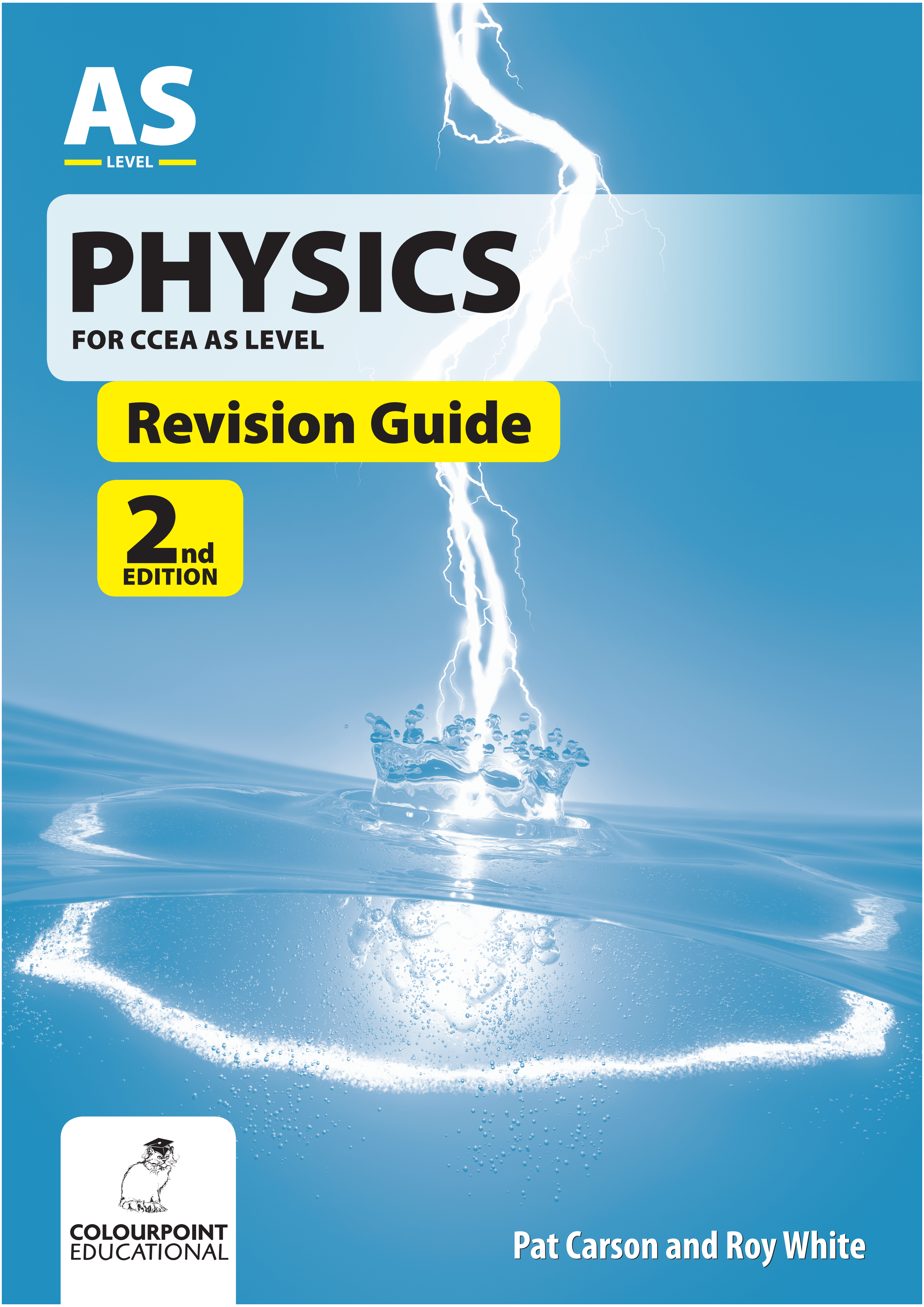
AS LEVEL

PHYSICS

FOR CCEA AS LEVEL

Revision Guide

2nd EDITION



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Contents

Unit AS 1:

Forces, Energy and Electricity

1.1 Physical Quantities

Students should be able to:

1.1.1 describe all physical quantities as consisting of a numerical magnitude and unit;

1.1.2 state the base units of mass, length, time, current, temperature, and amount of substance and be able to express other quantities in terms of these units;

1.1.3 recall and use the prefixes T, G, M, k, c, m, μ, n, p and f, and present these in standard form;

Physical Quantities

To describe a physical quantity we first define a characteristic unit. To state a measurement of a physical quantity, such as force, we need to state two things:

1. A **magnitude** (a numerical value) and
2. A **unit**.

International System of Units (SI units)

The SI system of units defines seven base quantities from which all other units are derived. The table below shows the **six base quantities and the units in which they are measured**.

Quantity	Unit	Symbol
mass	kilogram	kg
time	second	s
length	metre	m
electric current	ampere	A
temperature	kelvin	K
amount of substance	mole	mol

Multiples and submultiples of these base units are commonly used:

Prefix	Factor	Symbol
femto	10^{-15}	f
pico	10^{-12}	p
nano	10^{-9}	n
micro	10^{-6}	μ
milli	10^{-3}	m
centi	10^{-2}	c
kilo	10^{3}	k
Mega	10^{6}	M
Giga	10^{9}	G
Tera	10^{12}	T

Derived Units

Many SI units are **derived**. They are defined in terms of two or more base units. For example velocity, in metres per second, which is written as m s^{-1}. You must be able to write a physical quantity in terms of its base units. Note that a linear format should be used to express (base) units, i.e. there should be no solidus (slash) in the units. For example, metres per second should be written as m s^{-1} and not as m/s. (CCEA GCE Physics Summer Series 2016 Chief Examiner's Report).

Worked Example

The derived unit for energy is the joule. What are the base units of energy?

To calculate the base units for energy we can use any valid formula for energy such as that below for kinetic energy, E_k:

E_k = ½mv^2 (the ½ being a number has no units)

unit for energy = unit for mass × unit for velocity × unit for velocity

= kg × m s^{-1} × m s^{-1}

= kg m^2 s^{-2} which gives the joule **in terms of base units only**.

Significant Figures

The number of **significant figures** (s.f.) in a number is found by counting all the digits from the first **non-zero** digit on the left. A zero between two non-zero digits **is** significant.

For example 12.35 has four significant figures, because we start counting from the 1 which is the first non-zero digit on the left. The number 0.0516 has three significant figures, counting from the 5 which is the first non-zero digit on the left. The leading zeroes are essential to give the magnitude of the number. The value of π to six significant figures is 3.14159.

When you have to perform calculations on a set of measurements then the result should be given to the same number of **significant figures** as the initial values. For example, $3.25^2 = 10.5625$, but this should be quoted as 10.6.

Rounding

Rounding involves reducing the number of significant digits in a number. The result of rounding is a number having fewer non-zero digits, yet be similar in magnitude. The result is less precise but easier to use. For example, 9.51356 rounded to two significant figures is 9.5.

The procedure for rounding is:

- Decide how many significant figures you want. In the example of 9.51356 given above, this is two.
- Decide which is the last digit to keep, in this case the 5.
- Increase it by 1 if the next digit is 5 or more (this is called rounding up).
- Leave it the same if the next digit is 4 or less (this is called rounding down).

Variations in the final answer based on the rounding of intermediate values will **not** cost a candidate marks (CCEA GCE Physics Summer Series 2016 Chief Examiner's Report).

Exercise 1

1. (a) The SI unit of force is the newton. Express the newton in SI base units.

   (b) The SI unit of pressure is the pascal. Pressure is defined as Force ÷ Area. Express the pascal in SI base units.

   (c) Momentum is defined as mass × velocity. What are SI base units of momentum?

2. The magnitude of a physical quantity is quoted in the following way 5.5 kJ ms^{-1}.

   (a) Explain the meaning of each prefix.

   (b) What physical quantity is being quoted in this way?

   (c) What are the SI base units of this physical quantity?

3. The energy, E, of a photon of wavelength, λ, is given by the equation $E = hc \div \lambda$,

   where c is the speed of light. Find the SI base units in which h is measured.

4. All physical quantities consist of a magnitude and a unit. Express each of the physical quantities below in the unit indicated.

   (a) 23.1 cm in m

   (b) 25 km hr^{-1} in m s^{-1}

   (c) 3.5 MJ in kJ

1.2 Scalars and Vectors

Students should be able to:

1.2.1 distinguish between and give examples of scalar and vector quantity;

1.2.2 resolve a vector into two perpendicular components;

1.2.3 calculate the resultant of two coplanar vectors by calculation or scale drawing, with calculations limited to two perpendicular vectors;

1.2.4 solve problems that include two or three coplanar forces acting at a point, in the context of equilibrium;

Distinguishing Scalars and Vectors

A **vector** is a physical quantity that needs magnitude, a **unit** and a **direction**.

A **scalar** is a physical quantity that requires only magnitude and a unit.

Here is a table of some of the more common vectors and scalars:

Vector	Scalar
Displacement	Distance
Velocity	Speed
Acceleration	Rate of change of speed
Force	Mass
Momentum	Electric charge
	Kinetic energy
	Temperature
	Area
	Volume
	Time
	Electric Current*

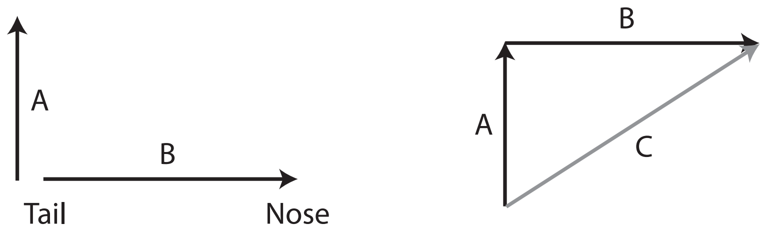
* In addition to having magnitude, direction and a unit, vectors are combined vectorially, for example as the parallelogram of forces. However, electric currents are combined algebraically and so are considered scalar quantities. For example, consider two currents entering a junction: the current leaving is the algebraic sum of the two.

Combining Coplanar Vectors

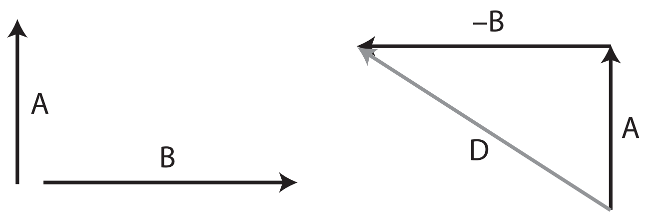
When we add vectors we have to take into account their direction as well as their magnitude. When we add two or more vectors, the final vector is called the **resultant**. For two forces of 15 N and 10 N acting in the **same direction**, the resultant is 25 N. For two forces of 15 N and 10 N acting in opposite directions, the resultant is 5 N in the direction of the larger force.

Adding and Subtracting Vectors

If the vectors are not in a straight line then we use the **nose to tail** method to find the resultant. In the diagram below the resultant of the two vectors, A and B, is C. **C = A + B**



The resultant of subtracting the vector B from A is another vector D. The vector **–B** is a vector of the **same magnitude as B** but in the **opposite direction**. Effectively we add the negative vector so **D = A + (–B)**



By drawing the vectors to scale and adding them in pairs we can find the resultant of any number of vectors, provided we know their magnitude and direction. This method can be used even if the vectors are not at right angles.

Worked Example

Look at the diagram. Linda moved 3.0 m to the east (AB) and then 4.0 m to the north (BC). Find the magnitude and direction of the resultant.

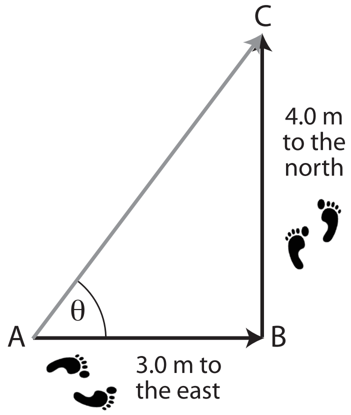
$AC^2 = AB^2 + BC^2 = 3^2 + 4^2 = 25$

$AC = \sqrt{25} = 5.0$

Although she has moved a total distance of 7.0 m, her displacement is **5.0 m** (AC) from the start. Since displacement is a vector, a magnitude and a direction are both needed.

$\tan\theta$ = opposite ÷ adjacent = 4.0 ÷ 3.0 = 1.33

giving **θ = 53°** (to 2 s.f., same as the initial values).

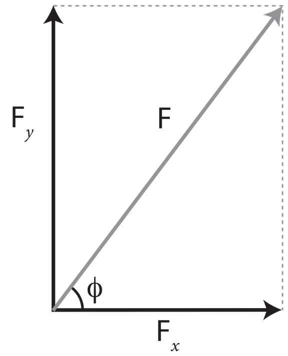


Components of a Vector

It is often useful to split or **resolve** a vector into two parts or components. The diagram shows a vector F that has been resolved into two components that are at right angles to each other.

$\sin\phi$ = opp ÷ hyp = F_y ÷ F so, $\mathbf{F_y = F \sin\phi}$

$\cos\phi$ = adj ÷ hyp = F_x ÷ F so, $\mathbf{F_x = F \cos\phi}$



The Inclined Plane

Consider a mass, *m*, on a plane inclined at angle θ to the horizontal. Its weight, *mg*, acts vertically downwards as in Diagram A. The component of the weight parallel to the plane is *mg* sin θ as in Diagram B. The normal reaction to the plane is equal to the component of the weight perpendicular to the plane ($N = mg\cos\theta$) as in Diagram C.

Diagram A

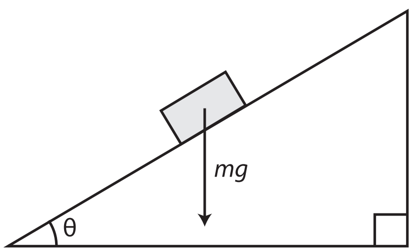


Diagram B

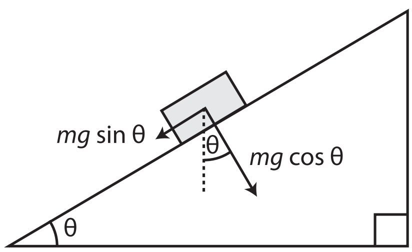
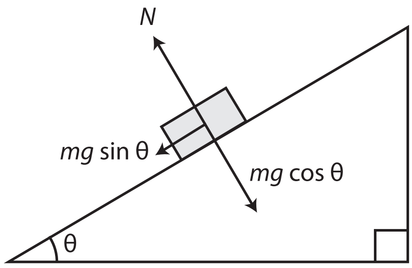


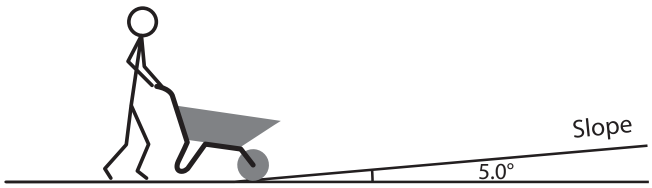
Diagram C



Worked Example

A man, pushing a wheelbarrow and load of total mass 22 kg, approaches a slope inclined at 5.0° to the horizontal, as shown in the diagram. Calculate the total force the man must exert on the wheelbarrow and its contents to move it up the slope at a constant speed of 1.5 m s⁻¹. The frictional force is constant at 12 N.

(CCEA January 2009, amended)



The constant speed means there is no resultant force. Both friction and the component of the weight parallel to the plane act down the slope. The man must therefore exert a force of equal size up the slope.

Force required = Friction + Component of weight parallel to plane

= 12 + 22 × 9.81 × sin 5° = 31 N (to 2 s.f., same as the initial values)

Equilibrium of Forces

If the resultant force on an object is zero then it is in **translational equilibrium.** Consider the worked example below.

Worked Example

Two tugs are used to rescue a small ship which has lost engine power and is close to some rocks. The tugs just manage to hold the ship stationary against a current producing a force of 250 kN on the ship. Tug A develops a force of 200 kN in the direction shown on the diagram. Find the magnitude and direction θ of the force F developed by tug B if the three forces acting on the ship are in equilibrium. (CCEA legacy June 2009, amended)

Since the forces are in equilibrium the vertical components of the forces balance and the horizontal components also balance.

Vertical: $\mathbf{F \sin \theta}$ = 200 sin 35 = 115 kN

Horizontal: $F \cos \theta$ + 200 cos 35 = 250 kN

so $\mathbf{F \cos \theta}$ = 86 kN

Remembering that sin ÷ cos = tan, we can divide the equations in bold type to give:

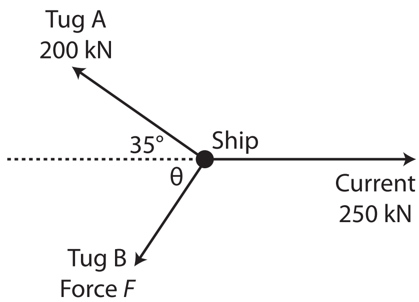
$\tan \theta = 115 \div 86$

so $\theta = \tan^{-1}(115 \div 86) = 53°$

Substituting for θ gives:

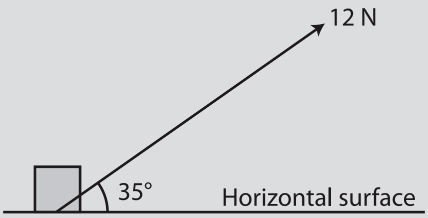
$F = 86 \div \cos 53° = 143$ kN

So, F = 143 kN at 53° to the horizontal.

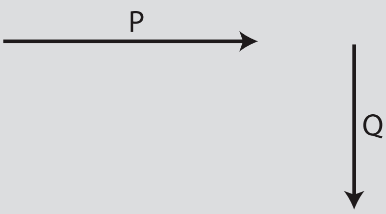


Exercise 2

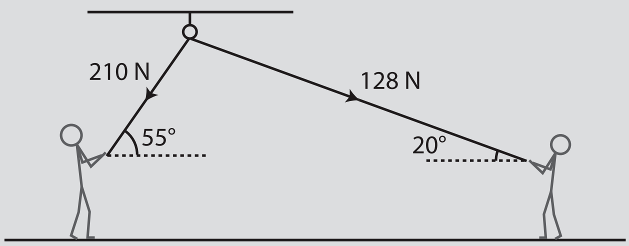
1. The following is a list of physical quantities:
   Work, Distance, Power, Displacement, Speed, Velocity.
   (a) Underline those that are vectors.
   (b) State the difference between a vector and a scalar.
   (CCEA January 2010 amended)
2. The diagram shows a force of 12 N acting on a brick resting on a horizontal surface. Calculate the resultant horizontal force acting on the brick.
   (CCEA January 2011 amended)



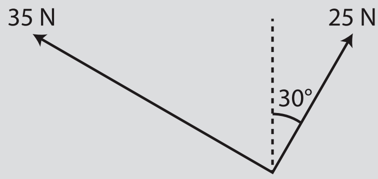
3. The diagram shows two vectors P and Q. Sketch the constructions necessary to obtain the vectors A and B, where A = 2P + 3Q and B = P – 2Q.



4. The diagram shows two children playing by pulling on a rope connected through a smooth hook on a beam. Child A pulls with a force of 210 N at an angle of 55° from the horizontal.
   (a) Calculate the vertical component of the force with which child A is pulling.
   When child B pulls on the rope with a force of 128 N at 20° above the horizontal, the rope does not move.
   (b) What condition must be met for this to happen?
   (c) Confirm, by calculation, that the forces given satisfy this condition.
   (CCEA January 2010 amended)



5. Two forces act at right angles to each other as shown. Calculate the resultant force and its direction relative to the vertical.



1.3 Principle of Moments

Students should be able to:

1.3.1 define the moment of a force about a point;

1.3.2 use the concept of centre of gravity; and

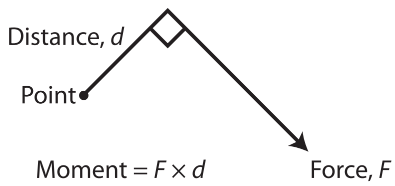
1.3.3 recall and use the principle of moments;

Moment of a Force

The moment of a force about a point is defined as the product of the force and the perpendicular distance from the point to the line-of-action of the force.

Moment = Force × Perpendicular distance from the point to force

The force is measured in N and the distance in m. Moments are measured in newton–metres, written as N m. The direction of a moment can be clockwise or anti-clockwise. The moment in the diagram below is **clockwise**.

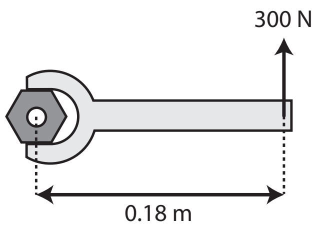


Worked Example

A mechanic tries to remove a rusted nut from fixed bolt using a spanner of length 0.18 m. When he applies his maximum force of 300 N, the nut does not turn.

By placing a steel tube over the handle of the spanner, the length is increased to 0.27 m. When he applies the same maximum force of 300 N at the end of the steel tube, the nut is just loosened.

Calculate the minimum force that would have been necessary to loosen the nut if the length of the spanner had remained 0.18 m.



The moment required to loosen the nut is

$300 \times 0.27 = 81$ N m

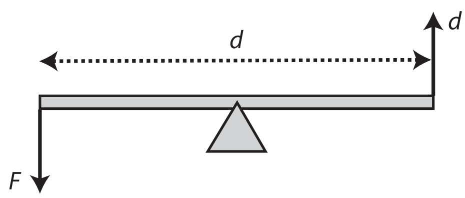
If the force required to loosen the nut, when the length is 0.18 m, is F.

$F \times 0.18 = 81$

$F = 81 \div 0.18 = 450$ N

Couples

A single force acting on an object will make it move off in the direction of the force. A **couple** is two forces that act in opposite directions, not along the same line, and which cause rotation. A couple produces an **unbalanced moment.**



The moment of each force about the pivot is $F \times \frac{1}{2}d$

The sum of these two moments is therefore $F \times \frac{1}{2}d + F \times \frac{1}{2}d = F \times d$

Moment of a couple = One force × Perpendicular separation of the forces

Centre of Gravity and Centre of Mass

The **centre of gravity** of an object is the point at which we can take its **weight** to act.

The **centre of mass** of an object is the point at which we take its **mass** to be concentrated.

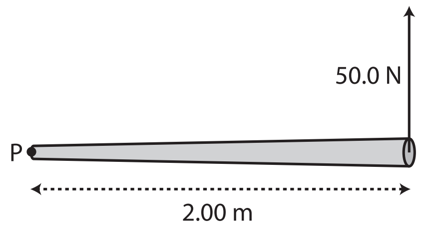
A resultant force acting through the centre of mass would cause the object to move in a straight line but without causing it to rotate. For most everyday situations the centre of gravity coincides with the centre of mass.

Principle of Moments

When an object is in rotational equilibrium, the sum of the clockwise moments about any point is equal to the sum of the anticlockwise moments about the same point.

Worked Example

A non-uniform rod of mass 5.50 kg and length 2.00 m is pivoted at a point P at one end of the rod. The rod is held horizontally by a tension of 50.0 N acting vertically in a light string fixed to the other end of the rod, as shown. Calculate
(i) the distance of centre of gravity from the point P
(ii) the size and direction of the force acting through point P.



(i) Let the distance from the centre of gravity to the pivot be *d*.

Then, taking moments about point P,
ACWM = CWM, so $50 \times 2 = (5.50 \times 9.81) \times d$,
so $d = 100 \div 54.0 = 1.85$ m (to 3 s.f., same as initial values)

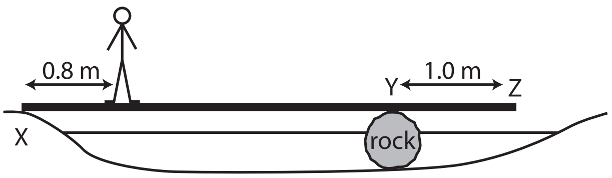
(ii) The weight of the rod is approximately 53.96 N and it acts vertically downwards at the centre of gravity. The total upward forces must balance the total downward forces, so the force through P is **upwards** and of size 3.96 N.

Reactions

Many AS questions require the student to **determine the reactions** at points of support. Study carefully the following worked example from an AS paper.

Worked Example

A boy uses a uniform plank of wood of mass 30 kg and length 4.0 m to cross a river. He places one end of the plank on the river bank and rests the plank on a rock in the river as shown in the diagram.

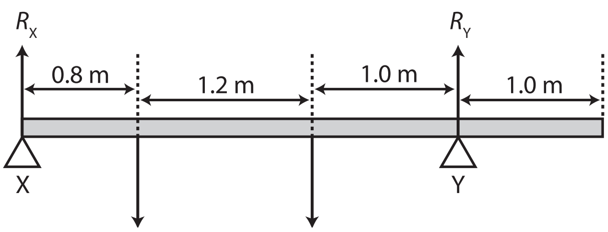


(i) The rock is 1 m from the end of the plank. The boy, who has a mass of 65 kg, stands 0.8 m from the river bank at end X. Calculate the vertical support force, provided by the rock, at Y and the support force provided by the bank, at X.

(ii) Will the boy be able to stand at end Z without the plank rising off the riverbank and the boy falling in the river? Explain your answer.

(CCEA June 2010, amended)

(i) Let the reaction at X be R_X and the reaction at Y be R_Y
To find the reaction at Y, take moments about point X.
We do this because the support force at X, R_X, has no moment about X and can therefore be ignored **if** we take moments about X.

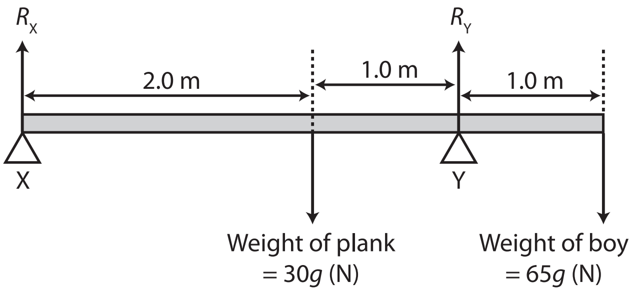


ACWM = CWM **about point X**
$R_Y \times 3 = 30g \times 2 + 65g \times 0.8$
$R_Y = 366$ N

ACWM = CWM **about point Y**
$R_X \times 3 = 1 \times 30g + 2.2 \times 65g$
$R_X = 566$ N

Observe that the total downward forces,
$95g = 95 \times 9.81 = 932$ N and the total upward forces
$R_X + R_Y = 566 + 366 = 932$ N.
This provides a convenient check that the reactions have been calculated correctly – it also provides an alternative method to calculate one reaction given the other.

(ii) In the diagram the 30*g* (N) force and the 65*g* (N) force are both 1.0 m away from Y.



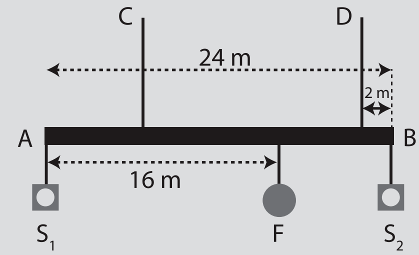
Now, since $65g > 30g$, there will always be a resultant clockwise moment about point Y. This resultant clockwise moment means that the plank is not in equilibrium and will **tip about Y** by lifting off the bank at X. So the boy is **unable to stand** at point Z without falling into the river.

Exercise 3

1. A stage lighting batten consists of a uniform beam AB, 24 m long, which weighs 600 N. The batten is suspended by two vertical cables C and D.

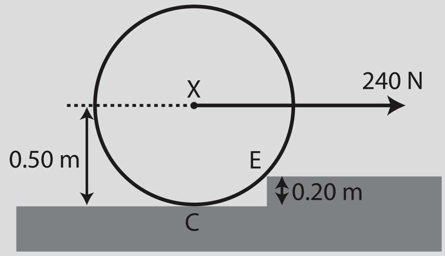
   The tensions in each cable are equal to 430 N. The batten supports two spotlights S_1 and S_2 each of weight 70 N and a floodlight F of weight 120 N. The arrangement and distances are shown in the diagram.

   How far is cable C from end A?



2. A wheel of radius 0.50 m rests on a level road at point C and makes contact with the edge E of a kerb of height 0.20 m, as shown in the diagram. A horizontal force of 240 N, applied through the axle of the wheel at X, is required just to move the wheel over the kerb.

   Find the weight of the wheel.

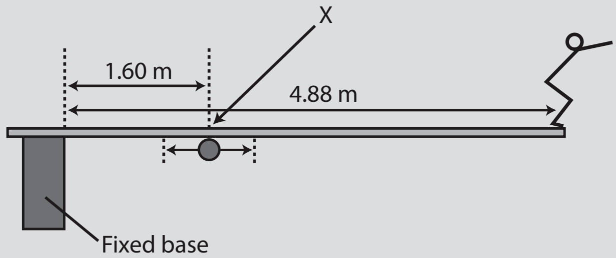


3. A diver stands on the end of an adjustable springboard as shown opposite.

   The diver exerts a moment on the springboard about the pivot at point X.

   (a) On what two factors will the size of the moment the diver exerts depend?

   The total length of the springboard is 4.88 m and the pivot X can be adjusted to move a distance of 0.28 m on either side of its centre position as shown in the diagram.



   (b) (i) Show that the **maximum** moment that a diver of mass 65 kg can exert when she stands on the end of the springboard is 2270 N m.

   (ii) A different diver of mass 75 kg now stands on their own on the end of the springboard. By how much, and in what direction, will the pivot need to be moved from its **central position** for this diver to exert the same moment as the 65 kg diver in (b)(i)?

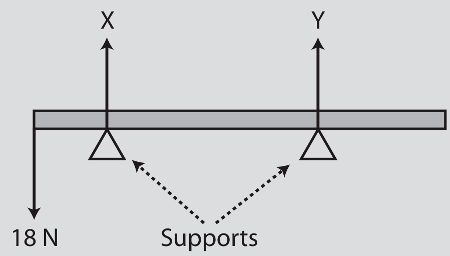
   (CCEA January 2010)

4. The diagram opposite shows a uniform plank of weight 30 N and length 3 m, resting on two supports. The supports are 0.5 m and 2.0 m from the left hand end of the plank. A weight of 18 N is suspended from the left hand end of the plank.

   (a) Find the reactions X and Y at the two supports.

   (b) By how much should the weight at the left hand end be increased so that the reaction at Y becomes zero?

   (CCEA January 2011)



5. Gymnasts are practising on a uniform wooden beam of weight 124 N and length 180 cm. In order to raise it above the floor, the beam is resting on two metal supports, A and B, each of which is at 20.0 cm from the end of the beam, as shown in the diagram.

   (a) Calculate the maximum weight of gymnast, W, who can stand at the left-hand end of the beam, without the beam beginning to tip up.

   (b) What upward force is provided by the support at A, when this gymnast is standing in this position?

   (CCEA June 2016 amended)

6. (a) A student states the principle of moments as:

   "When an object moves, the sum of the clockwise moments equal the sum of the anticlockwise moments."

   Identify two errors or omissions in the student's statement.

   A person holds a 1.5 kg dumb-bell in his hand and keeps his arm horizontal before lifting the mass upwards. The forearm pivots about the elbow joint and has a weight of 25 N, which acts 19.0 cm from this joint. The force in his bicep F_B acts vertically upwards at a distance of 6.8 cm from the elbow joint.

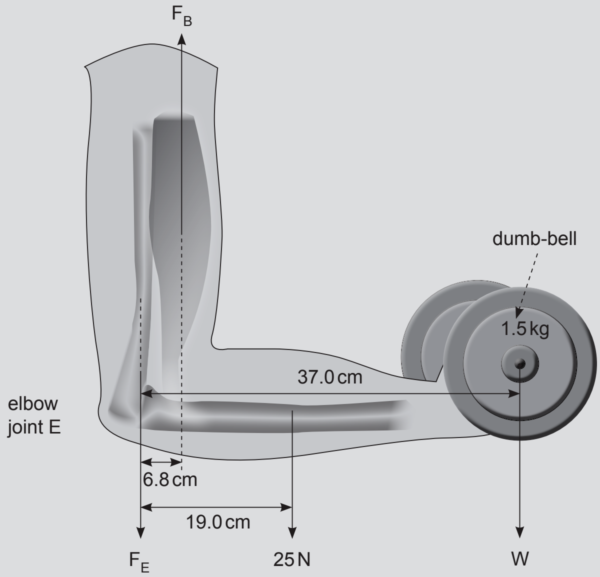
   The centre of gravity of the dumb-bell is 37.0 cm from the elbow joint. The vertical force at the elbow joint is labelled F_E. The situation is shown in the diagram opposite.

   (b) Using the principle of moments, calculate the magnitude of the force in the bicep F_B.

   (c) State an expression for the vertical force at the elbow joint F_E in terms of the other forces acting when the arm is held horizontal with the dumb-bell in the hand.

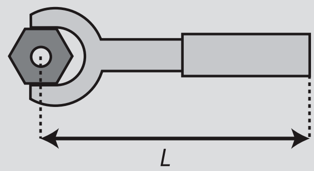
   (d) Determine the magnitude of the vertical force acting at the elbow joint F_E.

   (CCEA June 2015)



7. An extendable wrench is often used to remove the wheel nuts from a car. The length, *L*, of the shaft of the wrench can extend from 32 cm to 54 cm as shown opposite.

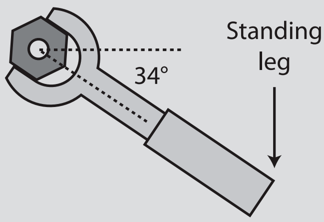
   (a) Calculate the percentage reduction in the force required to perform the same task with the wheel wrench at its longest compared to when it is at its shortest.



   A 62 kg woman attaches the wrench to a wheel nut and finds it makes an angle of 34° to the horizontal. She finds that by standing on the extreme end of the wrench, which is at its minimum length of 32 cm, she can just loosen the nut attached to the wheel.

   (b) Calculate the moment produced by the woman under these conditions.

   (CCEA June 2014, amended)



1.4 Linear Motion

Students should be able to:

1.4.1 define displacement, velocity, average velocity and acceleration;

1.4.2 recall and use the equations of motion for uniform acceleration;

1.4.3 describe an experiment using light gates and computer software to measure acceleration of free fall, g;

1.4.4 interpret, qualitatively and quantitatively, velocity-time and displacement-time graphs for motion with uniform and non-uniform acceleration;

Definitions

Displacement is the distance moved in a particular direction.

Speed is defined as the distance moved per second.

Velocity is defined as the displacement per second.

Average velocity is defined by the equation: $\text{Average velocity} = \dfrac{\text{Total displacement}}{\text{Total time taken}}$

Acceleration is defined as the rate of change of velocity with time.