

Science

M3X01513

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Module Aims

- To establish an understanding of engineering units of measurement.
- To establish an understanding of statics in engineering.
- To provide an introduction to electrical science.

Time lines

October – Early December: Lectures, materials required for the January exam (70%) - GO

December – Cohort is split into 4 groups and each group has one 3 hour session on the Thursday afternoon. This will be what the coursework is based upon (30%) - RG

- Units - basic SI units of length, mass and time, area and volume, density and relative density, mass and weight, force, work and power.
- Forces and moments - conditions of static equilibrium, forces and reaction, especially simply supported beams. Moments of a form. Resultant, couples, centre of gravity. Vector rotation. Resolution of forces. Polygon of forces.
- Electrical current/voltage. Mechanical analogies. Resistors in series and parallel. The heating effect of current, variation of resistance with temperature-incandescent lamp. Voltage divider and current divider. Simple circuit calculations, use of Ohm's law and Kirchhoff's laws.

Topic 1:

- SI units
- Derived units

Basic Units

The International System of Units (SI) defines the seven basic units from which all other units are derived.

- metre for length (US English: *meter*)
- kilogram for mass (note: **not** the gram)
- second for time
- ampere for electric current
- kelvin for temperature
- candela for luminous intensity
- mole for the amount of substance.

Metre

Kilogram

Second

Ampere

Basic Units

Units are linked to equations;

The units of speed is **m/s** or $\frac{m}{s}$

The equation for speed is

$$Speed = \frac{distance}{time}$$

Torque = force × distance so again the units are

N x m or Nm

m/s and Nm are called **derived units** because they arise from the basic units.

Derived Units

Given the following equations, calculate the derived units

$$\textit{Area} = \textit{length} \times \textit{width}$$

$$\textit{Volume} = \textit{Area} \times \textit{length}$$

$$\textit{Momentum} = \textit{mass} \times \textit{velocity}$$

$$\textit{Impulse} = \textit{force} \times \textit{time}$$

$$\textit{field strength} = \frac{\textit{force}}{\textit{mass}}$$

$$\textit{Acceleration} = \frac{\textit{speed}}{\textit{time}}$$

Derived Units

These are all derived from the seven basic units.

Examples are:

Square meter	m^2
Cubic meter	m^3
Meter per second	ms^{-1}
Acceleration	ms^{-2}
Density	Kgm^{-3}
Force	N
Work	J
Power	W

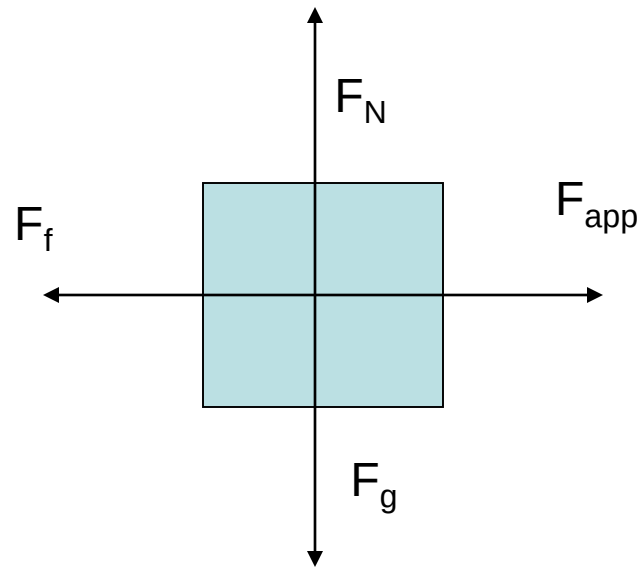
The relationship between these two sets of units is that all derived units are “derived” from basic units.

Topic 2:

- Free body diagrams
- Reaction Forces
- Static Equilibrium

Aim: How can we calculate forces acting on an object?

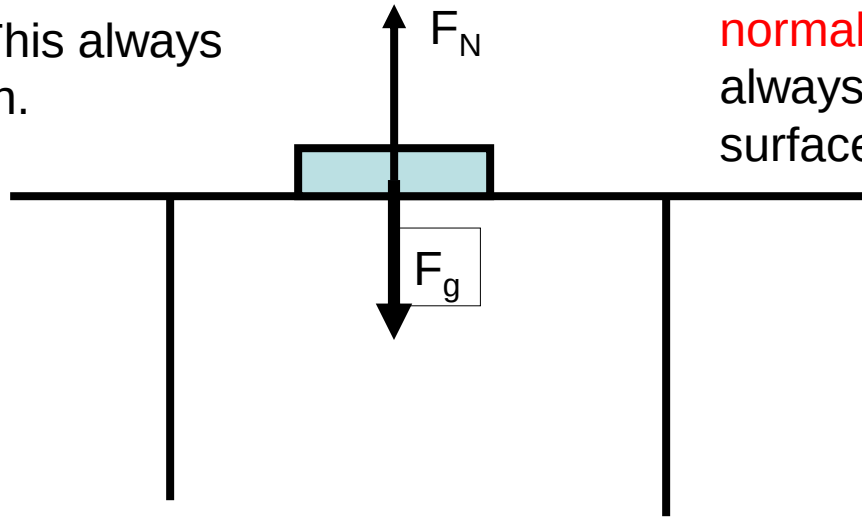
Free-Body diagrams



- Free-body diagrams – is a sketch that shows all of the forces acting on an object.

- A free-body diagram of the forces acting on a text book sitting on a table.

F_g – The force due to gravity: **Weight**. This always acts straight down.



F_N – The force due to the **normal** reaction. This is always perpendicular to the surface.

Rules

- Free body diagrams are usually represented by a simple shape; square or rectangle.
- Arrows that represent forces are drawn from the centre of the object.
- The normal reaction is **always perpendicular** to the surface.
- Weight always acts straight down.
- The force arrows are usually labelled as F and the type of force is indicated by the subscript that follows; eg

F_g – the force due to gravity

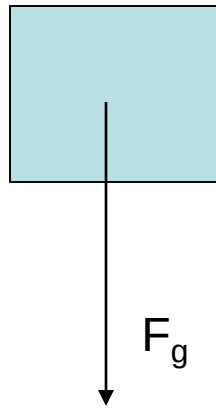
F_N – the force due to the normal reaction

F_T – the force due to tension

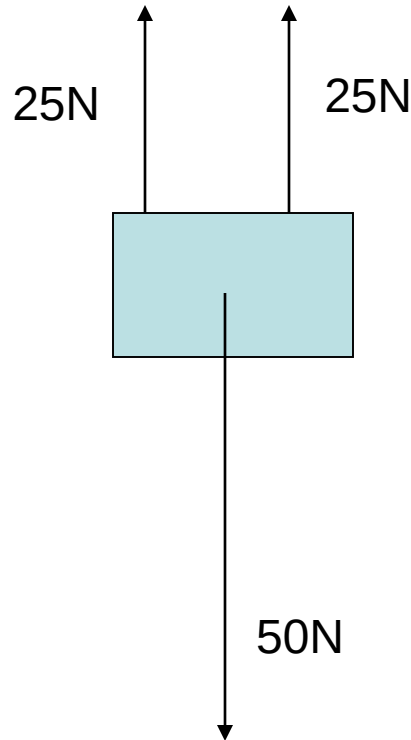
Sketch the following examples

- A 0.1 kilogram egg is free-falling from a nest in a tree. Neglect air resistance.
- A uniform, 50 newton object is suspended motionless from the ceiling by two ropes.
- A rightward force is applied to a book in order to move it across a desk

- A 0.1 kilogram egg is free-falling from a nest in a tree. Neglect air resistance.

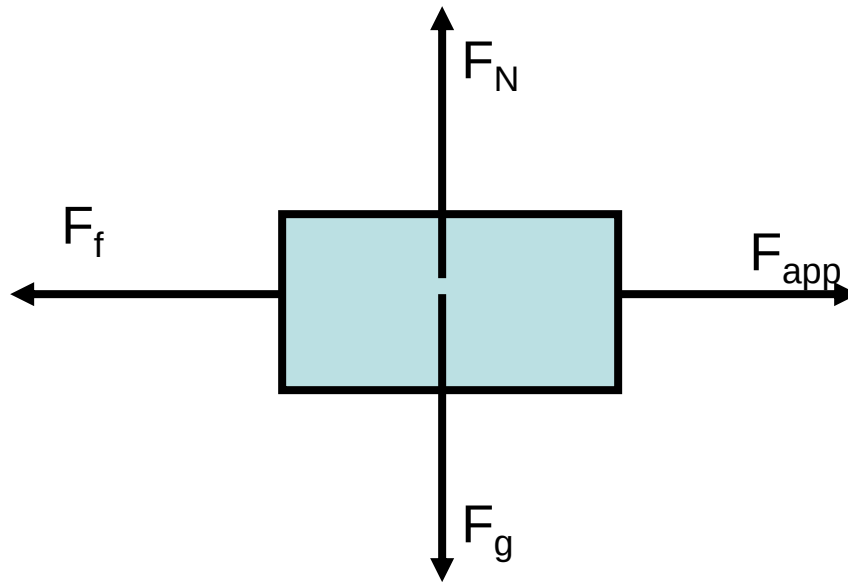


- A 50 newton object is suspended motionless from the ceiling by two ropes.



If the 50N object is **uniform**, what will the value of F_T be?

- A rightward force is applied to a book in order to move it across a desk.



Draw the free body diagrams for the following:

- A football that has been kicked so that it is moving diagonally upwards
- A car being driven around a circular part of a race track
- Tug of war
- A submarine travelling at a constant depth
- A box being pushed up a rough surface
- A box resting on a rough inclined slope

Vectors and Scalars

All physical quantities (e.g. speed and force) are described by a magnitude and a unit.

VECTORS – also need to have their direction specified
examples: displacement, velocity, acceleration, force.

SCALARS – do not have a direction
examples: distance, speed, mass, work, energy.

Representing Vectors

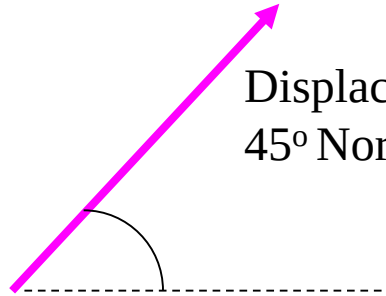
An arrowed straight line is used.

The arrow indicates the direction and the length of the line is proportional to the magnitude.

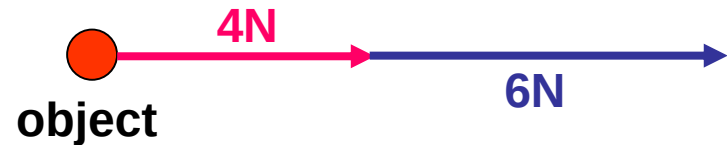
Displacement 50m EAST



Displacement 25m at
45° North of East

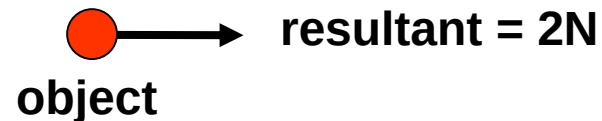
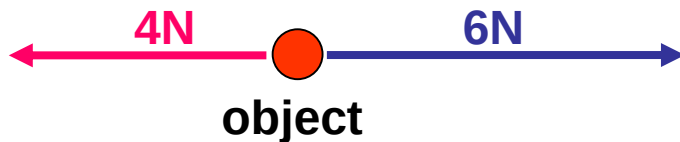


Addition of vectors 1



The original vectors are called **COMPONENT** vectors.

The final overall vector is called the **RESULTANT** vector.



Addition of vectors 2

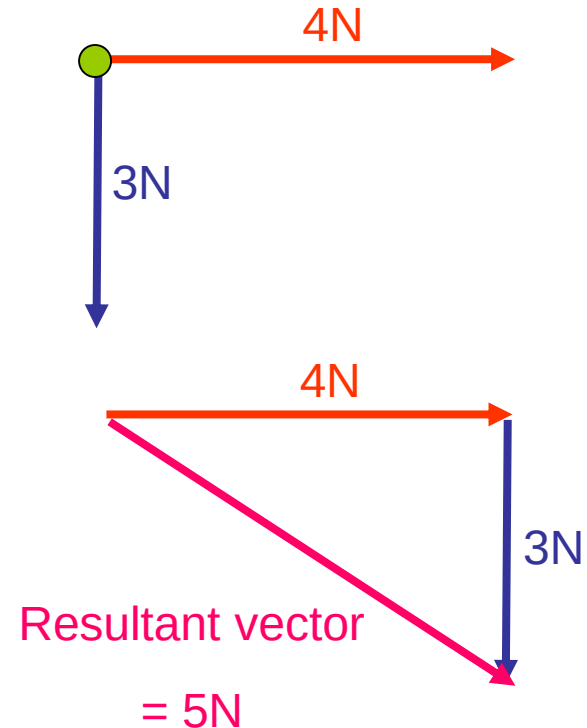
With two vectors acting at an angle to each other:

Draw the first vector.

Draw the second vector with its tail end on the arrow of the first vector.

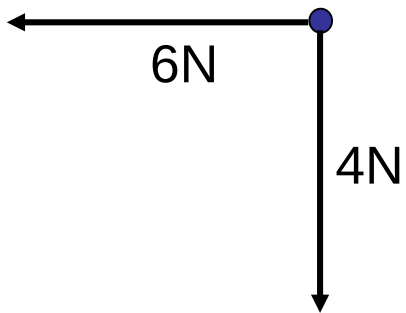
The resultant vector is the line drawn from the tail of the first vector to the arrow end of the second vector.

This method also works with three or more vectors.

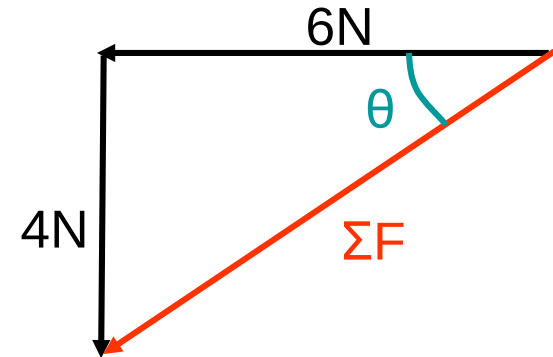


Question

Find the resultant force acting on an object in the situation below. You should also determine the direction of this force.



Scale drawing:



Calculation:

Pythagoras:

$$\Sigma F^2 = 6^2 + 4^2 = 36 + 16 = 52$$

$$\Sigma F^2 = 52$$

$$\Sigma F = 7.21 \text{ N}$$

$$\tan \theta = 4 / 6 = 0.6667$$

$$\theta = 33.7^\circ$$

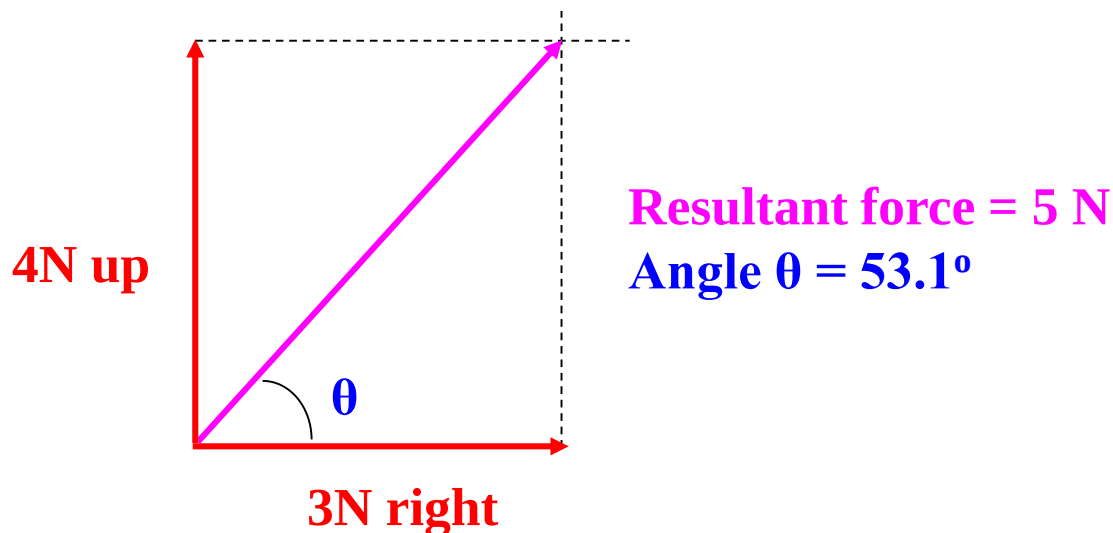
The resultant force is 7.21 N to the left 33.7 degrees below the horizontal (bearing 236.3°)

The parallelogram of vectors

This is another way of adding up two vectors.

To add TWO vectors draw both of them with their tail ends connected. Complete the parallelogram made using the two vectors as two of the sides. The resultant vector is represented by the diagonal drawn from the two tail ends of the component vectors.

Example: Calculate the total force on an object if it experiences a force of 4N upwards and a 3N force to the left.



Resolution of vectors

It is often convenient to split a single vector into two perpendicular components.

Consider force F being split into vertical and horizontal components, F_V and F_H .

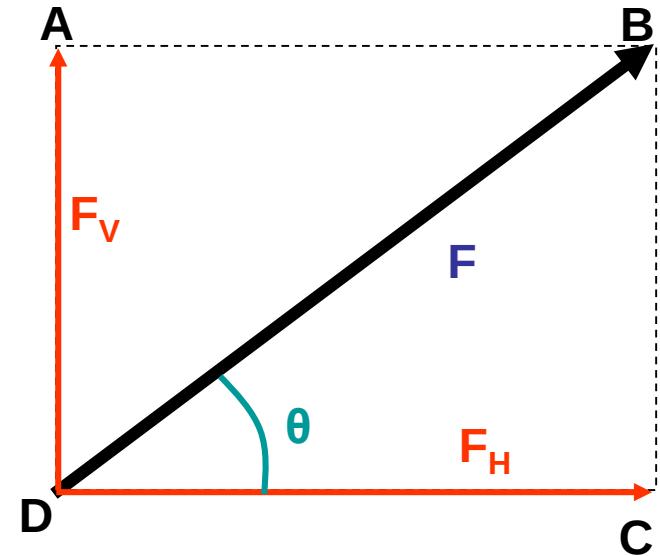
In rectangle ABCD opposite:

$$\sin \theta = BC / DB = DA / DB = F_V / F$$

Therefore: $F_V = F \sin \theta$

$$\cos \theta = DC / DB = F_H / F$$

Therefore: $F_H = F \cos \theta$



$$F_V = F \sin \theta$$

$$F_H = F \cos \theta$$

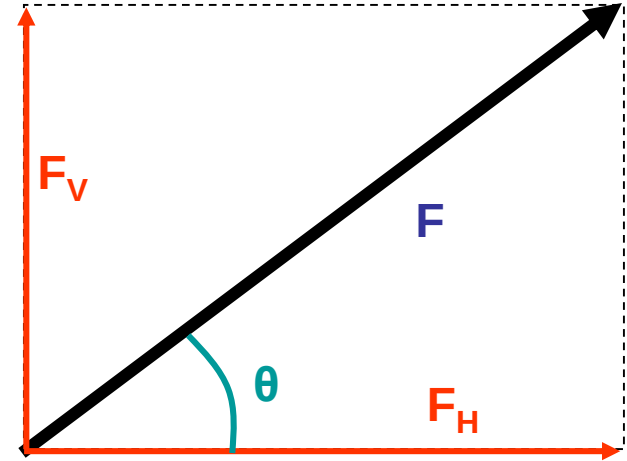
The 'cos' component is always the one next to the angle.

Question

Calculate the vertical and horizontal components if $F = 4\text{N}$ and $\theta = 35^\circ$.

$$\begin{aligned}F_V &= F \sin \theta \\&= 4 \times \sin 35^\circ \\&= 4 \times 0.5736 \\F_V &= 2.29 \text{ N}\end{aligned}$$

$$\begin{aligned}F_H &= F \cos \theta \\&= 4 \times \cos 35^\circ \\&= 4 \times 0.8192 \\F_H &= 3.28 \text{ N}\end{aligned}$$



Worksheet 1

Inclined planes

Components need not be vertical and horizontal.

In the example opposite the weight of the block W has components parallel, F_1 and perpendicular F_2 to the inclined plane .

Calculate these components if the block's weight is 250N and the angle of the plane 20° .

F_2 is the component next to the angle and is therefore the cosine component.

$$F_2 = W \cos \theta$$

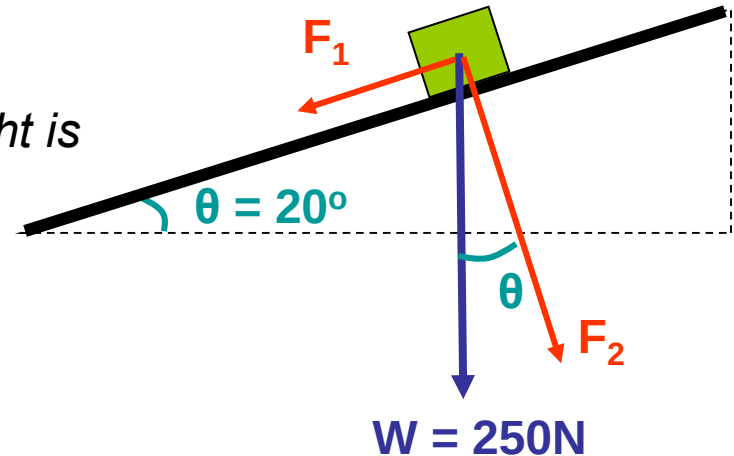
$$= 250 \times \cos 20^\circ = 250 \times 0.9397$$

$$F_2 = \text{component perpendicular to the plane} \\ = 235 \text{ N}$$

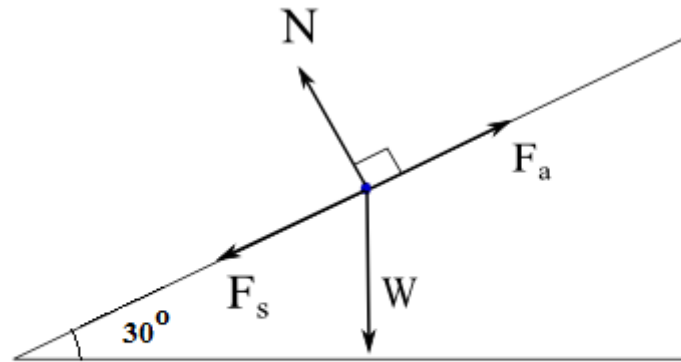
$$F_1 = W \sin \theta$$

$$= 250 \times \sin 20^\circ = 250 \times 0.3420$$

$$F_1 = \text{component parallel to the plane} \\ = 85.5 \text{ N}$$

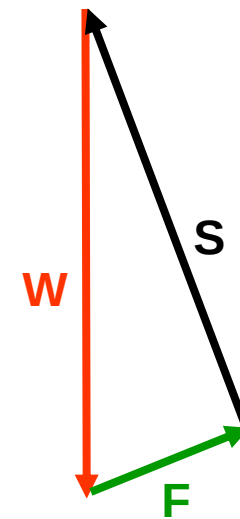
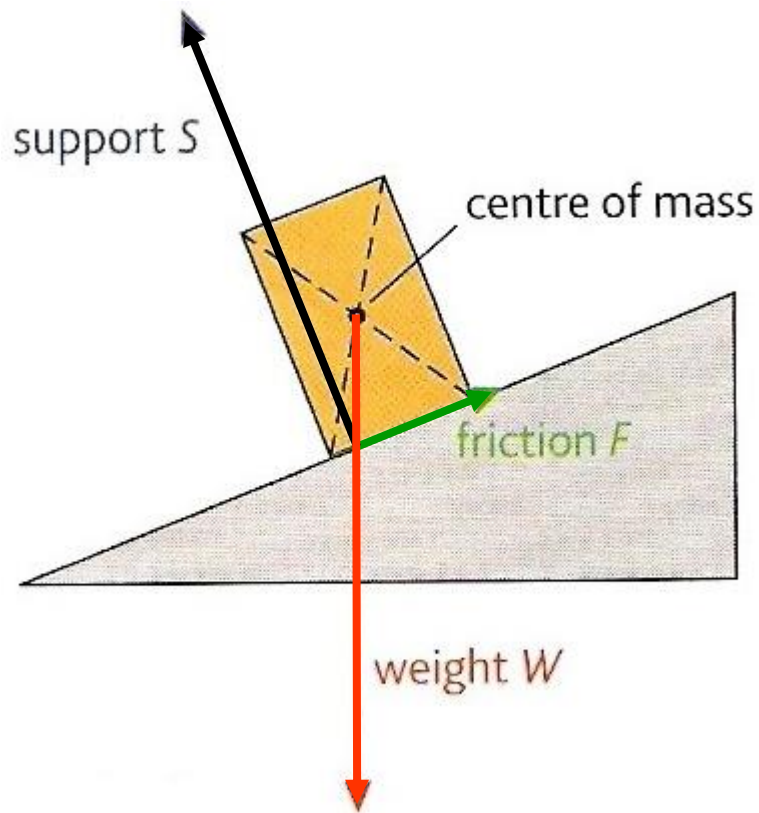


Inclined Plane Example



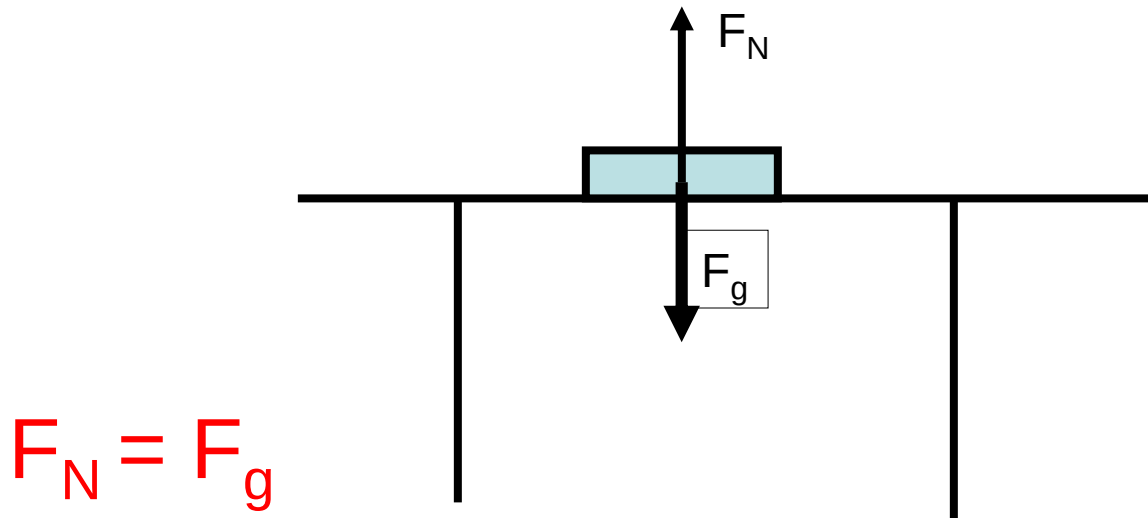
Equilibrium with three forces

Three forces acting on a body in equilibrium will form a closed triangle.



Triangle of forces

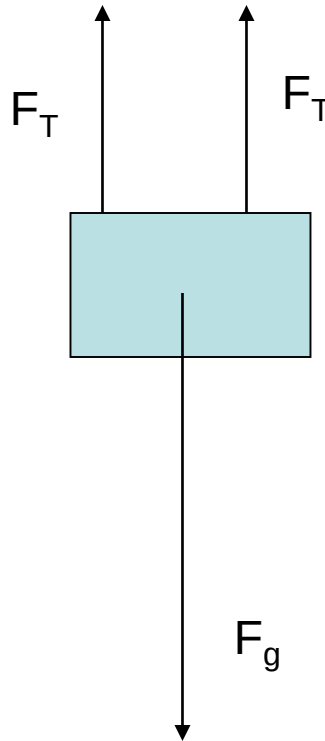
Equilibrium of Forces Example



$$F_N = F_g$$

This object is in equilibrium. We know this as it is not accelerating up or down. Therefore, we can say that the forces up equal the forces down so the **RESULTANT FORCE = 0**

Equilibrium of Forces Example



$$F_g = F_T + F_T$$

$$F_g = 2F_T$$

This object is in equilibrium. We know this as it is not accelerating up or down. Therefore, we can say that the forces up equal the forces down so the **RESULTANT FORCE = 0**

Worksheet 3

Equilibrium

When a body is in equilibrium it will
EITHER be at rest
OR move with a constant linear and
rotational velocity.

Conditions required for equilibrium:

1. The resultant force acting on the body must be zero.
2. The principle of moments must apply about any point on the body.

The moment of a force

Also known as the **turning effect** of a force.

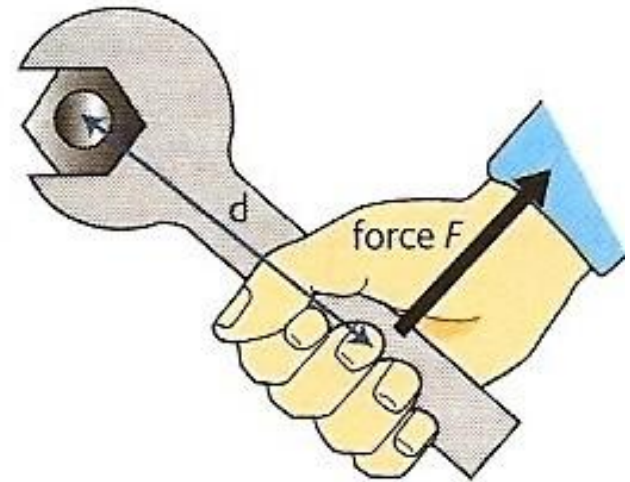
The moment of a force about any point is defined as:

**force x perpendicular distance
from the turning point to the
line of action of the force**

$$\text{moment} = F \times d$$

Unit: **newton-metre (Nm)**

Moments can be either **CLOCKWISE** or **ANTICLOCKWISE**



Force F exerting an
ANTICLOCKWISE
moment through the
spanner on the nut

Question

Calculate the moments of the 25N and 40N forces on the door in the diagram opposite.

moment = $F \times d$

For the 25N force:

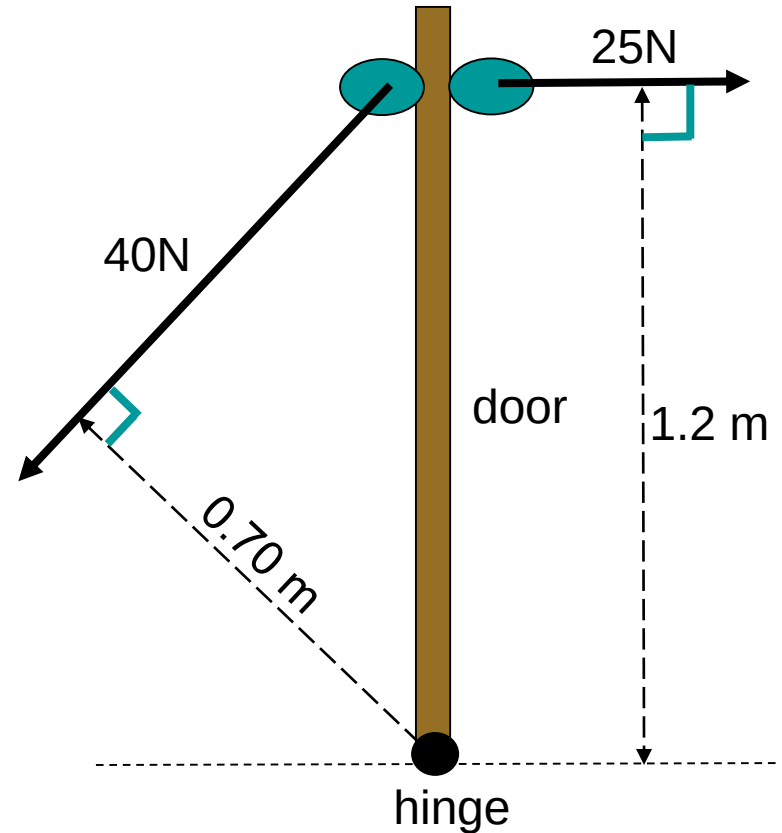
moment = $25\text{N} \times 1.2\text{m}$

= 30 Nm CLOCKWISE

For the 40N force:

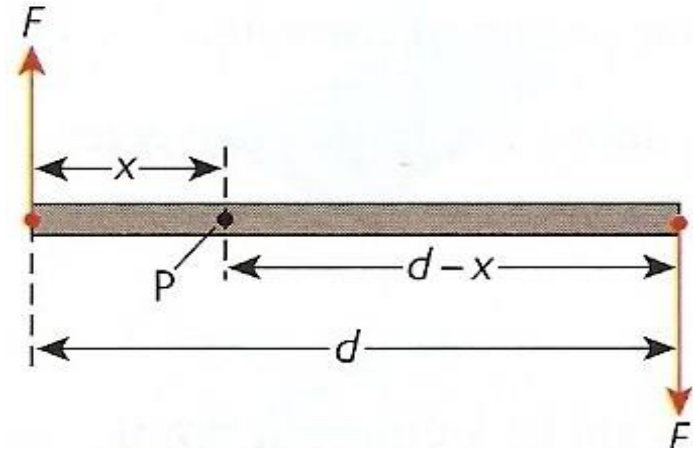
moment = $40\text{N} \times 0.70\text{m}$

= 28 Nm ANTICLOCKWISE



Couples and Torque

A couple is a pair of equal and opposite forces acting on a body, but not along the same line.



In the diagram above:

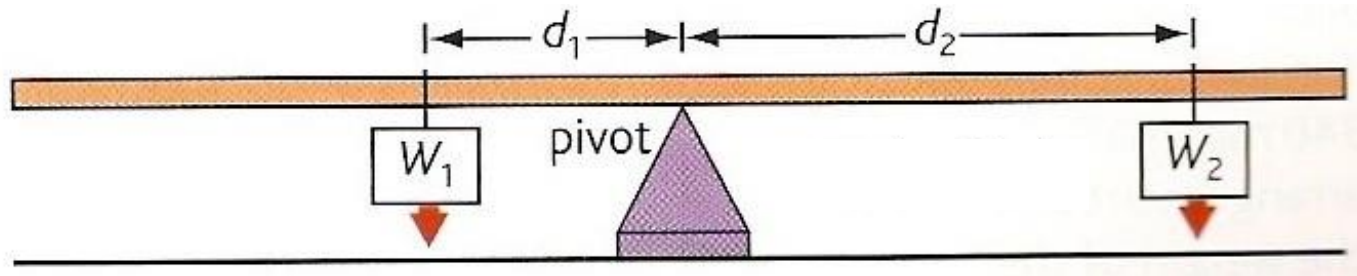
total moment of couple $= F x + F(d - x) = F d$
= One of the forces $\times$ the distance between the forces

Torque is another name for the total moment of a couple.

The principle of moments

When an object is in equilibrium (e.g. balanced):

the sum of the anticlockwise moments = the sum of the clockwise moments

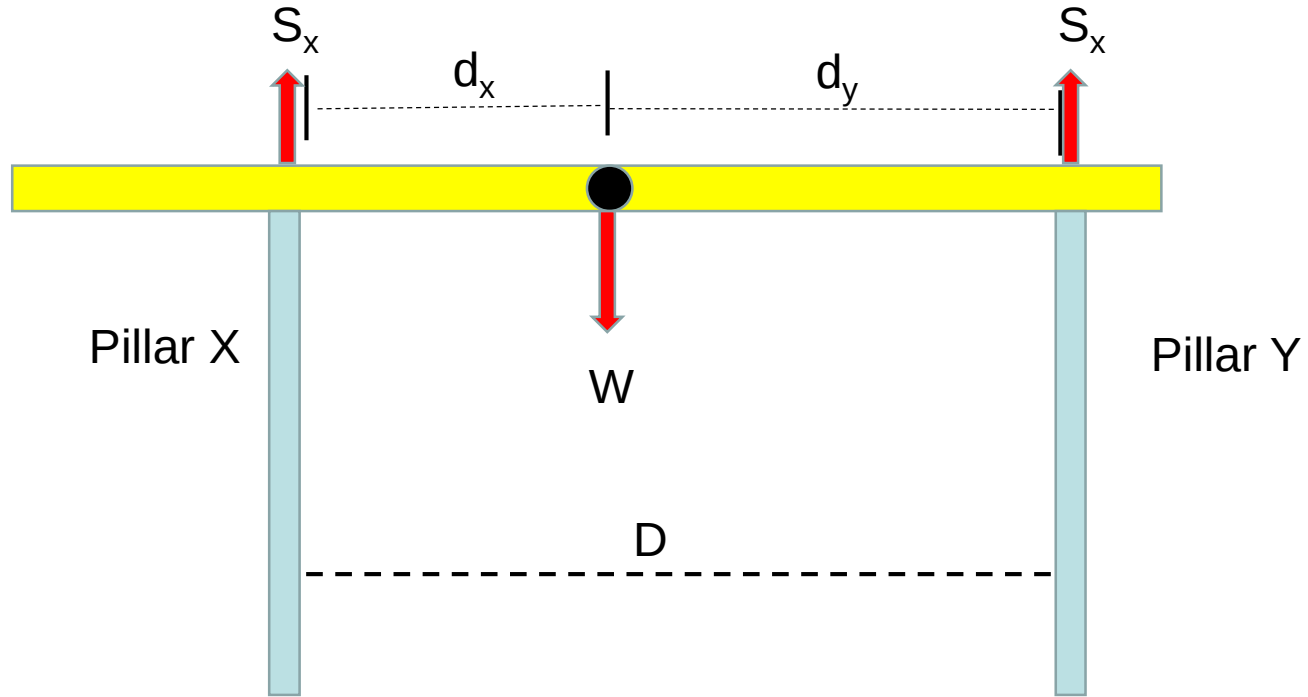


If the ruler above is in equilibrium:

$$W_1 d_1 = W_2 d_2$$

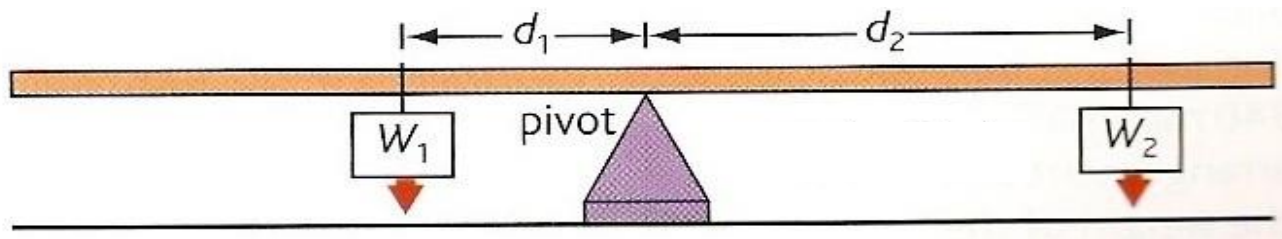
Worksheet 4

The principle of moments



Complete for a ruler in equilibrium:

W_1	d_1	W_2	d_2
5 N	20 cm	10 N	
4 N	15 cm		10 cm
6 N		2 N	36 cm
	25 cm	2 N	100 cm



Worksheet 5

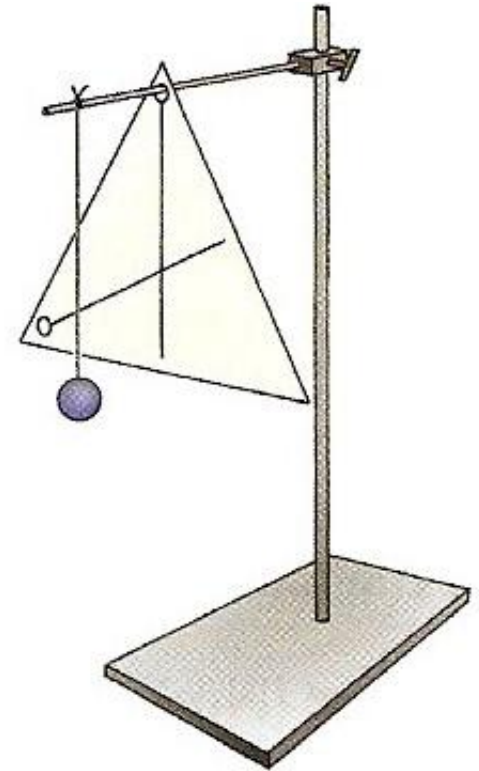
Centre of mass

The centre of mass of a body is the point through which a single force on the body has no turning effect.

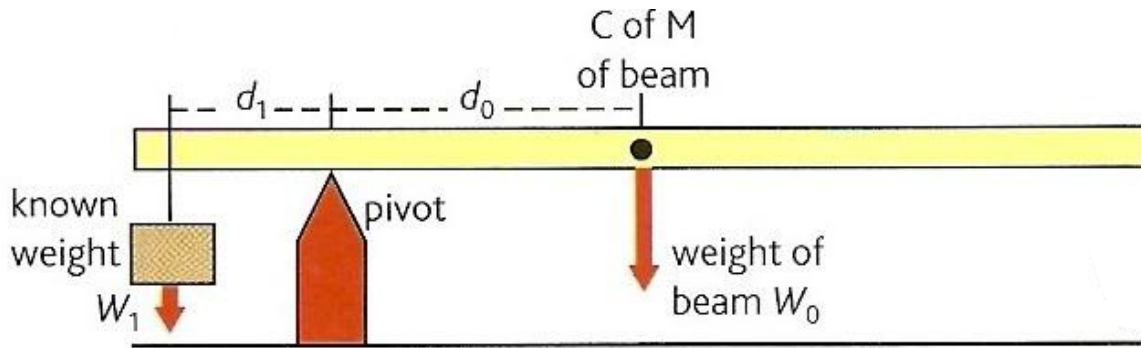
The centre of mass is also the place through which all the weight of a body can be considered to act.

The 'single force' in the definition could be a supporting contact force. e.g. from a finger below a metre ruler.

The diagram opposite shows the method for finding the centre of mass of a piece of card.



Question



Calculate the weight of the beam, W_0 if it is in equilibrium when:

$$W_1 = 6\text{N};$$

$$d_1 = 12\text{ cm};$$

$$d_0 = 36\text{ cm}.$$

Applying the principle of moments:

$$W_1 d_1 = W_0 d_0$$

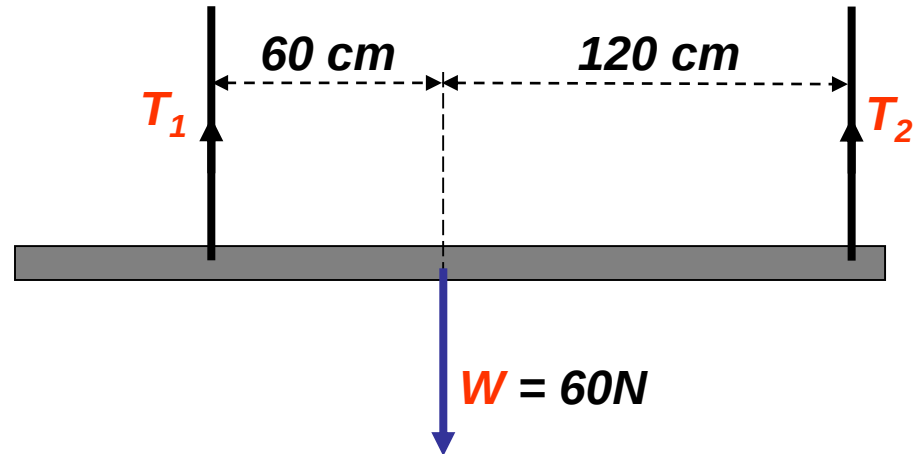
$$6\text{N} \times 12\text{ cm} = W_0 \times 36\text{ cm}$$

$$W_0 = 72 / 36$$

$$W_0 \text{ the weight of the beam} = 2\text{N}$$

Question 1

The rod shown opposite is held horizontal by two wires. If the weight of the rod is 60N calculate the values of the tension forces in the wires



If the rod is in equilibrium:

1. Resultant force = zero

Therefore:

$$W = T_1 + T_2 = 60\text{N}$$

2. Principle of moments applies about any point.

Let the point of contact of T_1 be the pivot.

total clockwise moments = total anticlockwise moments

$$60\text{N} \times 60\text{ cm} = T_2 \times 180\text{ cm}$$

$$T_2 = 3600 / 180$$

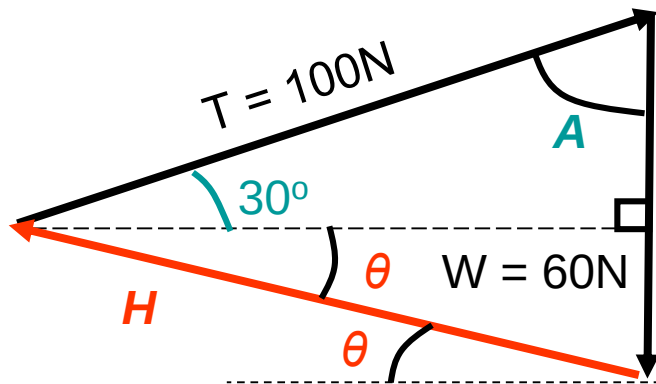
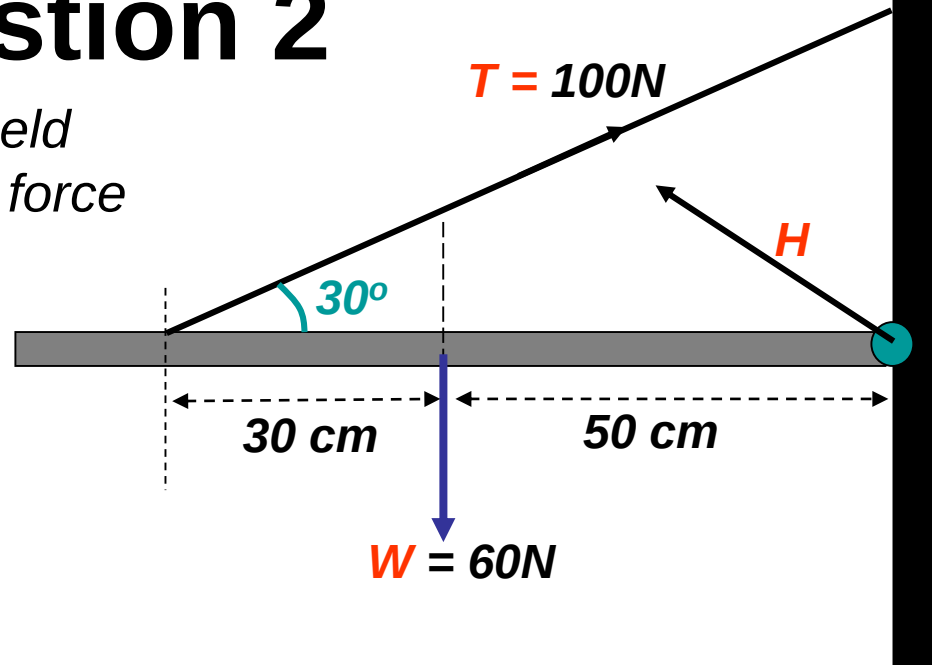
$$T_2 = 20\text{ N}$$

$$\text{and so } T_1 = 40\text{ N}$$

Question 2

The hinged rod shown opposite is held horizontal by a single wire. Find the force exerted by the hinge.

If the rod is in equilibrium then the three forces acting, W , T & H will form a closed triangle.



By scale drawing:

$$H = 87 \text{ N}$$

$$\theta = 7^\circ$$

By calculation !!!:

Angle $A = 60^\circ$ (angles in a triangle)

Applying the cosine rule: $H^2 = T^2 + W^2 - 2TW \cos A$

$$= 100^2 + 60^2 - 2(100 \times 60) \times \cos 60^\circ$$

$$= 10000 + 3600 - (12000 \times 0.5) = 7600$$

$$H = 87.2 \text{ N}$$

Applying the sine rule: $H / \sin A = W / \sin (\theta + 30)$

$$87.2 / \sin 60 = 60 / \sin (\theta + 30)$$

$$87.2 / 0.866 = 60 / \sin (\theta + 30)$$

$$100.7 = 60 / \sin (\theta + 30)$$

$$\sin (\theta + 30) = 60 / 100.7 = 0.596$$

$$\theta + 30 = 36.6^\circ$$

$$\theta = 6.6^\circ$$