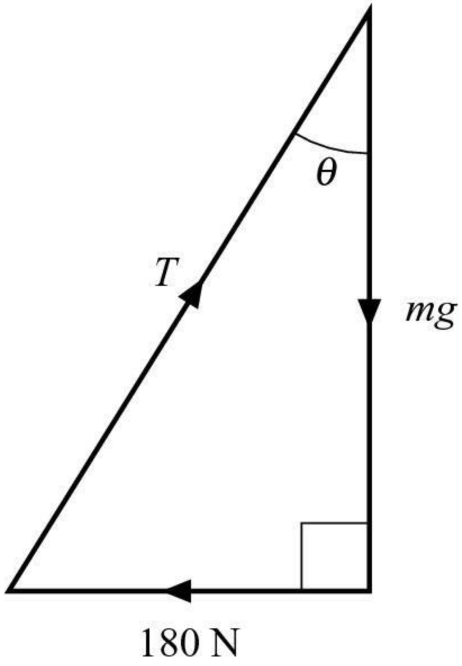
b. Three or more forces in equilibrium will form **closed vector triangle**



Three or more forces

- The tension T in the rope
  - Weight = $mg = 35 \times 9.81$
  - $T^2 = 180^2 + 343^2$

$$T = \sqrt{180^2 + 343^2} \approx 390 \text{ N}$$



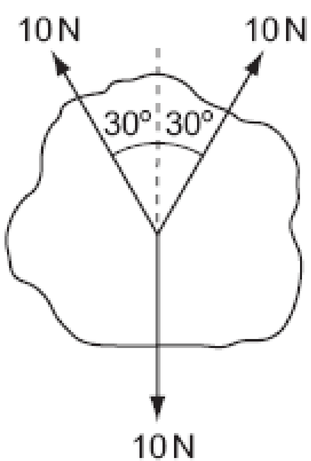
- the angle θ made by the rope with the vertical.
- $\tan \theta = \dfrac{180}{343}$

$$\theta = \tan^{-1}(0.525) \approx 28°$$

Three or more forces

2. **Unbalanced force**

   Three coplanar forces, each of magnitude 10 N, act through the same point of a body in the directions shown.



2. What is the magnitude of the resultant force?

- Force upward

  $= 10 \cos 30 + 10 \cos 30$

  $= 17.3$ N

- Force downward

  $=10$ N

- Net Force

  $= 17.3$ N $+ (-10$ N$)$

  $= 7.3$ N (upward)

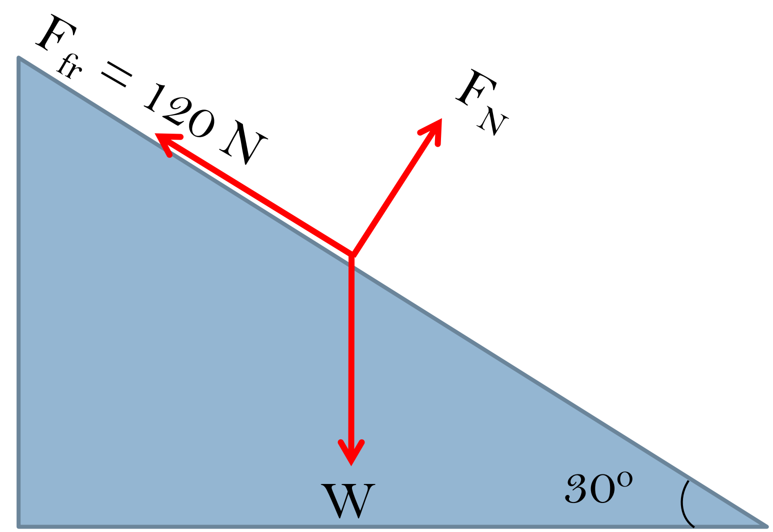
Forces on object at slope

Accelerate object

- A boy of mass 40 kg is on waterslide which slopes at 30o to the horizontal. The frictional force up the slope is 120 N. Calculate the boy's acceleration down the slope. The acceleration of free fall g to be 9.81 ms^{-2}.

Forces on object at slope

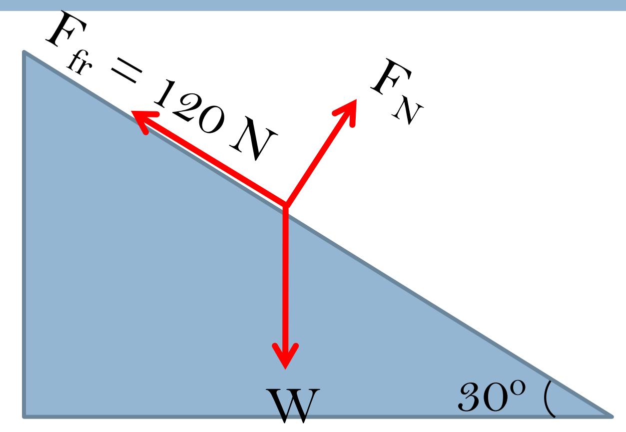
- Step 1
- Draw a free body diagram, showing all the forces acting. The forces are
  - The boy's weight
    - 40 x 9.81 = 392 N
  - The frictional force up the slope
    - F_{fr} = 120 N
  - The normal contact force, F_N
    - 90° to the contact surface

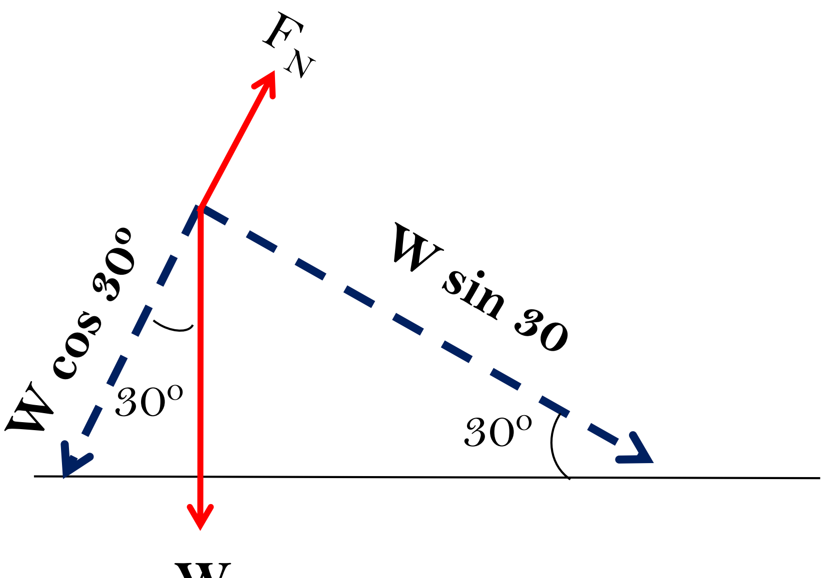


Forces on object at slope

Step 2 : calculate net force

- Force down the slope
  - Component W down the slope
    - W sin 30°
    - = 392 sin 30° = 196 N
  - Component F_N down the slope
    - F_N cos 90°
    - = 0 N
- **Net force** on the boy (directed down the slope)
  - 196 N + (-120 N) = ***76 N***





Forces on object at slope

- Step 3:
- Calculate acceleration down the slope:
- From equation F = ma,
  - We know, F net = 76 N
  - 76 N = 35 kg x a
  - a = $\underline{1.9\ ms^{-1}}$

Moments and Torque

- Centre of gravity
- Moment of forces
- Principles of moment & equilibrium condition
- Torque of a couple

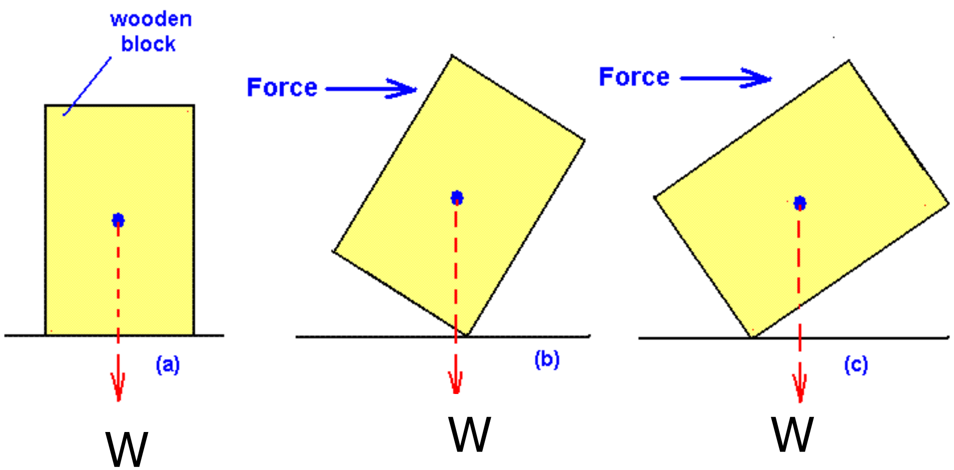
Centre of gravity

The **single point** at where all the **entire weight** of an object may considered to act.

Centre of gravity

The importance

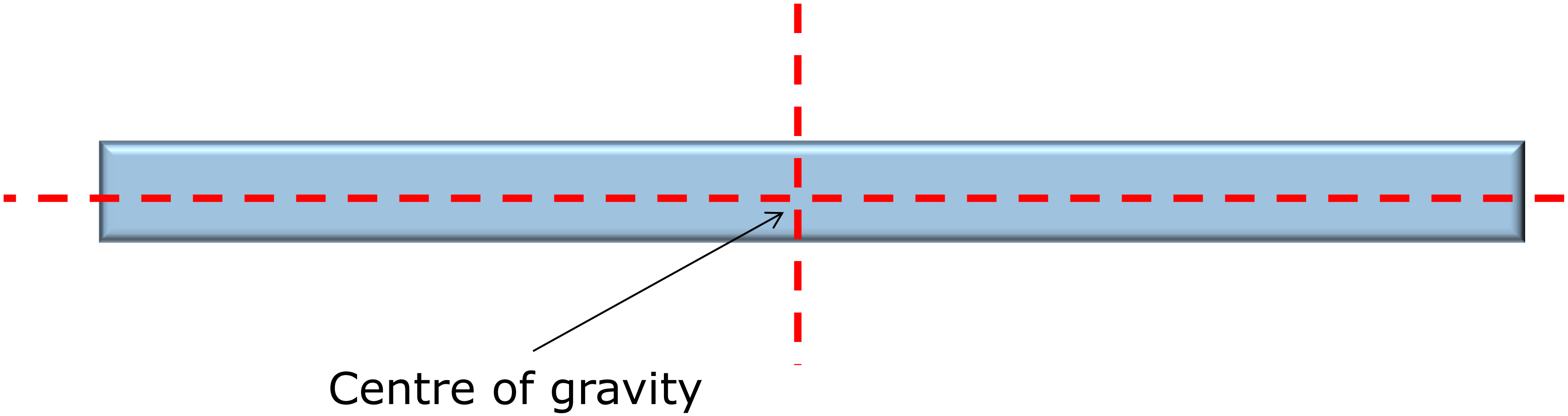
- In solving a problem, it is much easier to **indicate an object's weight** by a single force act at the centre of gravity instead of number of forces act on each part of the object



Where is object's Centre of Gravity?

- Depend either the objects are
  1. Geometrical / uniform or
  2. Non-geometrical

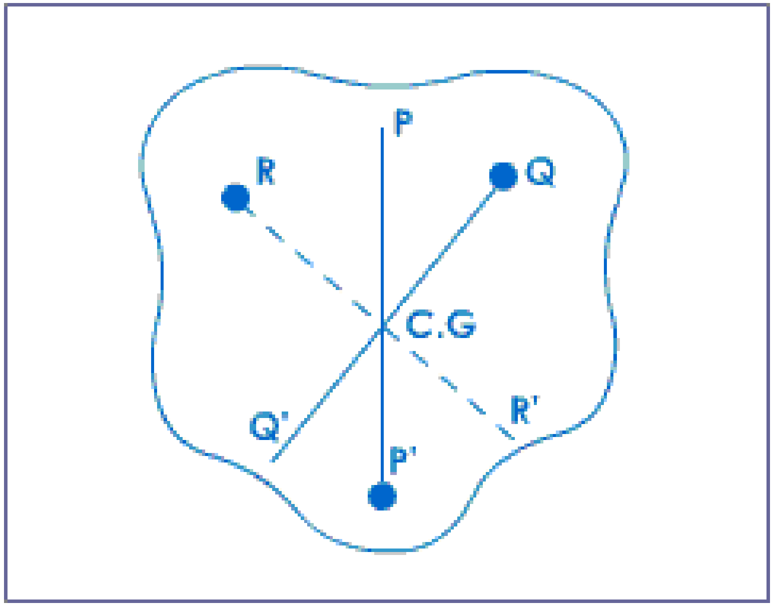
1. **For uniform object:**
   - Note that the centre of gravity is always located at the mid-point of any uniform object



Where is object's Centre of Gravity?

For non-uniform object

- Suspend the object freely on a single point (hole) using a string (with pendulum)
- Draw a line along the string location
- Repeat suspend the object at another point
- Draw the line along the string location
- The intersection point between the two lines is the centre of gravity of the object



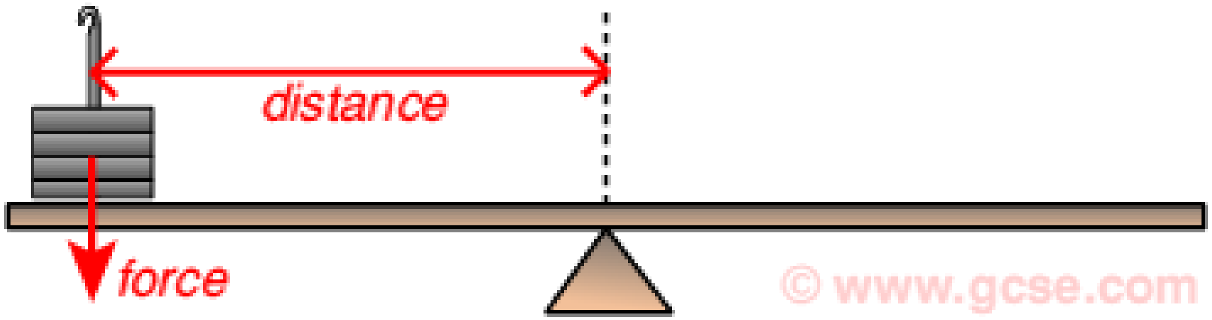
Moment of a force

Moment of a force

- If we have hinged or pivoted a body, any force applied make the body rotate or turn about the pivot.
- This **turning effect** is called a **moment, represent by symbol M**.
- It is a measure of a force tendency to rotate an object about some point.
- Moment depends on
  - The magnitude of force (the bigger the force, the greater the moment
  - The perpendicular distance of the force from the pivot (the greater the distance, the greater the moment)

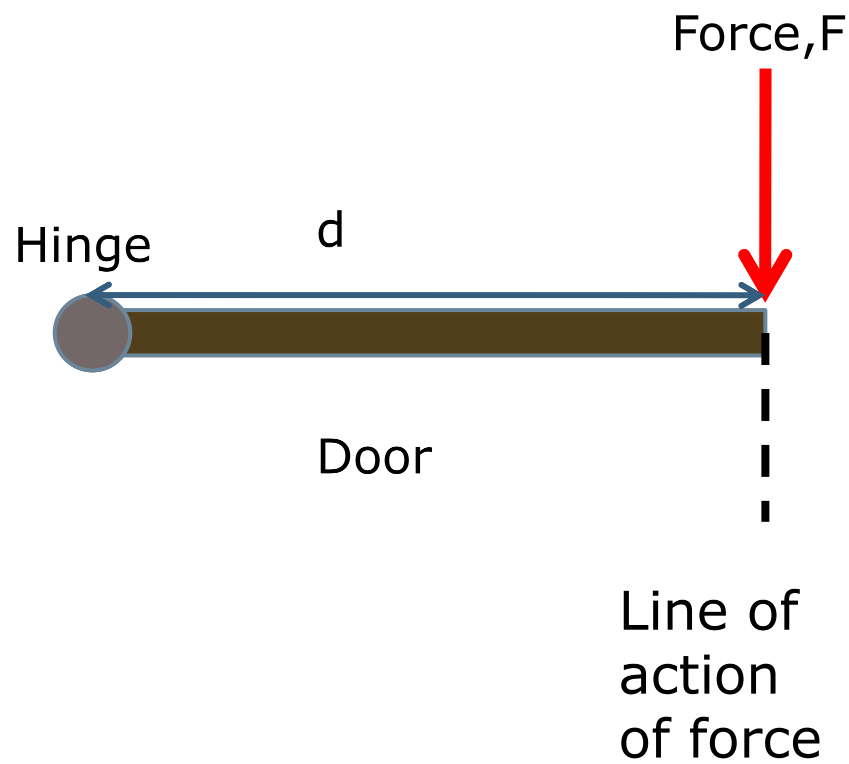
Moment of a force

- "A moment is defined as:
  - Force x perpendicular distance of the pivot from the line of action of the force
  - Unit = Nm

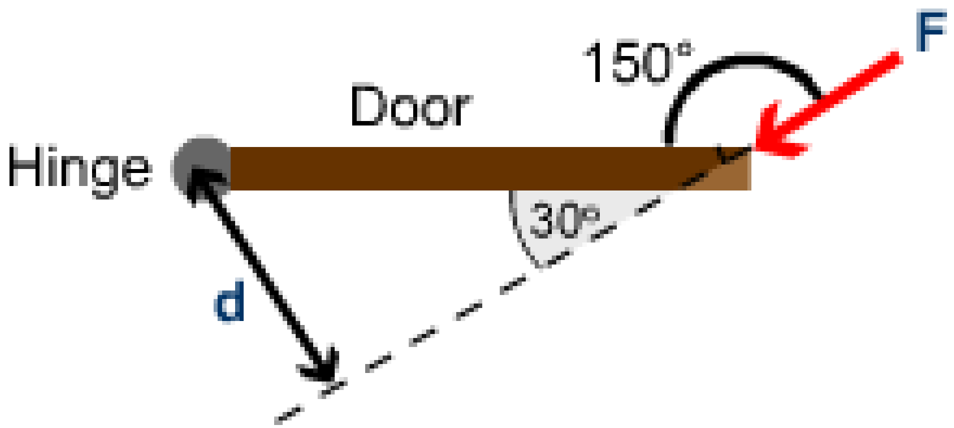


Force directly perpendicular on distance

- A force is acting at ***d*** distance from a door hinge. Calculate the moment, M
- Identify
  1. Pivot = hinge
  2. Line of action of force
  3. Distance from pivot to the line of action of forces (*length form pivot to the line of action of force*)
  4. Calculate M = F x d



Force not directly perpendicular on distance

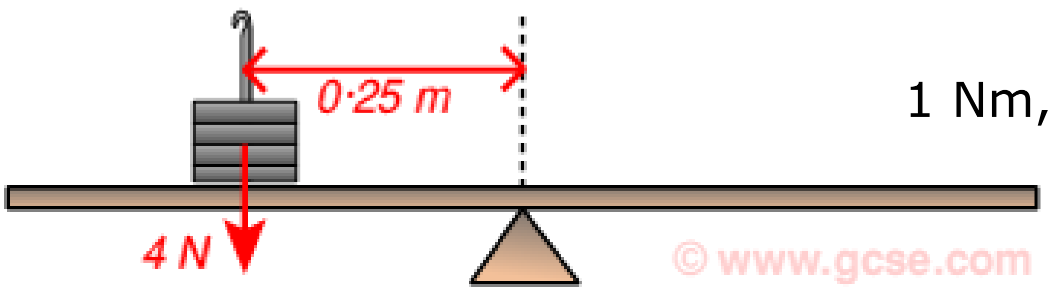


Moment = Force x perpendicular distance from pivot to line of action of force

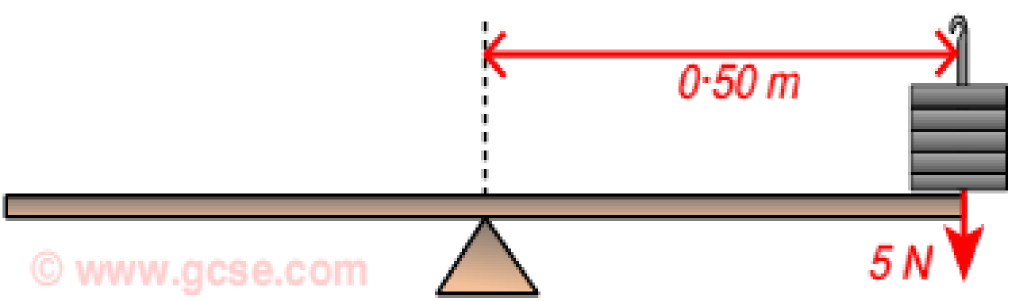
1. Hinge = pivot
2. Line of action of force (just extend the force vector) – broken lines
3. Draw a line from pivot until it meets line of action of force at 90°

Is Moment a vector quantity?

- Does the direction matter?
  - YES! Moments can either be *clockwise* or *anticlockwise.*
- Calculate the moments below. In which direction are they acting?

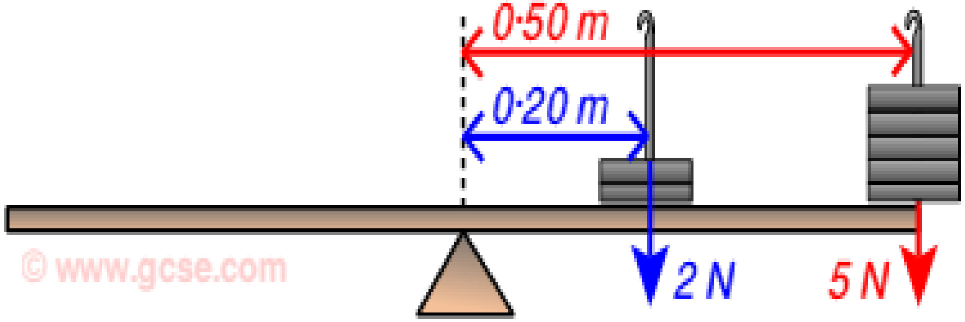


1 Nm, anticlockwise



2.5 Nm, clockwise

More than one force acting on object?

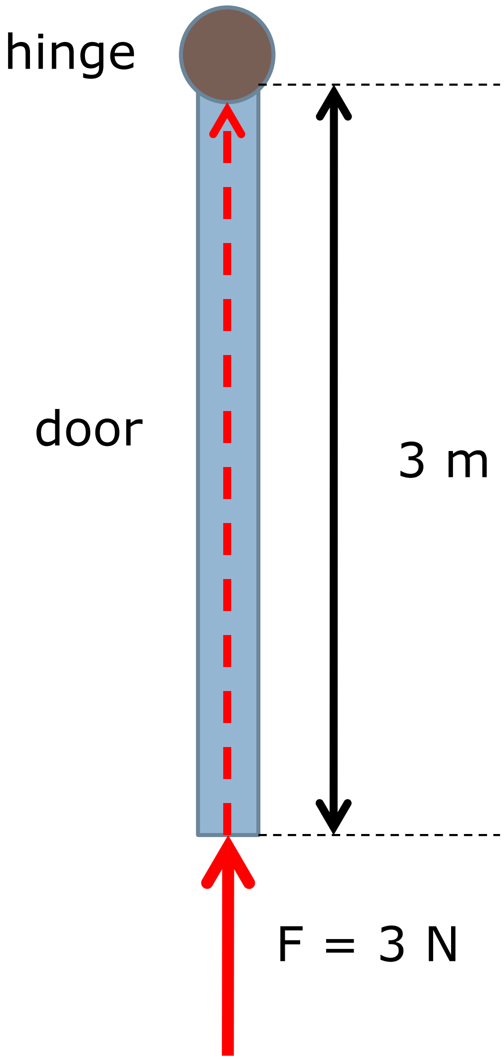


- Find the total moment acting on the bar above.
- When more than one force acts in the same direction, their overall turning effect (moment) is just the <u>*sum* of their moments.</u>
- But, be caution with the direction of the moment
- Both of force act clockwise direction at pivot point.
- So, total moment

  $= 2N(\ 0.20) + 5N(0.50\ m)$

  <u>**= 5.9 Nm**</u>

Question



- What is **moment due to this force?**
- **0 N**
- The line of action of the force, F goes through the hinge. So the distance between the line of action and the hinge (is **zero.** Hence the moment is **zero**

Equilibrium and principle of moment

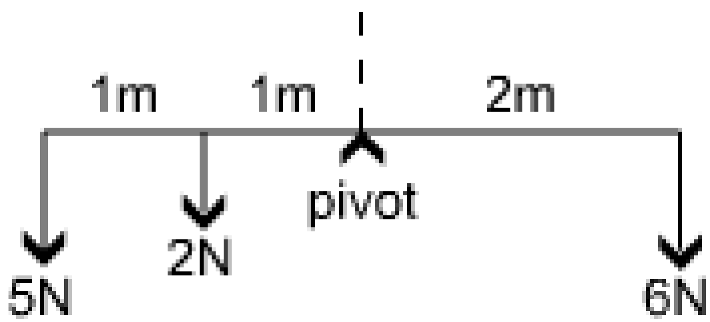
Equilibrium

We know that for a body to be in equilibrium

- **The sum of the forces in any direction is zero** ($\Sigma F = 0$)
  1. $F_x = 0$ and $F_y = 0$
  2. The object won't accelerate in any direction.
- But, when deal with moment, **the principle of moment** must take into consideration before we can say that an object is in equilibrium

Principle of moment

- If a body is in equilibrium under the action of a number of forces, then the total sum of the moments of the forces about **any point** is equal to zero
- Or we can say it as
- For the object to be in equilibrium, the **sum of the clockwise moment** about a point must equal to the sum of the anticlockwise moments about that point



(5x2)+(2x1) = (6x2)

12Nm clockwise = 12Nm anticlockwise

Equilibrium condition

$\sum$ F in any direction = 0

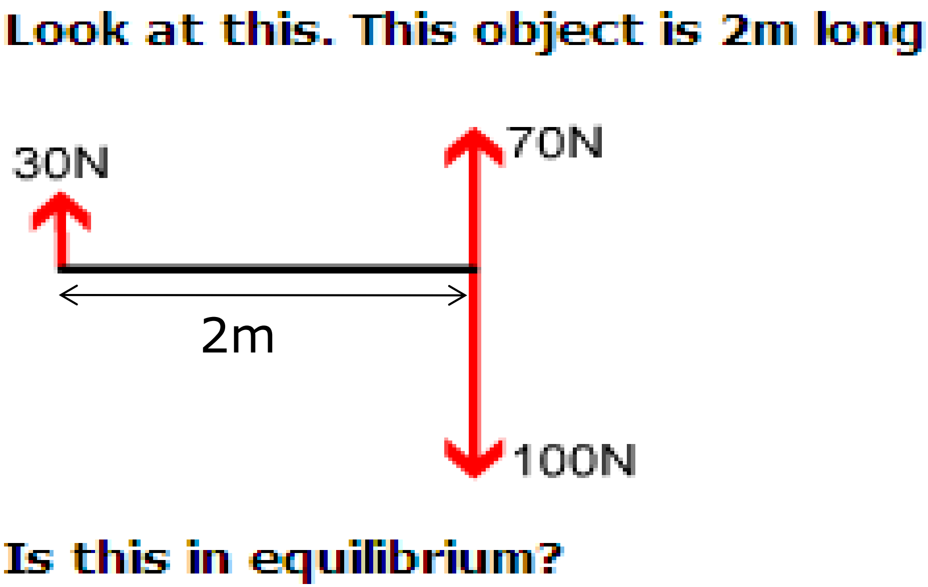
$\sum$ M about any same point = 0

Example

Are this object in equilibrium?

1. Let's apply the Equilibrium Conditions.

- **Condition 1:** Sum of the forces in any direction = 0
  - Sum Force up = Sum Forces down. Satisfied!
- **Condition 2:** Choose any point to take moments about. Example: choose the left hand end of the object

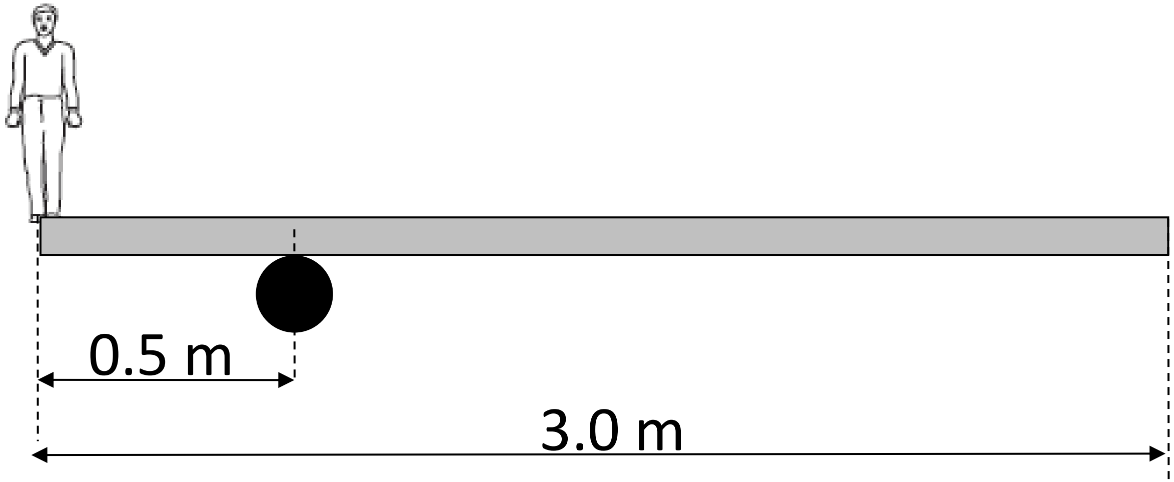


Example

2. **Calculate moment clockwise and anticlockwise**
   - **Clockwise moment**: 100N x 2m = 200 Nm
   - **Anticlockwise moments**: 70N x 2m = 140 Nm
   - The moment due to the 30N force is zero as its line of action passes straight through the point that we have chosen to take moments about. So we can ignore it!)
3. **Conclusion :**

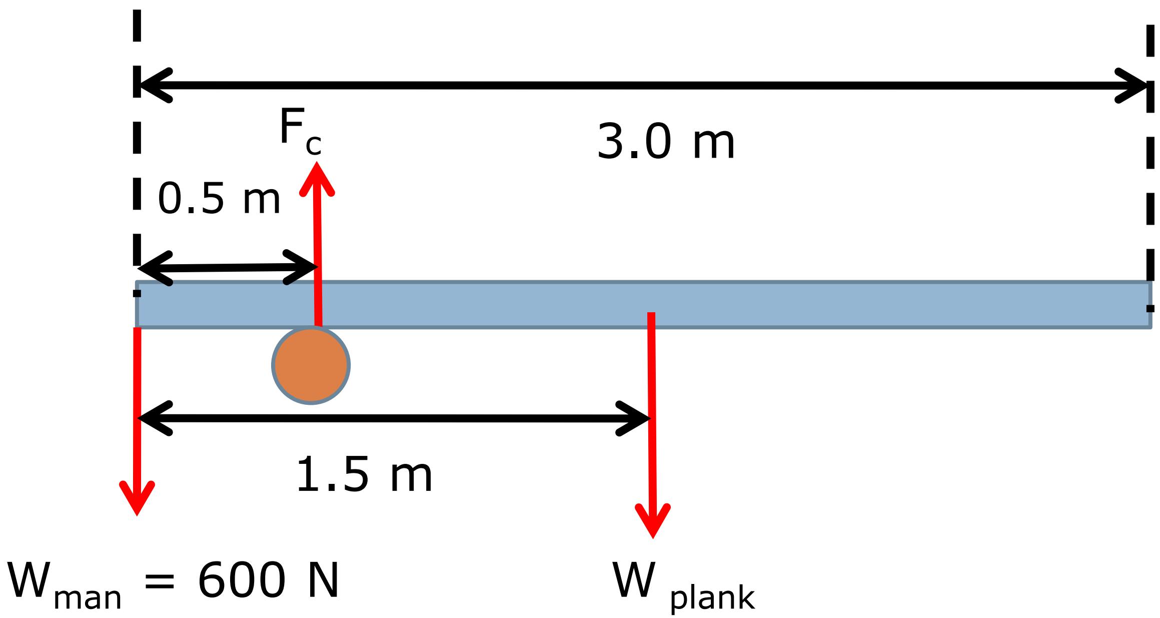
   So, clockwise moment ≠ anticlockwise moment. It means total moment at the point is not zero. Thus, moments are not balanced. The object isn't in equilibrium.

Example



- A man of weight 600 N stands at the end of a uniform wooden plank, which is pivoted as shown in the diagram.
  What is the weight of the wooden plank? ***(Assume that when the man stands on the plank, the plank still stationary)***
- Draw a free body diagram (show all forces act on the diagram)

Example



W_{plank} is directed downward from centre of gravity of the plank

- Moment of the forces at pivot. (so, value of F_c is negligible).
- Clockwise moment = W_{plank} x 1 m
- Anticlockwise moment = 600 N x 0.5 m = 300 Nm

Example

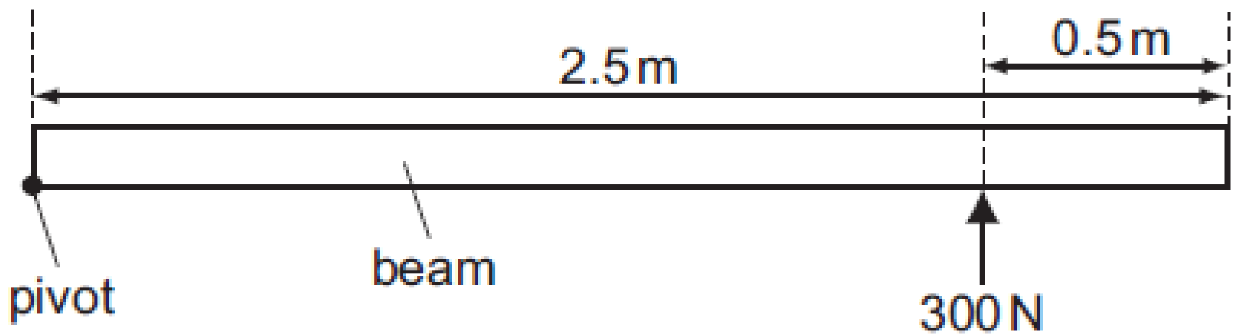
As object is in equilibrium,

1. $\mathbf{F_{upward} = F_{downward}}$
   - $F_c = W_{man} + W_{plank}$
   - $W_{plank} = F_c - 600\ N$

   (here we have 2 unknown, so, we cannot solve it). Thus, try to use principle of moment;

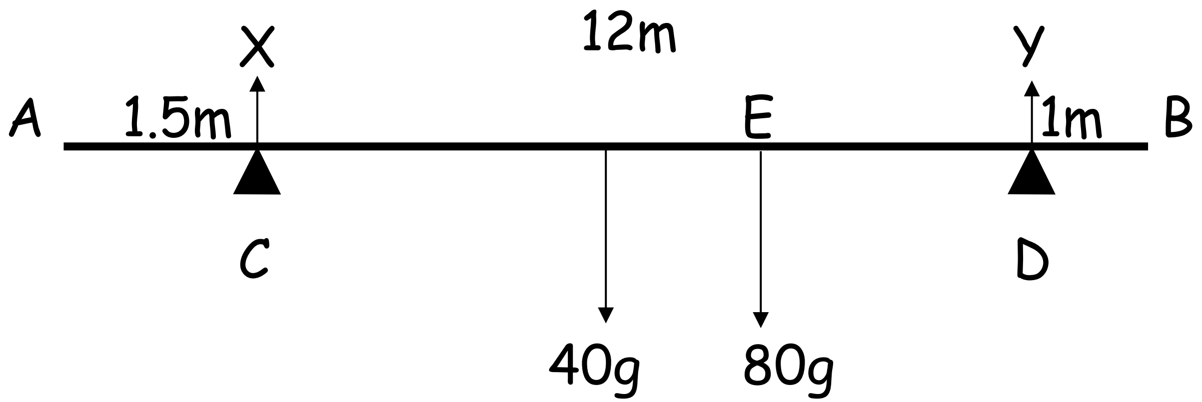
2. **moment clockwise = moment anticlockwise**
   - $300\ Nm = W_{plank} \times 1\ m$
   - So, $W_{plank} = 300\ N$

Question



- A long uniform beam is pivoted at one end. A force of 300 N is applied to hold the beam horizontally. What is the weight of the beam? 480 N

Question

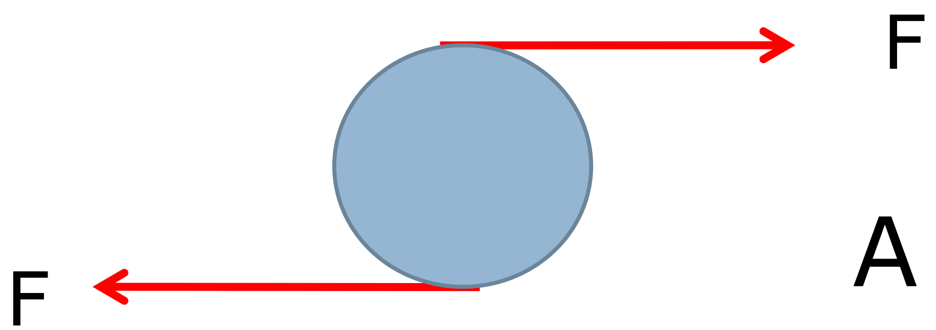


- A uniform beam AB of weight 40g and length 12m is supported in a horizontal position at C and D, where AC = 1.5m and DB = 1m. A man of weight 80g stands on the beam at the point E where EB = 2.5m. Find the reactions at C and D. (take g =9.81 Nkg^{-1})

Answer:
X= 330 N
Y= 847 N

Couple of force

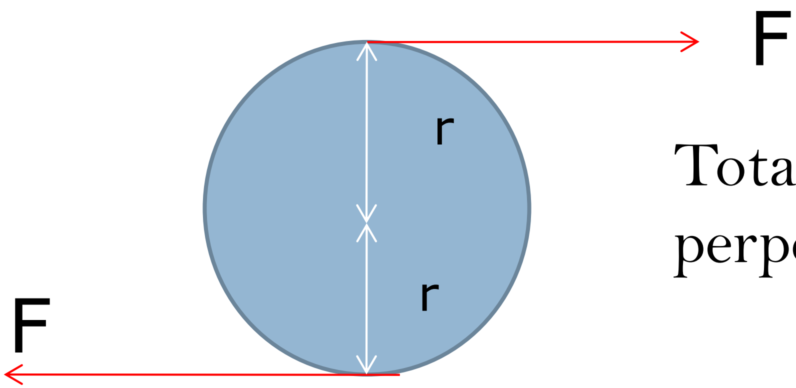
- If you have two forces acting on an object and the forces are:
  - Parallel
  - In opposite directions
  - Equal size



A Couple

Couple produce **rotation**. So the object will spin

Couple

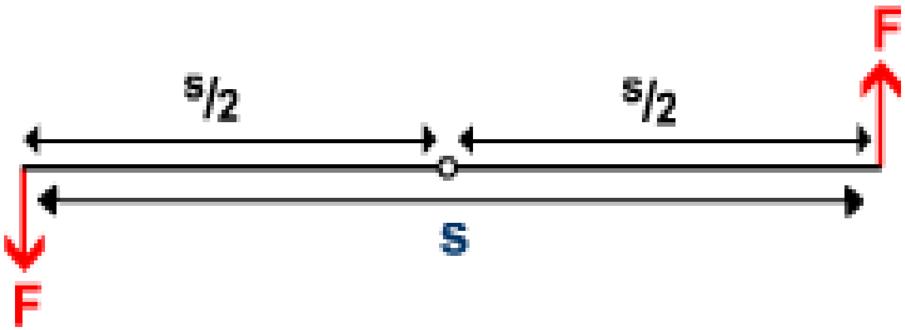


Total moment = one of the force x perpendicular distance between the forces

- Two parallel forces act at the opposite end of a diameter of a disc with radius, r. Each force produces a moment about the centre of the disc,
- M = F x 2r
- Total moment = 2 Fr

Torque

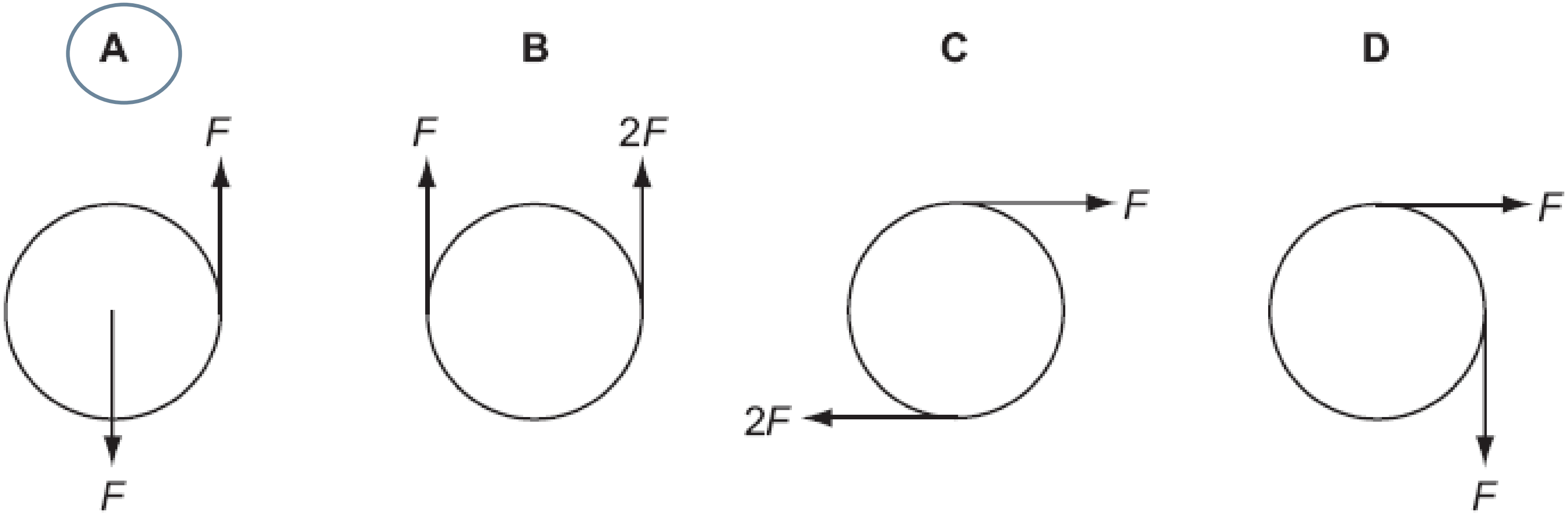
- This moment, although causes a turning effect is not called a moment because
  - **It produces by 2 forces, not 1**
- It is called a **<u>TORQUE</u> (symbol = τ)**
- **Definition:**
- **Torque is product of one of the forces in the couple and the perpendicular distance between the forces**



$$\tau = F \times s$$

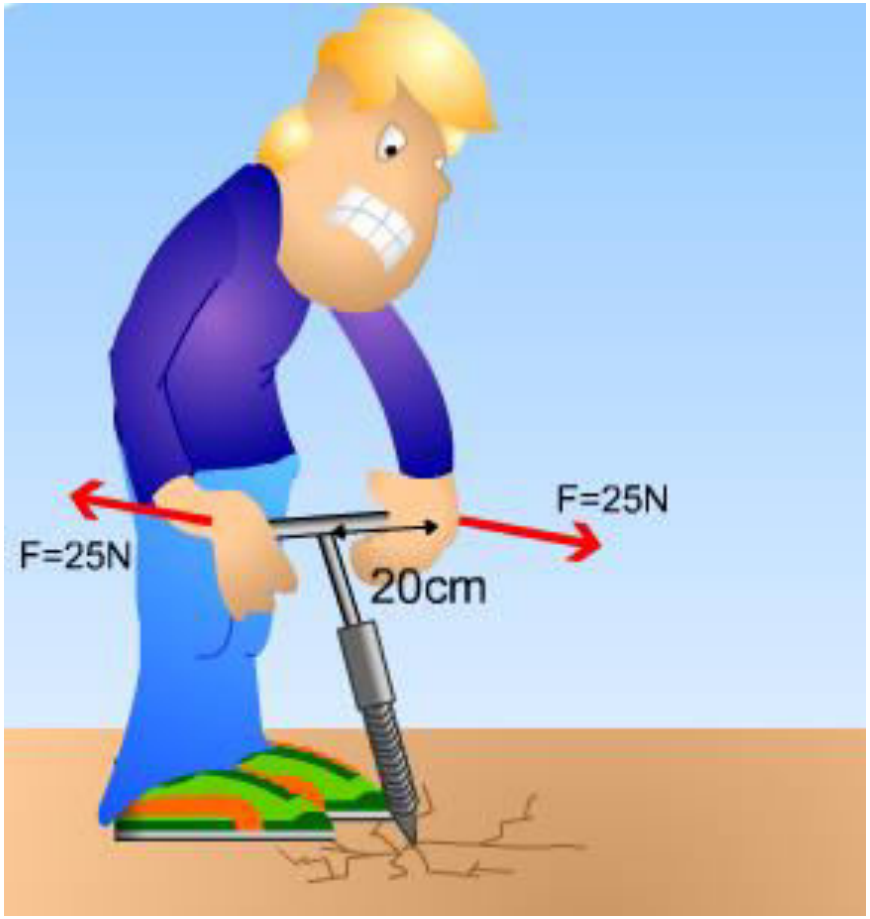
Question

- Tutorial (Q20)
  - Which pair of forces acts as a couple on the circular object?



Question

Calculate the torque produced by the man

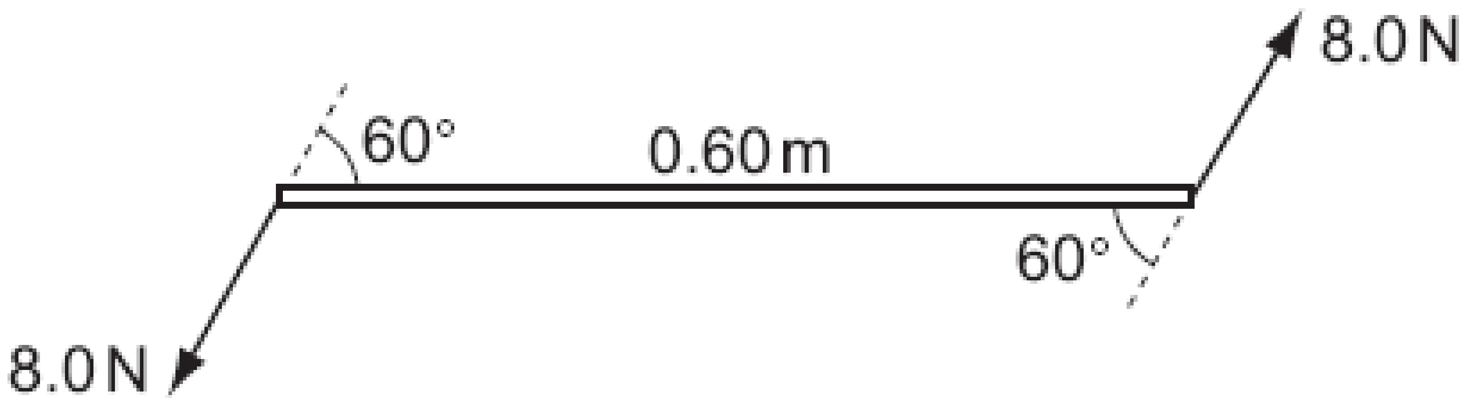


$\tau = F \times d$

$= 25 \times 0.40$

$= 10\ Nm$

Question



- Two 8.0 N forces act at each end of a beam of length 0.60 m. The forces are parallel and act in opposite directions. The angle between the forces and the beam is 60 °.
- What is the torque of the couple exerted on the beam?

4.2 Nm

END OF TOPIC

TUTORIALS

S15QP11

14 What is the **definition** of the force on a body?

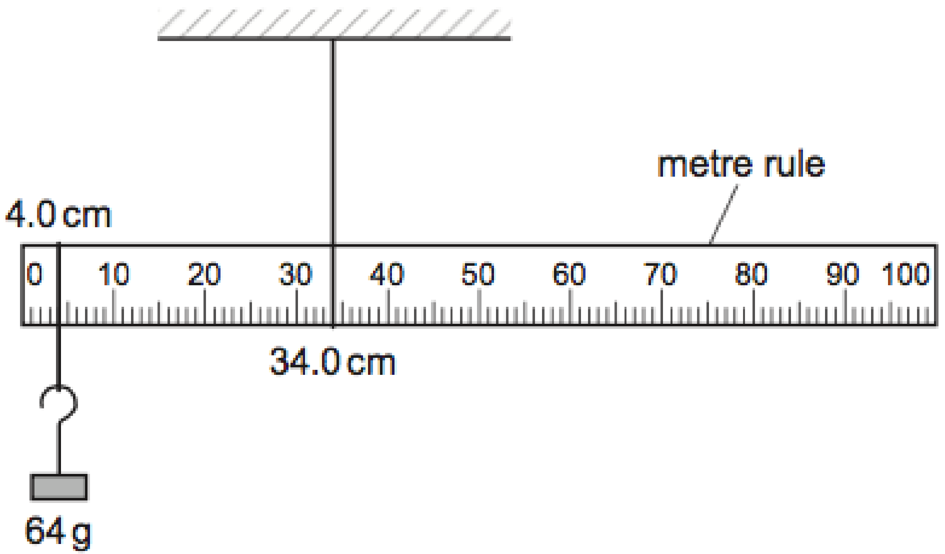
A the mass of the body multiplied by its acceleration

B the power input to the body divided by its velocity

C the rate of change of momentum of the body

D the work done on the body divided by its displacement

15 A uniform metre rule is pivoted at the 34.0 cm mark, as shown.



The rule balances when a 64 g mass is hung from the 4.0 cm mark.

What is the mass of the metre rule?

A 38 g **B** 44 g **C** 120 g **D** 136 g

S15QP22

3 A rod PQ is attached at P to a vertical wall, as shown in Fig. 3.1.

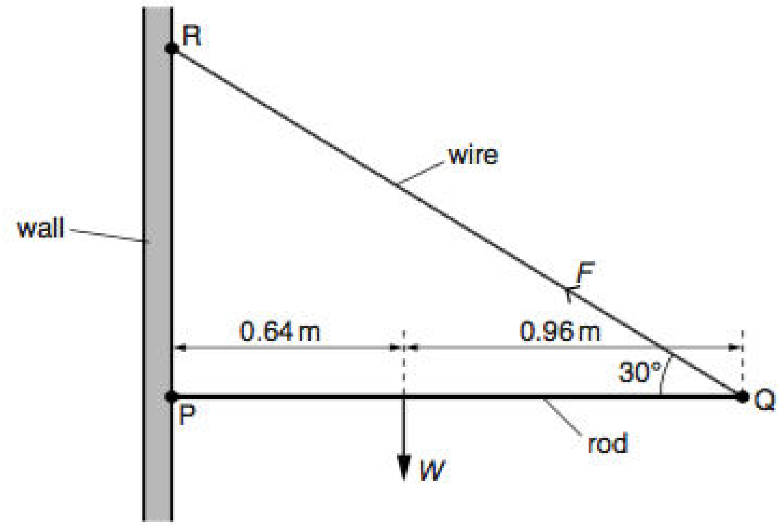


Fig. 3.1

The length of the rod is 1.60 m. The weight *W* of the rod acts 0.64 m from P. The rod is kept horizontal and in equilibrium by a wire attached to Q and to the wall at R. The wire provides a force *F* on the rod of 44 N at 30° to the horizontal.

(a) Determine

(i) the vertical component of *F*,

vertical component = ... N [1]

(ii) the horizontal component of *F*.

horizontal component = ... N [1]

S15QP22

(b) By taking moments about P, determine the weight *W* of the rod.

W = ... N [2]

(c) Explain why the wall must exert a force on the rod at P.

....

....

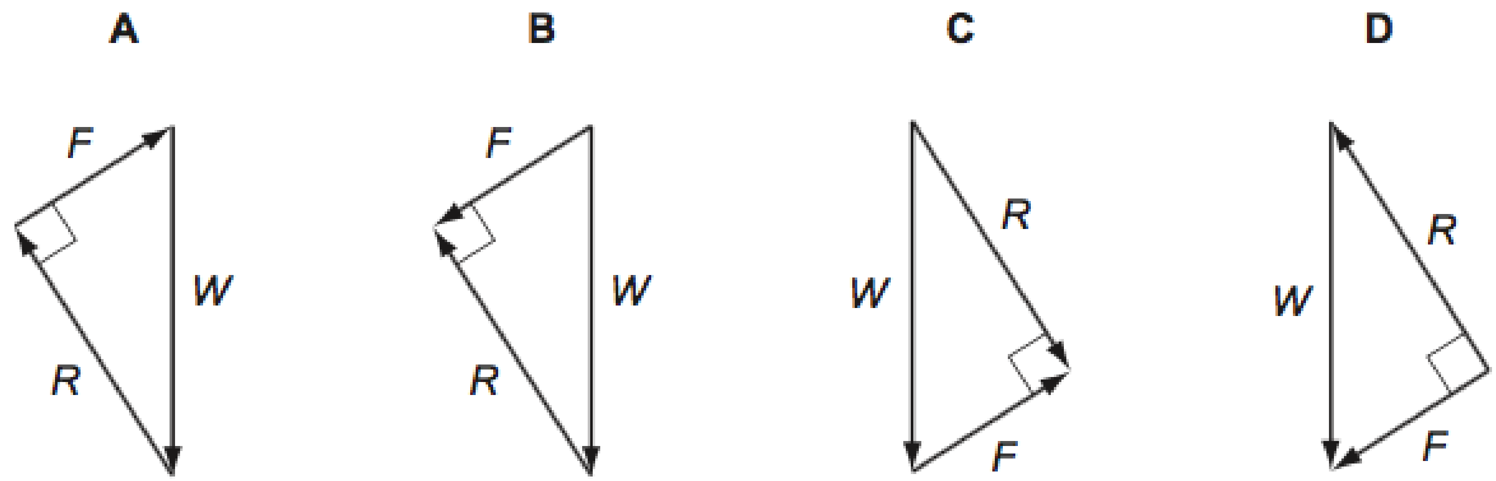
.... [1]

(d) On Fig. 3.1, draw an arrow to represent the force acting on the rod at P. Label your arrow with the letter S. [1]

12 A vehicle is at rest on a slope. It is considered to have three forces acting on it to keep it in equilibrium.

They are its weight *W*, a normal reaction force *R* and a frictional force *F*.

Which triangle of forces is correct?



S13QP12

13 All external forces on a body cancel out.

Which statement **must** be correct?

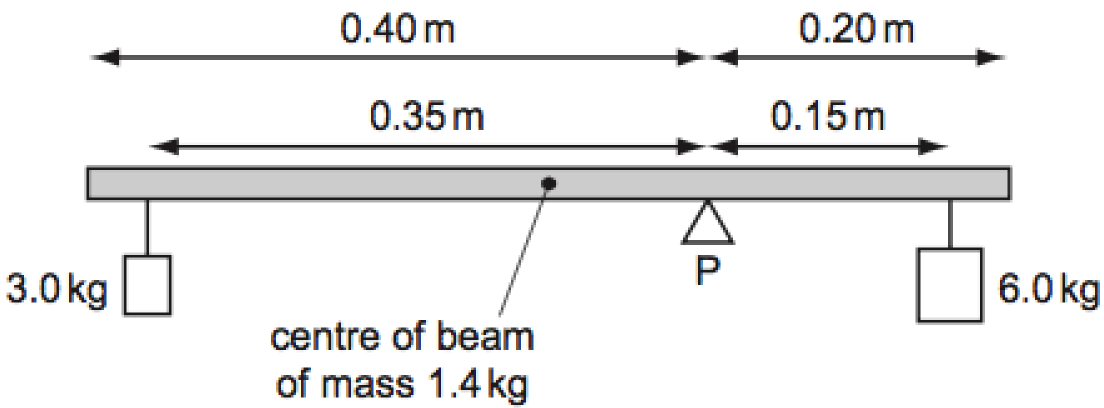
A The body does not move.

B The momentum of the body remains unchanged.

C The speed of the body remains unchanged.

D The total energy (kinetic and potential) of the body remains unchanged.

14 A uniform beam of mass 1.4 kg is pivoted at P as shown. The beam has a length of 0.60 m and P is 0.20 m from one end. Loads of 3.0 kg and 6.0 kg are suspended 0.35 m and 0.15 m from the pivot as shown.

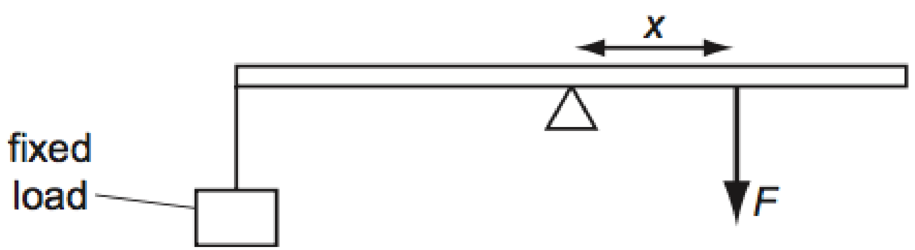


What torque must be applied to the beam in order to maintain it in equilibrium?

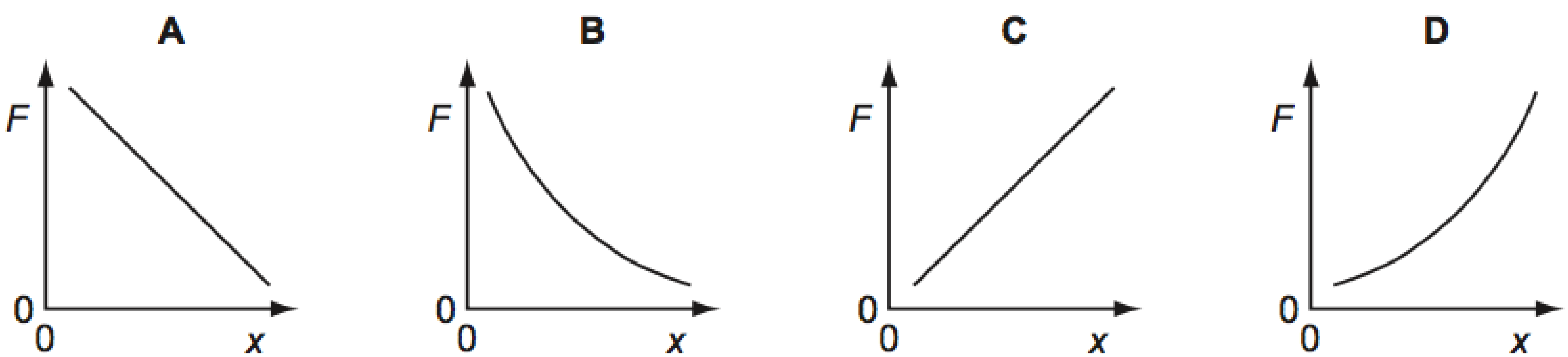
A 0.010 N m **B** 0.10 N m **C** 0.29 N m **D** 2.8 N m

S13QP11

14 A horizontal bar is supported on a pivot at its centre of gravity. A fixed load is attached to one end of the bar. To keep the bar in equilibrium, a force F is applied at a distance x from the pivot.

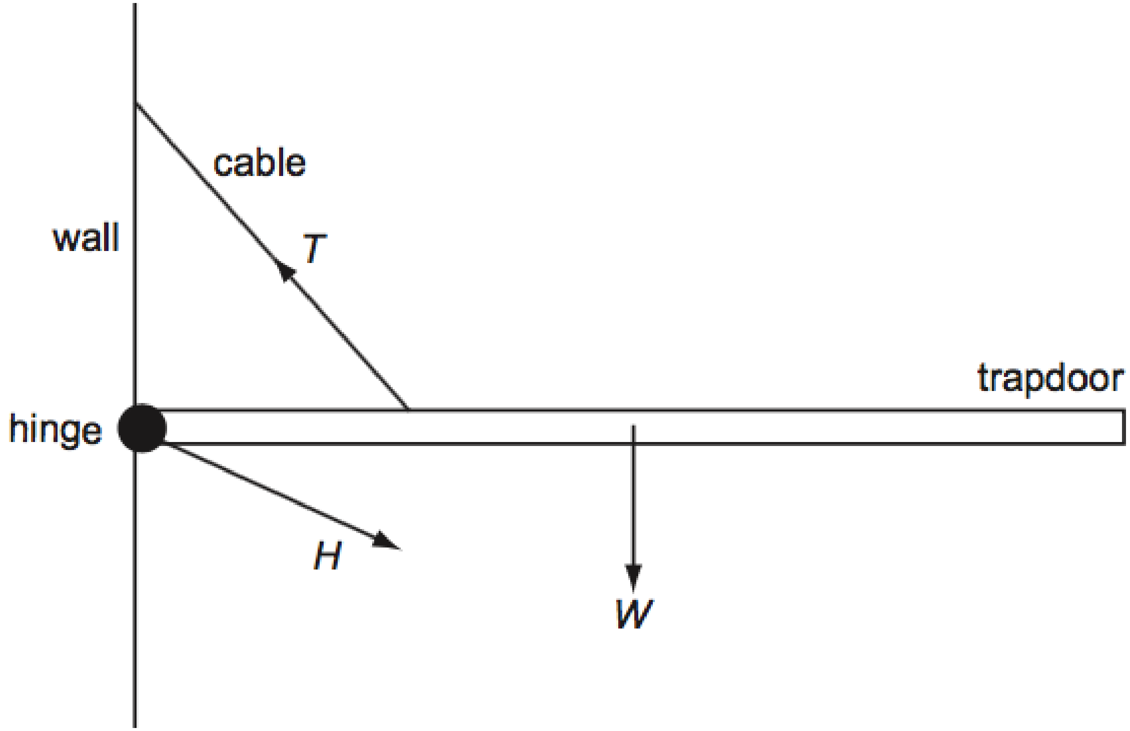


How does F vary with x?



16 A hinged trapdoor is held closed in the horizontal position by a cable.

Three forces act on the trapdoor: the weight *W* of the door, the tension *T* in the cable and the force *H* at the hinge.



Which list gives the three forces in **increasing** order of magnitude?

A *H*,*T*,*W* **B** *T*,*H*,*W* **C** *W*,*H*,*T* **D** *W*,*T*,*H*