# CHAP 5 FORCES

Lim WH July 2012

# Learning Outcomes

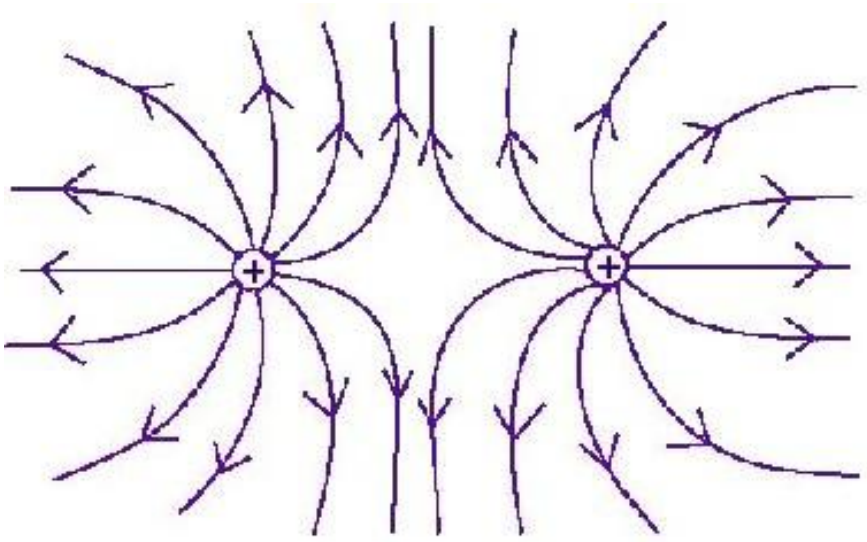
*(a)* describe the forces on mass and charge in uniform gravitational and electric fields, as appropriate

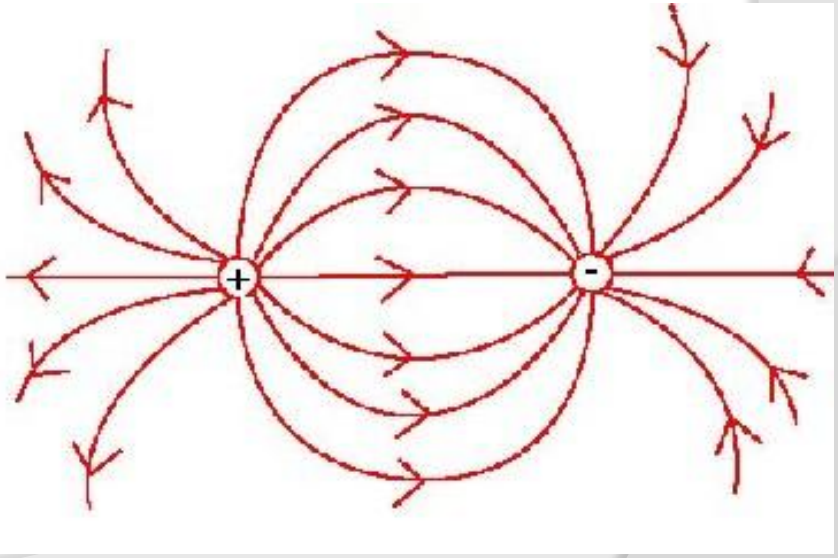
*(b)* show an understanding of the origin of the upthrust acting on a body in a fluid

*(c)* show a qualitative understanding of frictional forces and viscous forces including air resistance (no treatment of the coefficients of friction and viscosity is required)

# Electric force

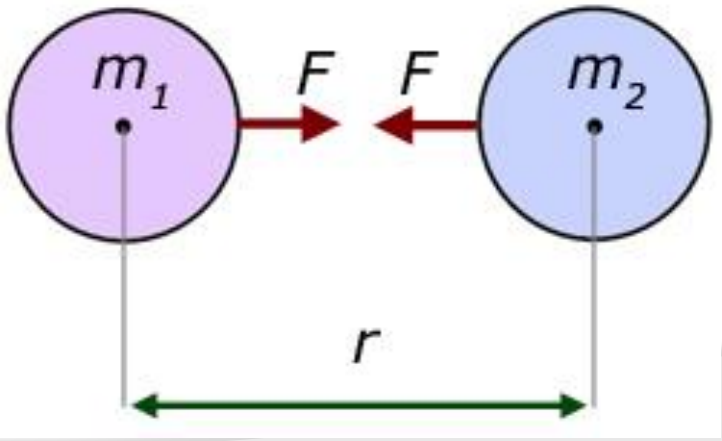
- Electric field is a region where electric charge is exerted by a force.
- Electric force exists between two charges
- Like charges attract, unlike charges repel.



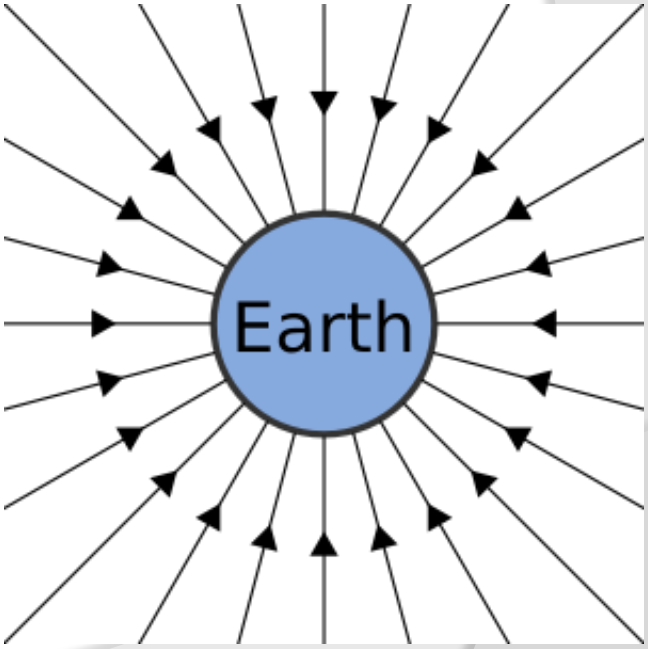



# Gravitational force

- Gravitational field is a region where a mass is exerted by a force.
- There is always an attraction between two masses.
- The force is significant when one of the masses is very large, e.g. the earth and a man.




- Gravitational force exerted by the Earth on a mass is known as the weight of the mass, i.e. **W**=mg.
- Gravitational field lines are always directed towards the centre of a mass.



# Upthrust

- the resultant force acting vertically upwards on an object immersed in a liquid.
- It arises due to the pressure difference between the top and bottom surfaces of the object.

# pressure difference

$p = \rho hg$

$p = F/A$

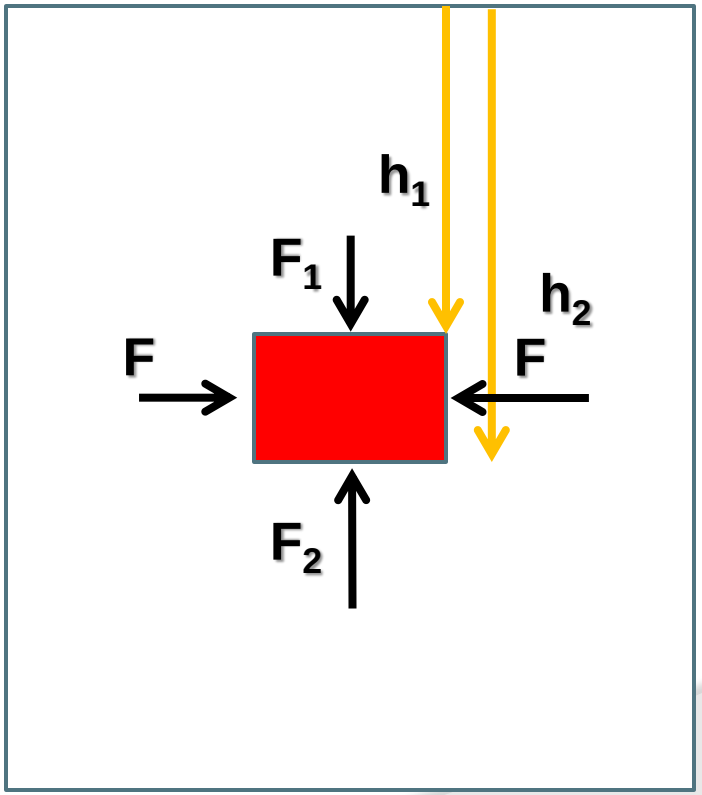
$h_2 > h_1$

$F_2 > F_1$

$U = F_2 - F_1$

$= P_2A_2 - P_1A_1$

$= (P_2 - P_1)\, A$



# Magnitude of upthrust $U = \rho V g$

A parachutist is falling in air and is accelerating.

State the forces acting on him in an ascending order of magnitude.

# PYQ

A cylindrical block of wood has a cross-sectional area $A$ and weight $W$. It is totally immersed in water with its axis vertical. The block experiences pressures $p_t$ and $p_b$ at its top and bottom surfaces respectively.

Which of the following expressions is equal to the upthrust on the block?

**A** $(p_b - p_t)A + W$

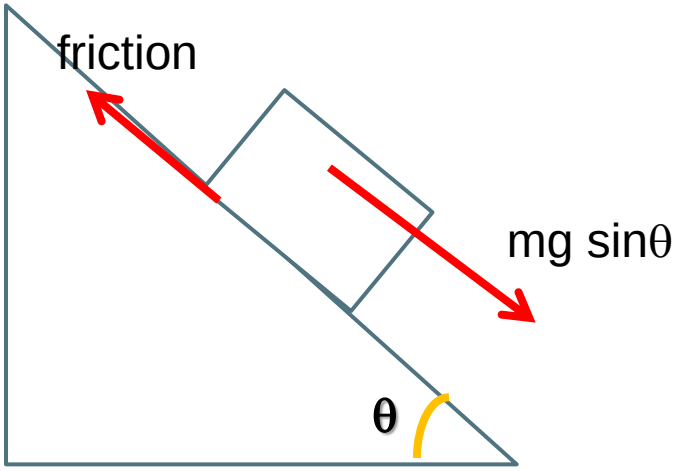
**B** $(p_b - p_t)$

**C** $(p_b - p_t)A$

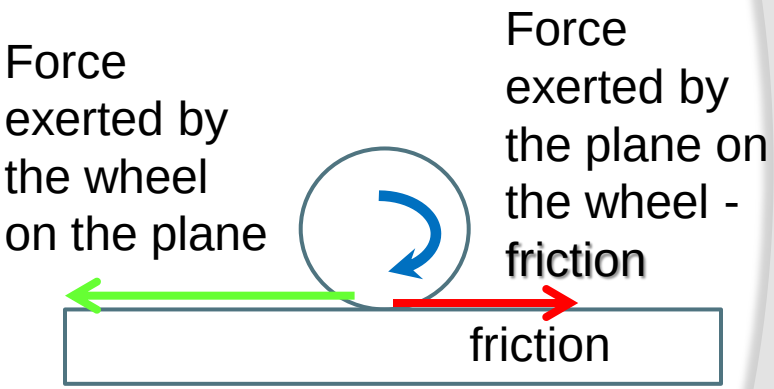
**D** $(p_b - p_t)A - W$

# Frictional force

- Friction results from the two surfaces being pressed together closely, causing intermolecular attractive forces between molecules of different surfaces. As such, friction depends upon the nature of the two surfaces and upon the degree to which they are pressed together.



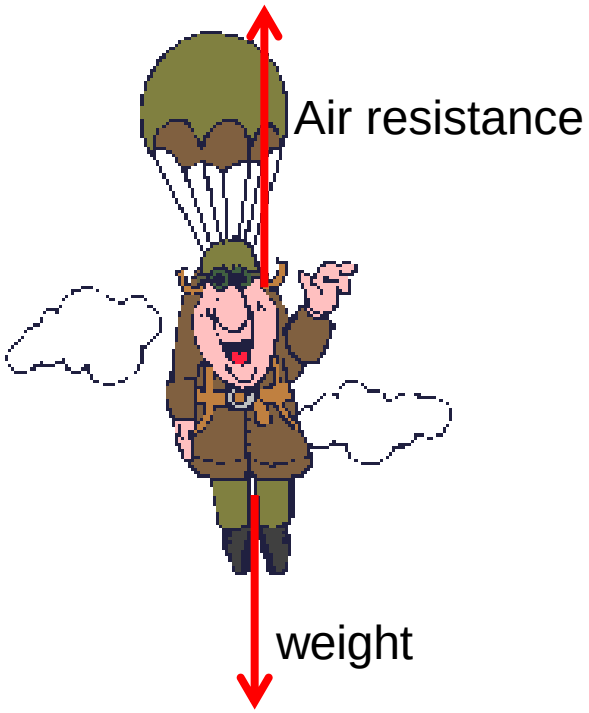

A wooden block is sliding down the plane when mg sinθ > friction.



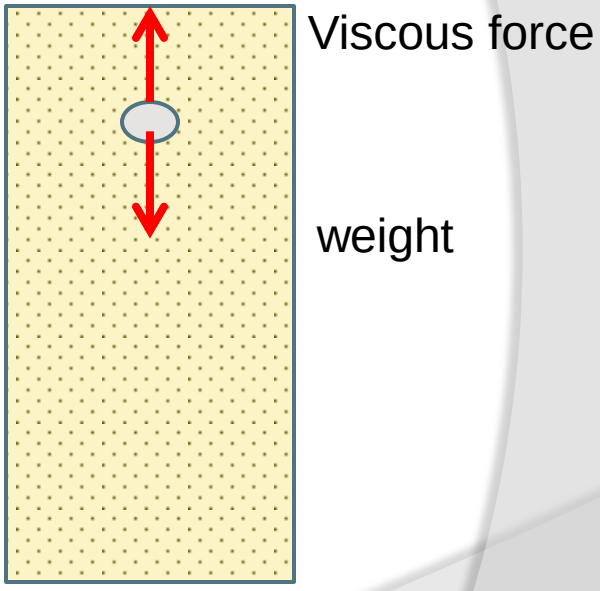

A wheel is rolling on the plane and moving to the right. Friction provides driving force for a car.

# viscous forces – opposing motion

A parachutist falling in air




A sphere falling in oil



# Learning Outcomes

*(d)* use a vector triangle to represent forces in equilibrium

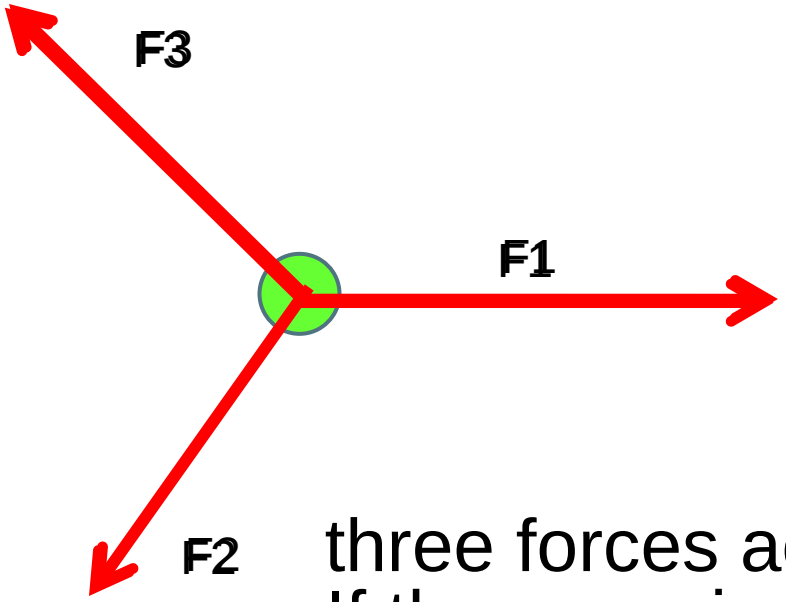
*(e)* show an understanding that the weight of a body may be taken as acting at a single point known as its centre of gravity

*(f)* show an understanding that a couple is a pair of forces that tends to produce rotation only

# What is meant by '*equilibrium*'?

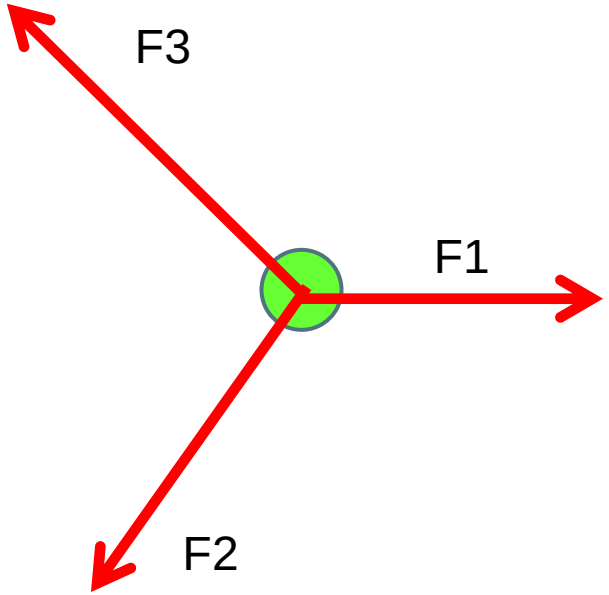
- When an object is said to be in equilibrium, there is no resultant force and no resultant moment acting on the object. Therefore this object will either remain stationary or continue to move with constant velocity.

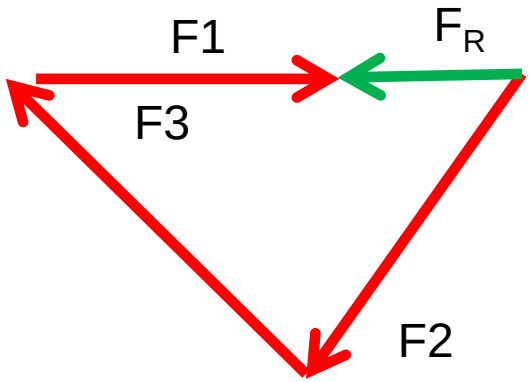
# Equilibrium of forces




three forces act on a mass.
If the mass is in equilibrium, these three forces balance each other and (1) form a triangle.

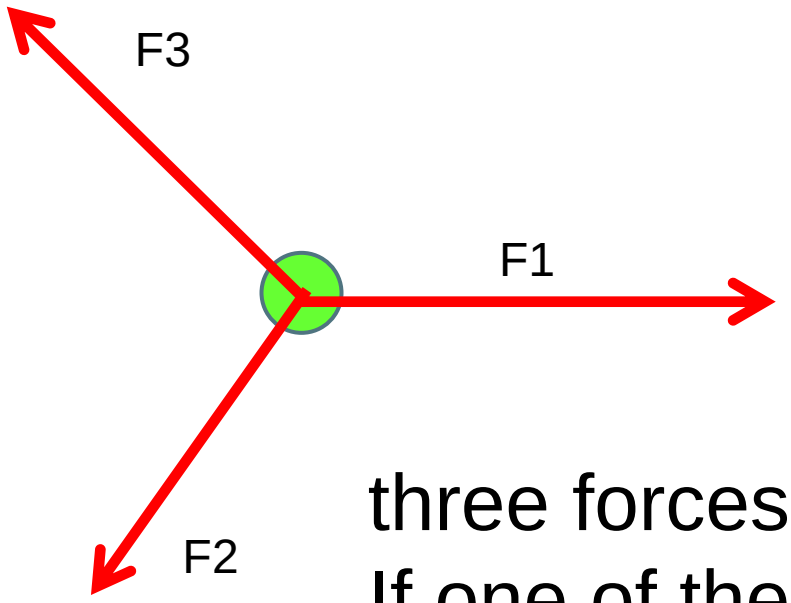
# Equilibrium of forces



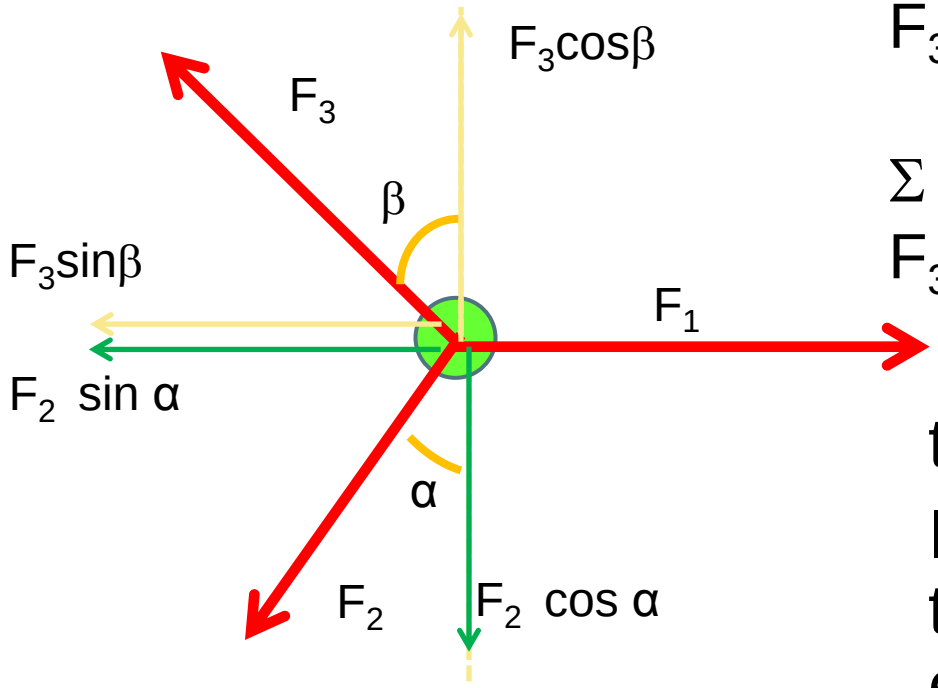

Not a triangle?

# Equilibrium of forces




three forces are in equilibrium.
If one of the forces is removed ??

# Equilibrium of forces




$\Sigma F_y = 0$

$F_3\cos\beta = F_2\cos\alpha$

$\Sigma F_x = 0$

$F_3\sin\beta + F_2\sin\alpha = F_1$

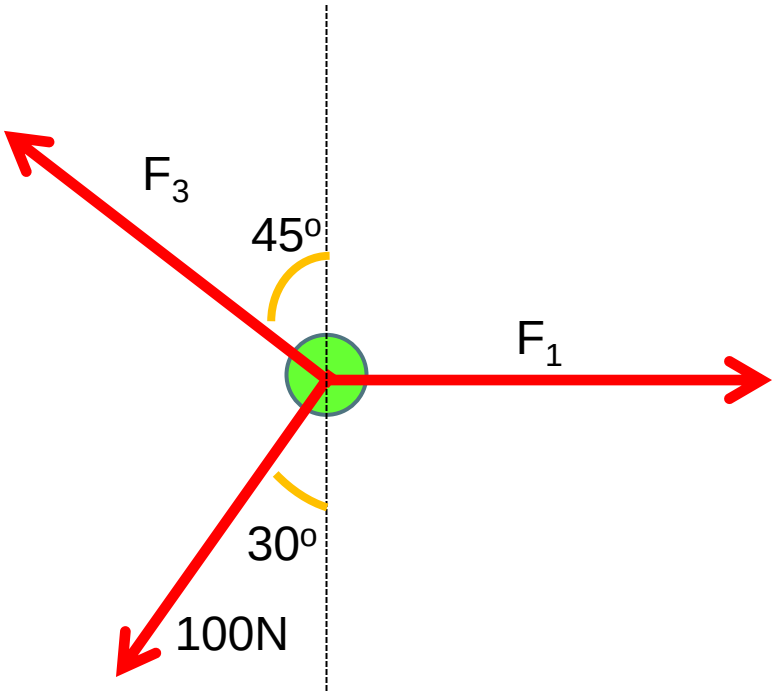
three forces act on a mass.

If the mass is in equilibrium, these three forces balance each other

(2)$\Sigma F_x = 0$ ; $\Sigma F_y = 0$

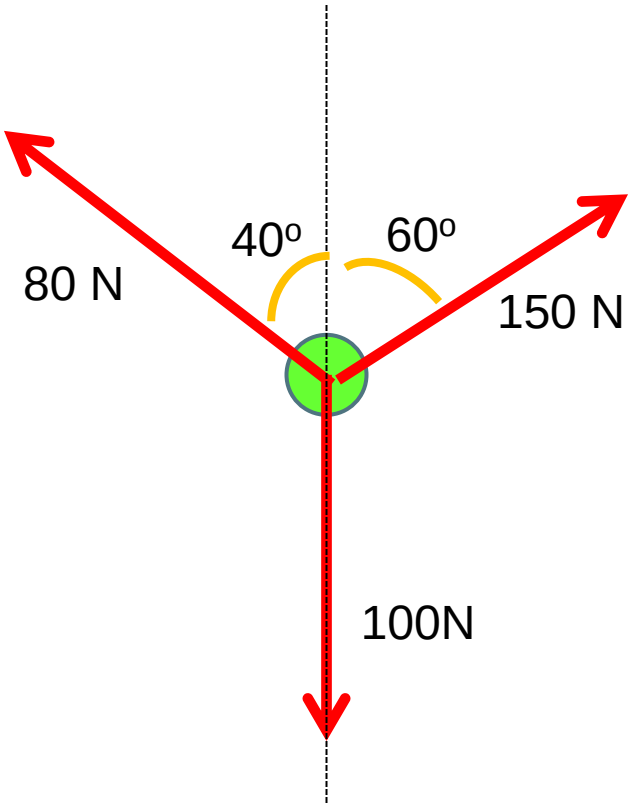
# Example 1

Determine the values of the forces for the mass to be in equilibrium



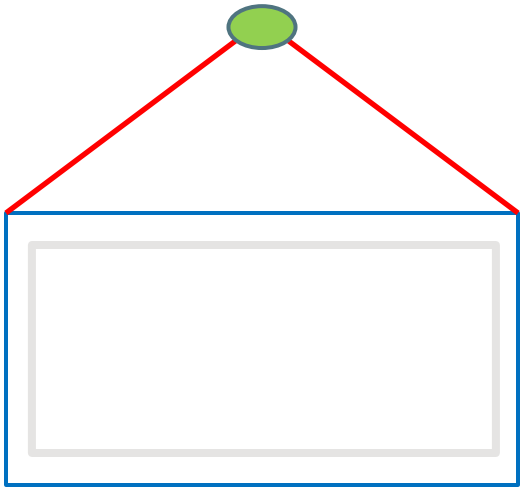
# Example 2

Three forces act on a mass. Determine if the mass is in equilibrium.



# Example 3

A photo frame is hung at a peg on the wall as shown below.



Draw a free body diagram to show all forces acting on

(a) The frame

(b) The peg

# Example 4

A ship is towed at steady speed into port by two tugs, each tug pulling the ship by a steel cable. If each cable is under a tension of 3000 N and the angle between the two cables is 45°.

(a) the 'drag' force on the ship,

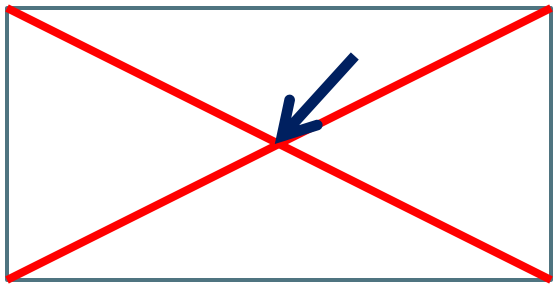
(b) the resultant force on the ship if one of the cables snaps.

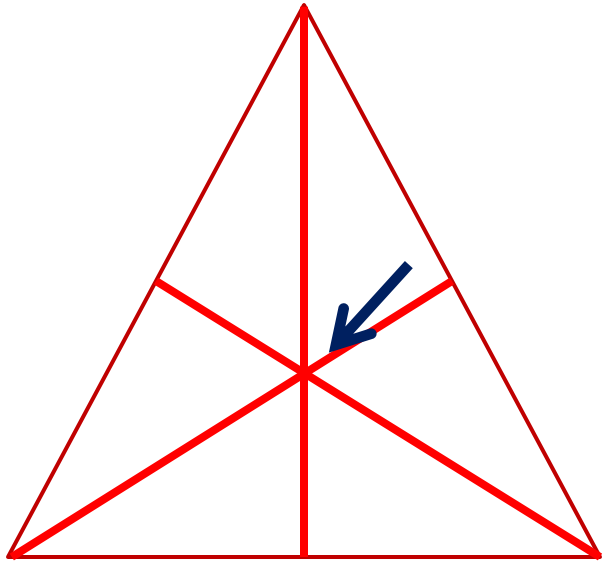
# Centre of Gravity (CG)

- As long as there is a mass, there is a gravitational force exerted by the earth (weight) on it.
- To simplify calculations, a representative point is necessary.
- CG is a point at which the whole weight is considered to act on.

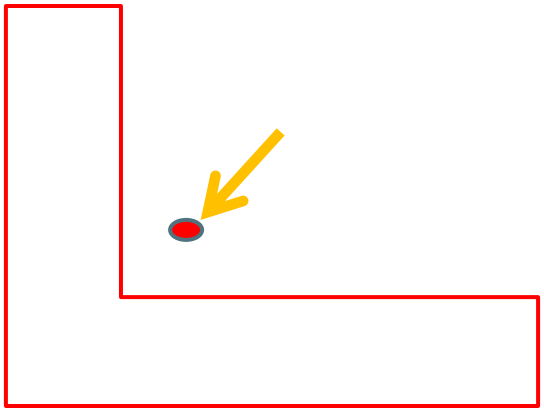
# Centre of Gravity (CG)

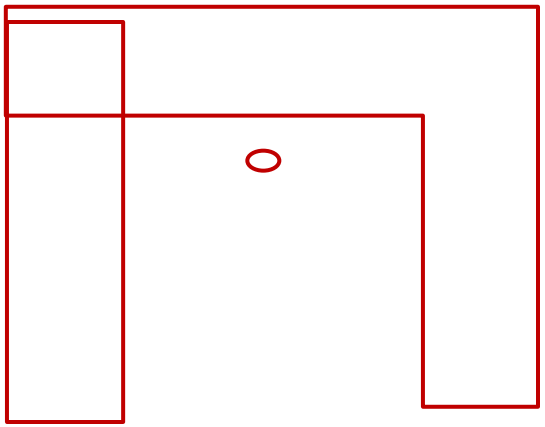
- For a uniform mass, the centre of gravity is the centre of geometry.





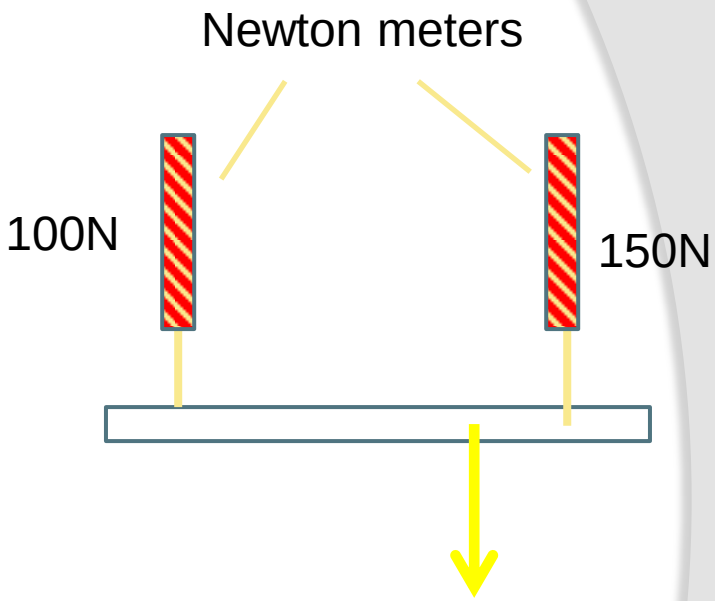
# Centre of Gravity (CG)





# Centre of Gravity (CG)

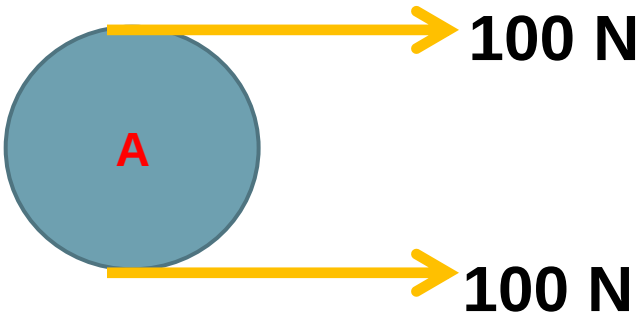
- For a non-uniform mass, the centre of gravity is towards the heavier side.

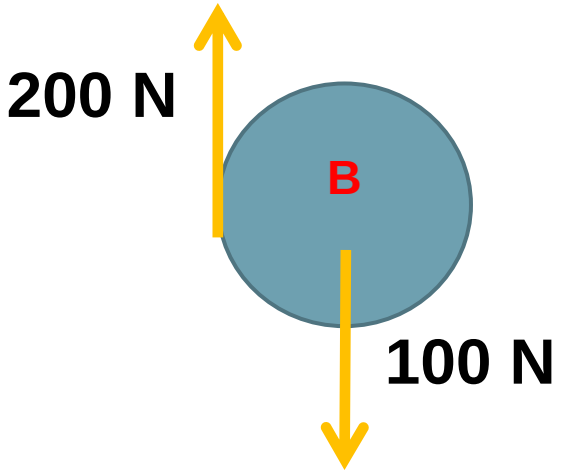


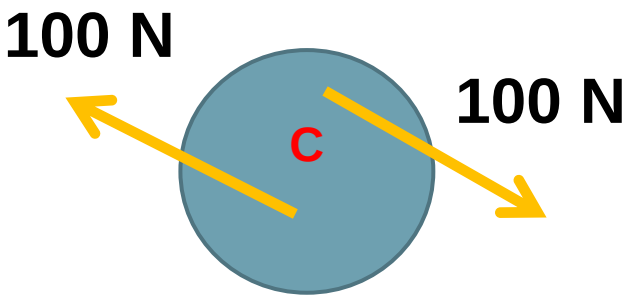
# A couple of forces

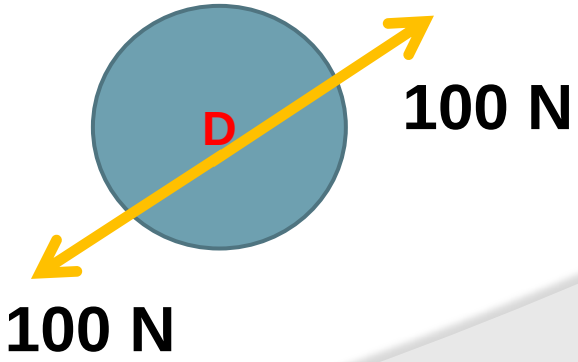
- A pair of parallel forces
- with equal magnitude (i.e. no resultant force)
- act in an opposite direction
- separated by a distance, d
- produce purely turning effect (i.e. no linear acceleration)

# Is it a couple of forces?



# Learning Outcomes

*(g)* define and apply the moment of a force and the torque of a couple

*(h)* show an understanding that, when there is no resultant force and no resultant torque, a system is in equilibrium

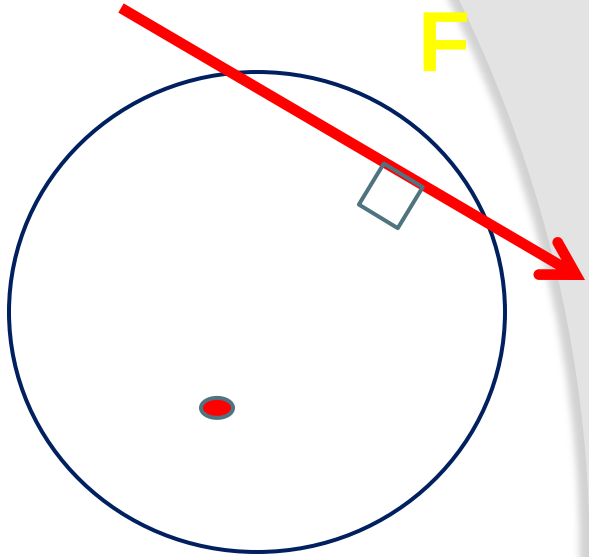
*(i)* apply the principle of moments.

# Force

- Linear motion
- Rotational motion

# Moment

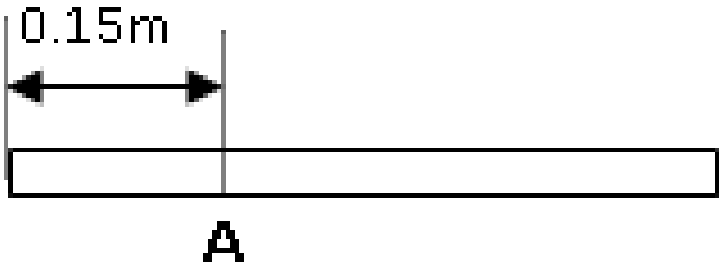
- **a measure of the ability of a force to rotate a body about a given point.**
- **It is the product of the force F and the perpendicular distance between the point of rotation and the line of action of the force, i.e. Fd**
- **It is a vector quantity.**
- **unit Nm (but why not J ? )**



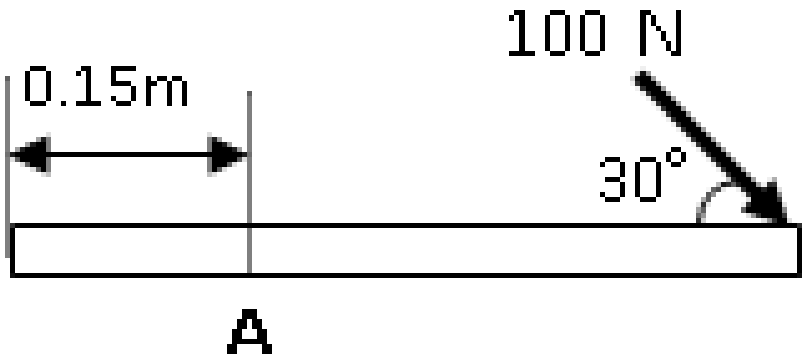
# Example 1

A uniform beam of weight 60 N and length 0.8 m is pivoted at point A.

**(a)** Determine the moment of the weight about point A.

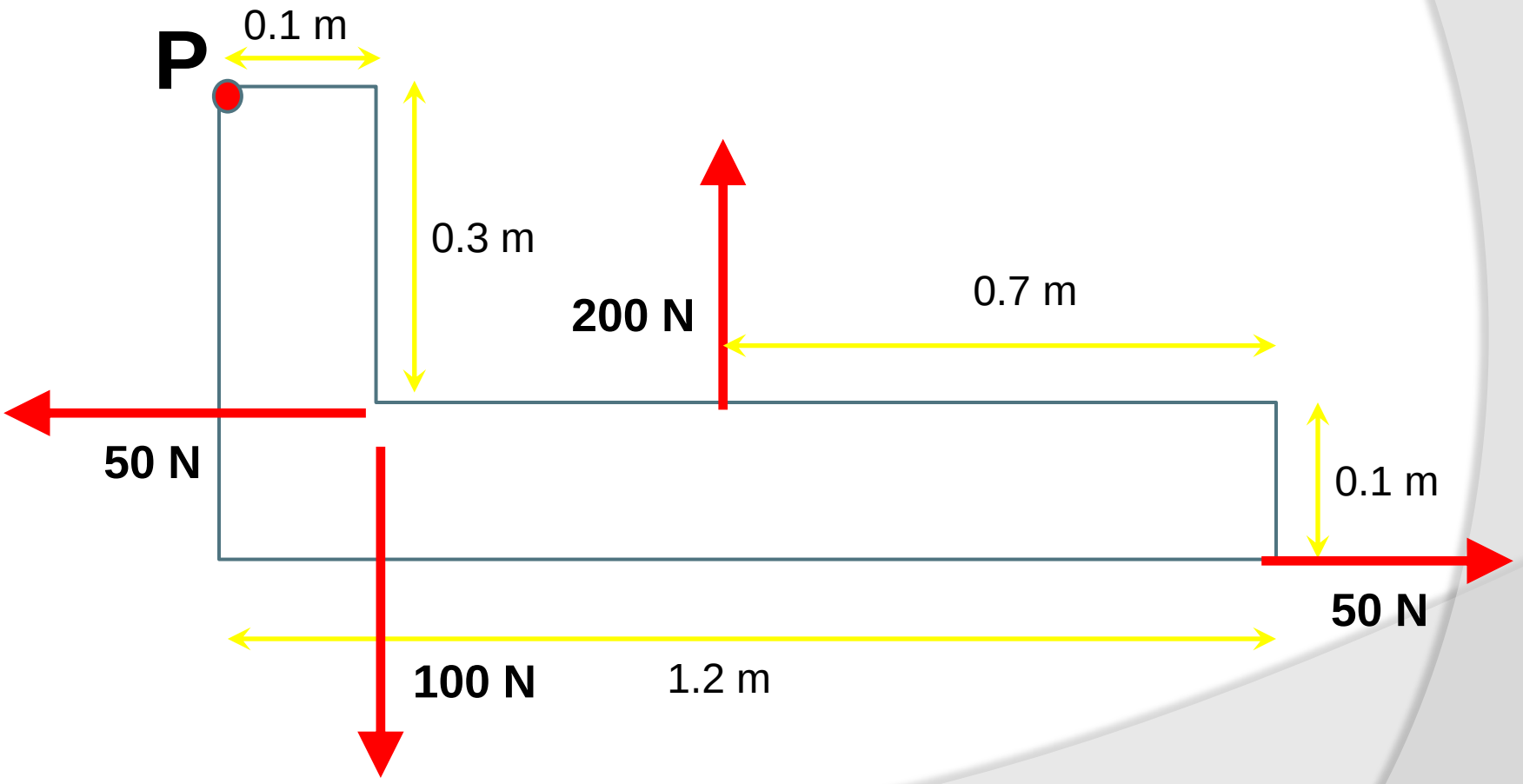


(b) Another force 100 N is acting at 30$^{o}$ to the beam as shown in the diagram. Determine the resultant moment of the forces about point A.



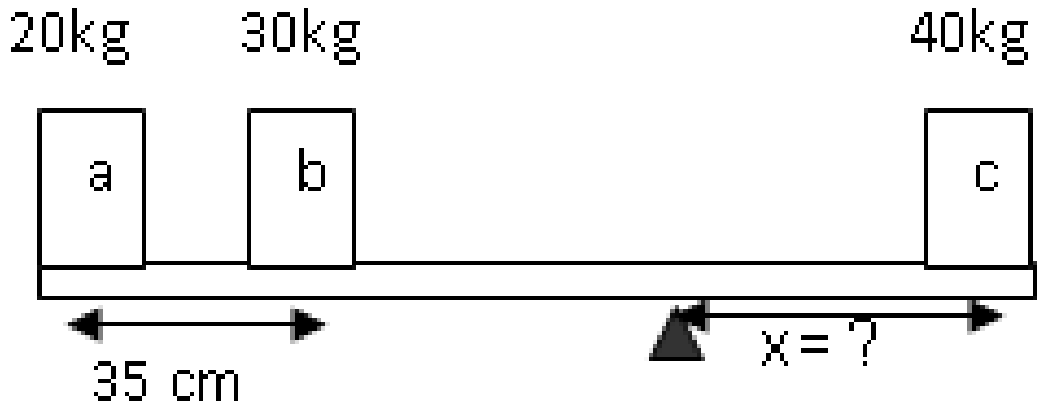
# Example

- Determine the resultant moment at P



# Try this

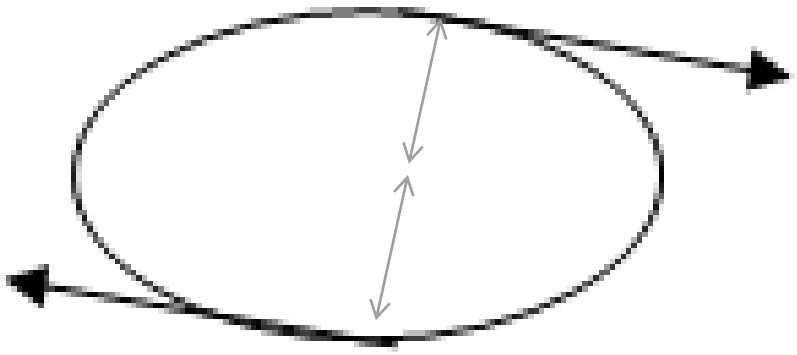
At what distance a fulcrum should be located to balance the loads on the beam of 1 m? The weight of the beam can be ignored.



# torque

Moment of a couple of forces

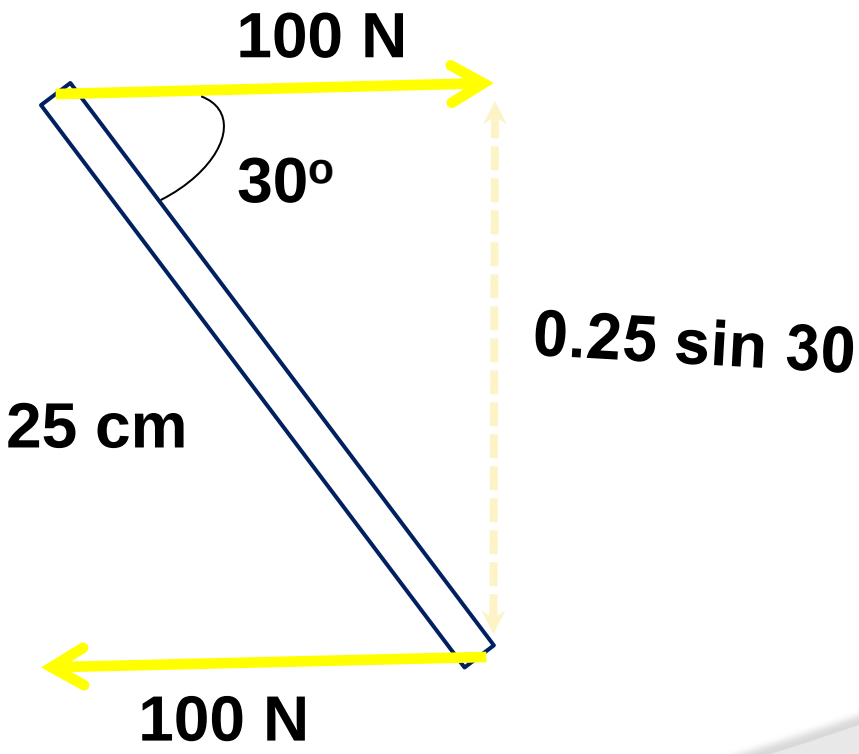
The **torque** of a couple is the product of one of the forces and the perpendicular distance between them



$$F d_1 + F d_2$$
$$= F (d_1 + d_2)$$
$$= F d$$

# Example

Determine the torque of the couple. The length of the beam is 25 cm.

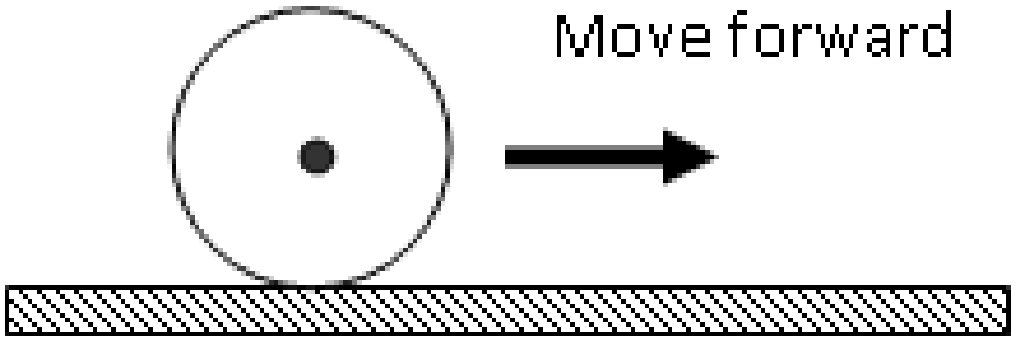


# Try this

A torque of 100 Nm acts at the axle of a wheel of a car which moves forward as shown below with a constant speed. The wheel has a diameter of 0.70 m.

a) Mark the direction of rotation of the wheel about the axle

b) Mark the direction of frictional force acting on the wheel and hence calculate the value.



# Principle of moments.

When a body is in equilibrium, anticlockwise moment about any point is equal to clockwise moment about the same point.

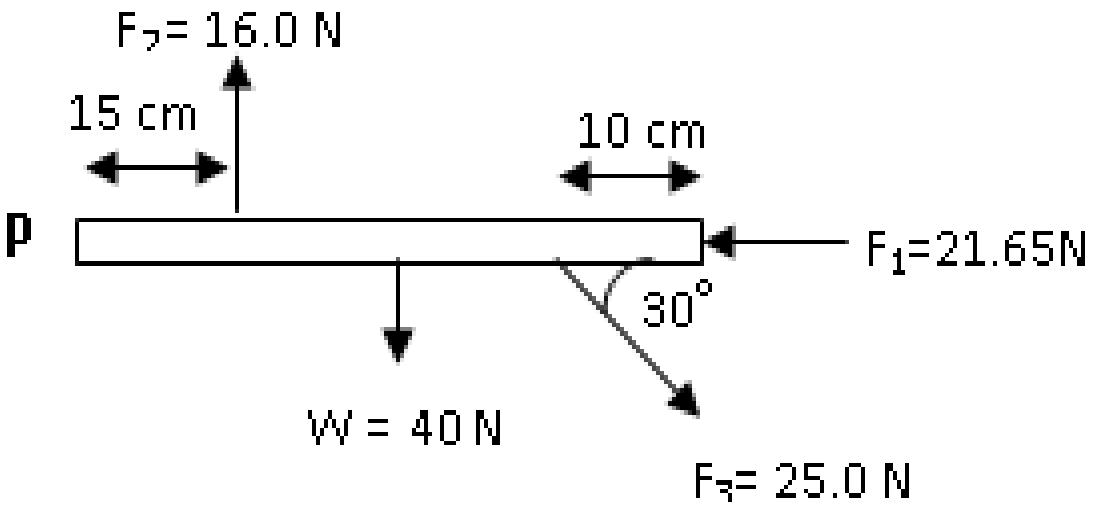
# Two conditions for a body to be in equilibrium

(1) Resultant force is zero along any direction

(2) Resultant moment is zero about any point

# Try this

A uniform beam of 70 cm and weight 40 N is acted by four forces, as shown below:




a) Determine the resultant force acting on the beam. Show your workings.

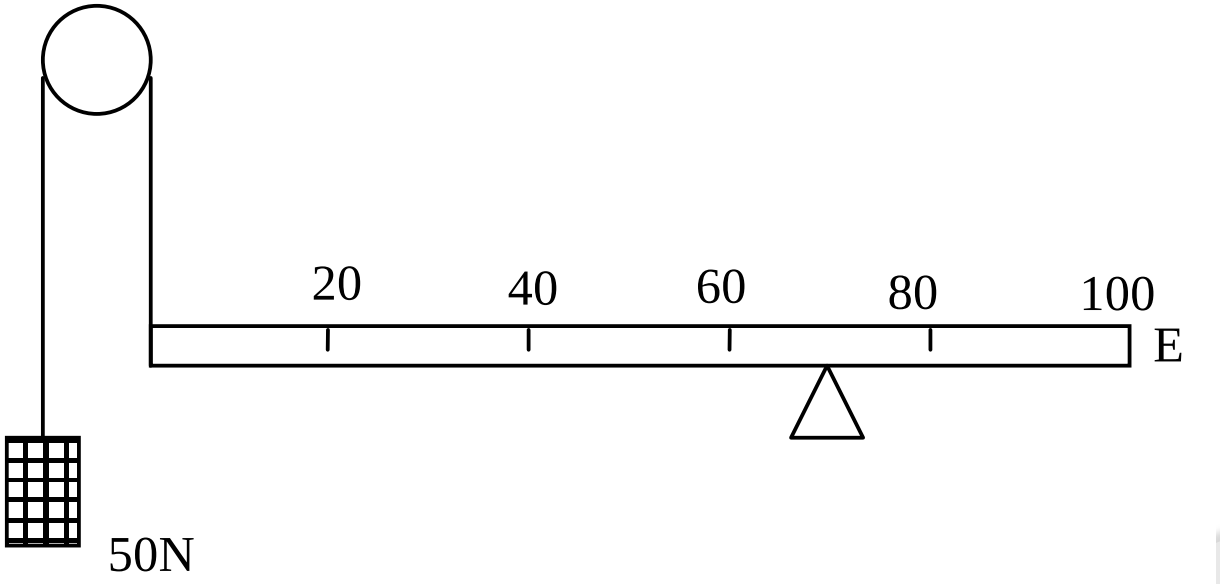
b) Calculate the moment of each force about point P.

c) Are the moments of the forces balanced? If not, what is the resultant moment?

d) If a force of 36.5 N is exerted to balance the beam, at what distance should it be applied?

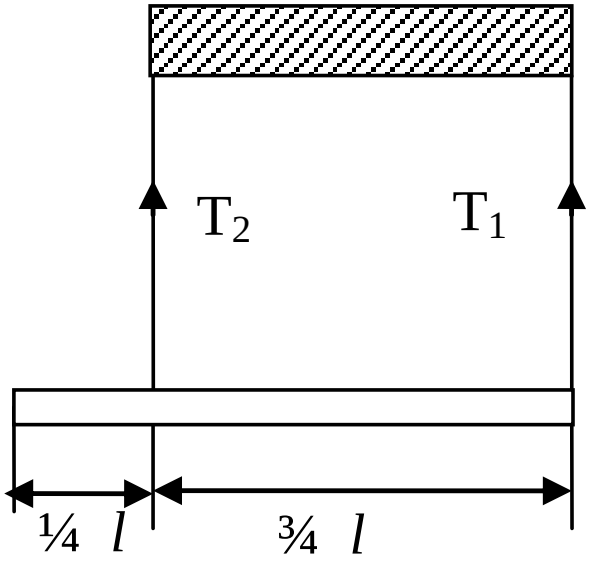
# Example

A uniform plank of weight 120 N is 100 cm long and rests on a support that is 30 cm from end E. A load of 50 N is tied to another end of the plank with a rope that runs through a frictionless pulley. At what distance from E must a 100 N weigh be placed in order to balance the plank?



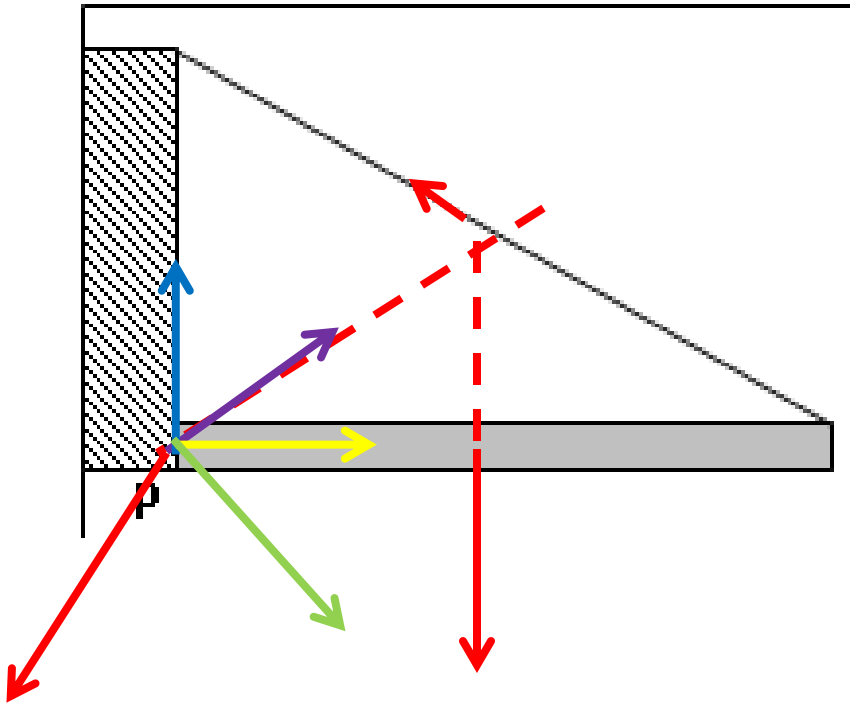
# Try this

A heavy uniform beam of length *l* is supported by two vertical cords as shown:



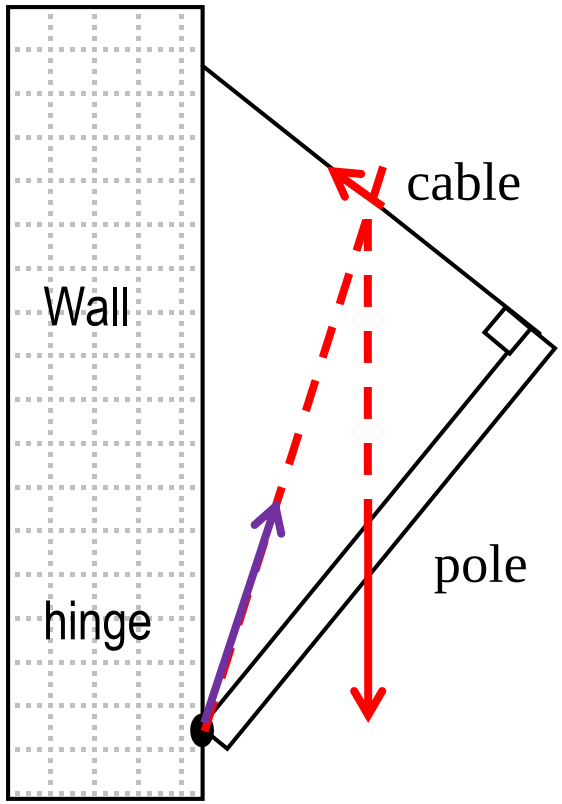

What is the ratio of $T_1 / T_2$ of the tensions in these cords? [3]

# For a body in equilibrium, label forces acting on the pole



Three forces have to intercept at the same point such that the perpendicular distance of each force from the interception point is zero and hence produces zero resultant moment.

# For a body in equilibrium, label forces acting on the pole



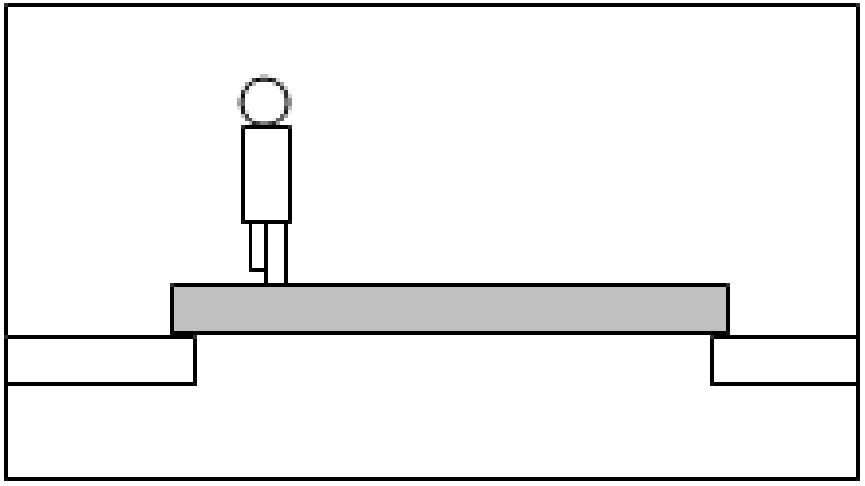
# Problem solving for bodies in equilibrium:

1. Draw free body diagram, identify & show all the forces acting
2. Resolve forces into two perpendicular components
3. Equations when equilibrium is achieved $\sum Fx = 0$ & $\sum Fy = 0$
4. $\sum$ antiCW Moment $=$ $\sum$ CW Moment
5. Three equations are obtained to solve three unknown forces.

# Example 1

A uniform beam of length 5 m and weight 1400 N, resting on supports at each end, carries a man of weight 500 N at a distance of 1 m from one end as shown in the diagram.

Calculate the forces exerted by the beam on the supports.

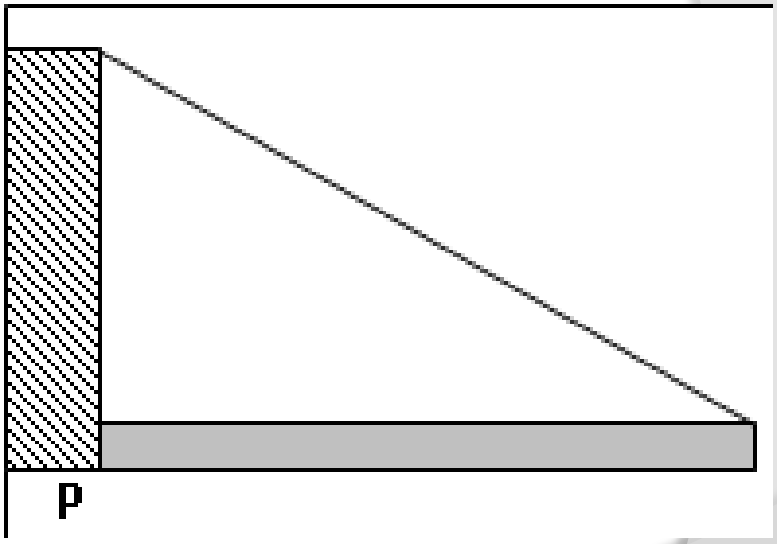


# Example 2

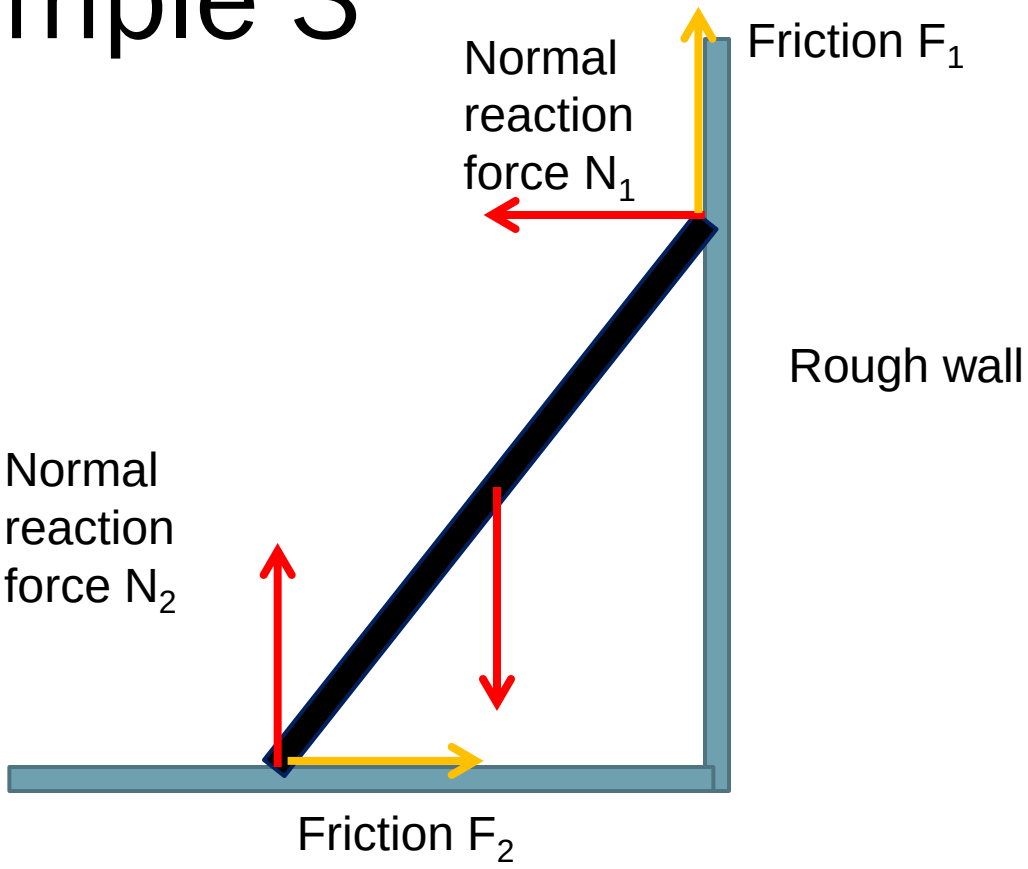
A beam of weight 200 N and length 1 m is hinged at point P. A string of 1.5 m is attached from the end of the beam to the wall.

Calculate:

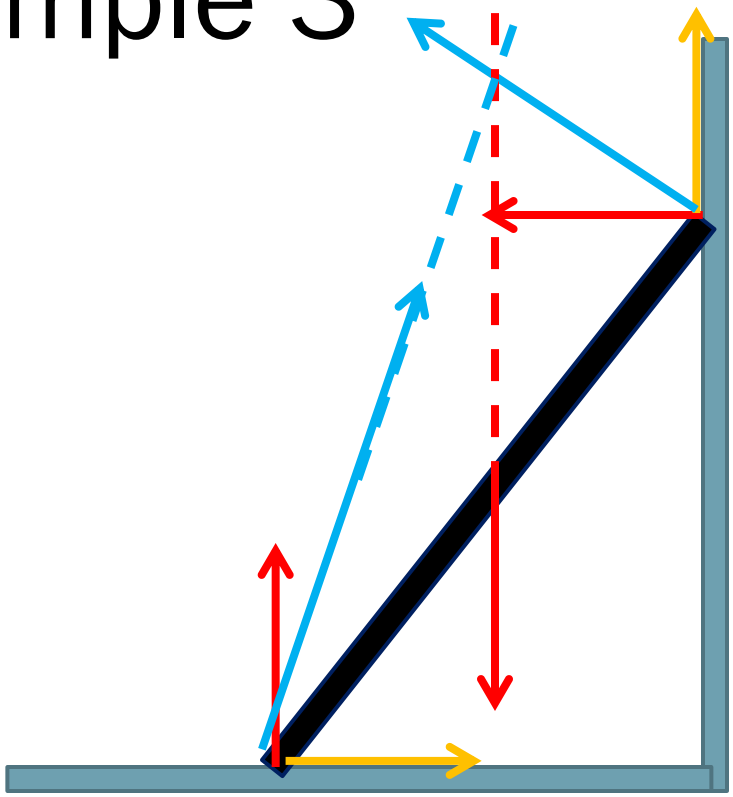
a) the tension on the string
b) the force acting on the hinge



# Example 3


Normal reaction force $N_1$
Friction $F_1$
Rough wall
Normal reaction force $N_2$
Friction $F_2$
Rough floor

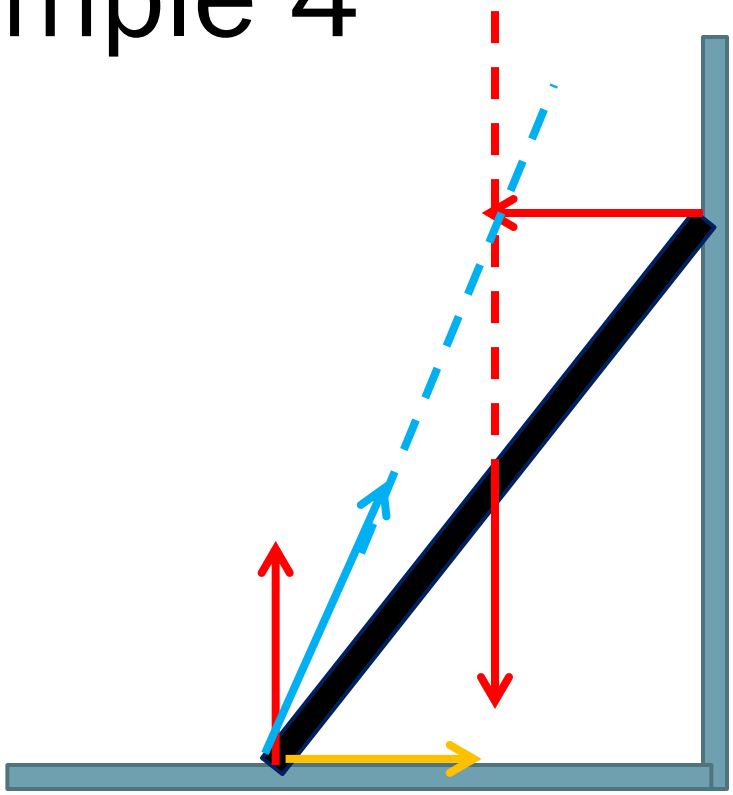
# Example 3



Rough wall

Rough floor

# Example 4



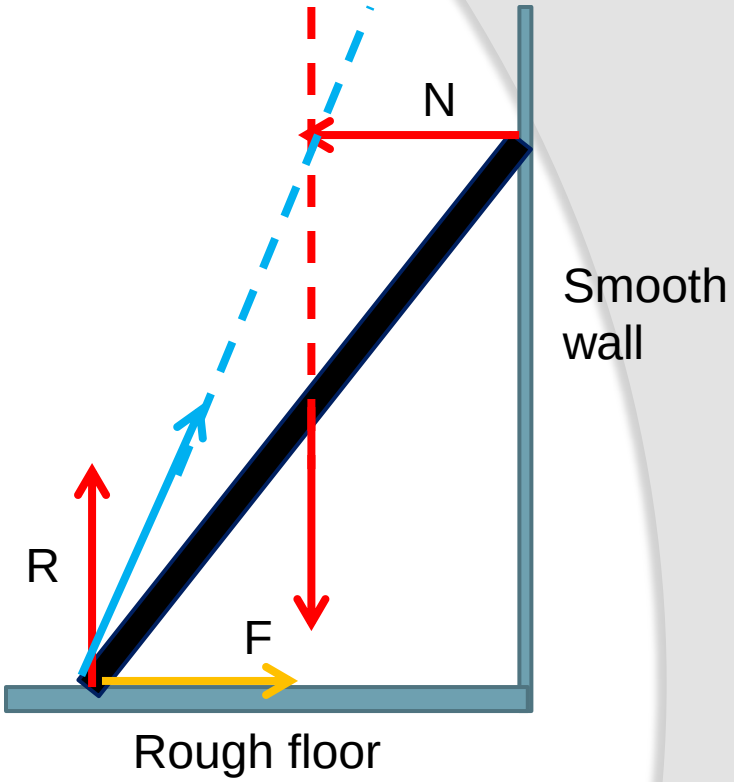
Smooth wall

Rough floor

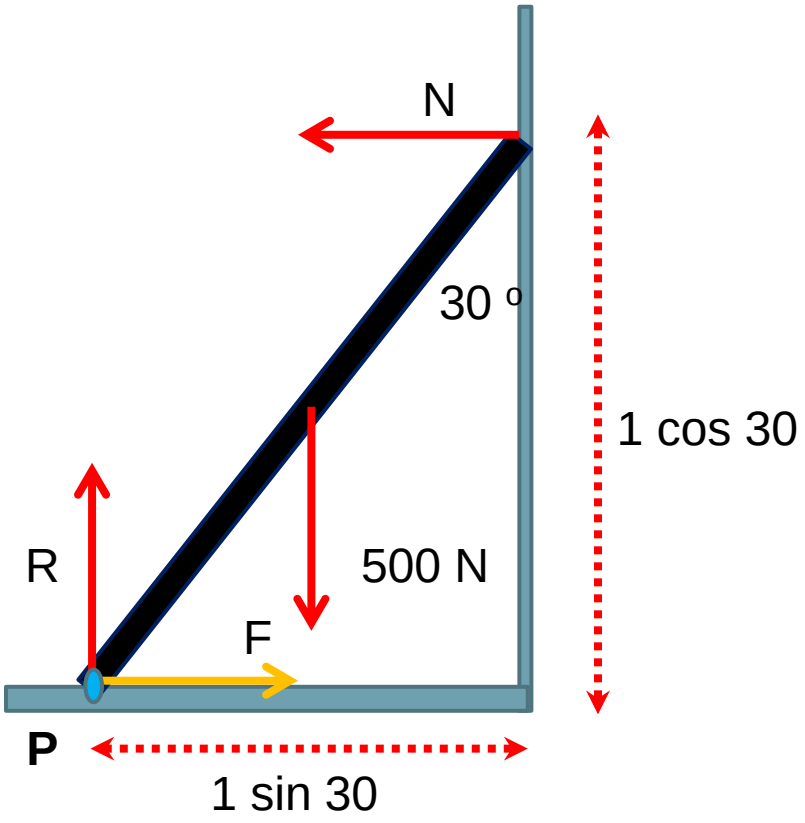
# Example 5

A uniform ladder of weight 500 N and length 1 m is placed on a rough floor, leaning against a smooth wall with an angle of 30$^{o}$ to the vertical.

Calculate the magnitude of the forces acting on the floor and the wall respectively.



# Solution




Choose a point where there are most unknowns, i.e. P

About P,

CW moment by W = ACW moment by N

500 x 1sin30/2 = N1cos30

N = ……

F= N = ……

R = W = ……

the magnitude of the force acting on the wall , N = ……..

the magnitude of the force acting on the wall = ……

# The End