A PHYSICS ALPHABET
ABBREVIATIONS AND UNITS USED IN THIS BOOK[1]

Quantity (with symbol)		Unit
Area (e.g. surface area)	A	m^2
Acceleration	a	m/s^2
Specific heat capacity	c	J/(kg °C)
Energy or Work	E	J
Extension	e	m
Frequency	f	Hz
Force	F	N
Friction force	F_F	N
Gravitational field	g	N/kg
Height	h	m
Current	I	A
Spring constant	k	N/m
Moment	M	N m
Mass	m	kg

Quantity (with symbol)		Unit
Normal reaction force	N	N
Pressure	P	Pa $=$ N/m^2
Power	P	W
Momentum	p	kg m/s
Charge	Q	C
Resistance	R	Ω
Displacement	s	m
Temperature	T	°C
Time period	T	s
Time	t	s
Voltage	V	V
Volume	V	m^3
Speed or velocity	v	m/s
Weight	W	N

Quantity (with symbol)		Unit
Wavelength	λ (lambda)	m
Friction co-efficient	μ (mu)	no unit
Density	ρ (rho)	kg/m^3

Δ (delta) means __________. So Δh means _______________.

	1 km = 1000 m	1 Mm = 10^6 m	1 Gm = 10^9 m
1 cm = 0.01 m	1 mm = 0.001 m	1 µm = 10^{-6} m	1 nm = 10^{-9} m

Units with powers. Note for example:
1 cm^2 means 1 cm $\times$ 1 cm = 0.01 m $\times$ 0.01 m = 10^{-4} m^2

[1] A list of formulae and data is given on the inside back cover.

FORMULAE AND DATA[2]

The meaning of all symbols in the formulae, and the units used, are given on the inside of the cover. If you need to revise a formula, turn to the page listed alongside it in this table.

Topic	Formula	Page	Topic	Formula	Page
Velocity and Displacement	$\Delta s = v\,\Delta t$	P 11	Energy or Work Done	$\Delta E = F\,\Delta s$	P 35
Acceleration and Velocity	$\Delta v = a\,\Delta t$	P 14	Gravitational Potential Energy	$\Delta E = W\Delta h = mg\,\Delta h$	P 37
Weight	$W = mg$	P 17	Energy and Power	$\Delta E = P\,\Delta t$	P 38
Force and Acceleration	$F = ma$	P 19	Energy and Temperature change	$\Delta E = mc\Delta T$	P 42
Momentum	$p = mv$	P 20			
Momentum and Force	$\Delta p = F\,\Delta t$	P 21	Moment	$M = Fs$	P 41

Topic	Formula	Page	Topic	Formula	Page
Energy and Voltage	$E = QV$	P 23	Density	$\rho = m/V$	P 43
Charge and Current	$\Delta Q = I\,\Delta t$	P 26	Friction	$F_F = \mu N$	P 45
Resistance	$V = IR$	P 30	Springs and Force	$F = ke$	P 47
Electrical Power	$P = IV$	P 32	Pressure	$P = F/A$	P 49

Topic	Formula	Page	Topic	Formula	Page
Frequency	$f = 1/T$	P 50	Wave Equation	$v = f\lambda$	P 51

In the questions on these worksheets, unless otherwise given, take

- **Gravitational field strength on Earth (g) as 10 N/kg**
- **Acceleration of a dropped object without air resistance (g) as 10 m/s^2**

Other data will be given on each worksheet when you need it.

[2] A list of quantities, symbols and data is given on the inside front cover.

Isaac Essential Physics

Step up to GCSE Physics

Anton Machacek
Isaac Physics Project

Periphyseos Press
Cambridge, UK.

Periphyseos Press
Cambridge

Cavendish Laboratory
J. J. Thomson Avenue, Cambridge CB3 0HE, UK

Published in the United Kingdom by Periphyseos Press, Cambridge
www.periphyseos.org.uk

First published 2022

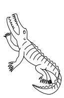
Printed and bound in the UK by Short Run Press Limited, Exeter.

Typeset in LaTeX

A catalogue record for this publication is available from the British Library

ISBN 978-1-8382160-5-4 Paperback

Use this collection of worksheets in parallel with the electronic version at http://isaacphysics.org/books/step_up_phys. Marking of answers and compilation of results is free on Isaac Physics. Register as a student or as a teacher to gain full functionality and support.

 used with kind permission of M. J. Rutter.

Note for the Student

Physics is the part of Science which uses maths the most. Most physics ideas can be written down as equations more easily than they can be written down in words. The courses you study later (like GCSE) will require you to use many equations to solve problems.

In each two-page section, an idea is explained. You then have a worked example and then a set of questions to answer. Practising the questions will build your confidence. You can then make a flying start to GCSE.

Note for the Teacher

The material in this book builds on concepts which have already been introduced to students in a qualitative fashion. This book places these ideas on a more mathematical footing.

Students, teachers and schools are welcome to use this material with students prior to beginning formal GCSE (or equivalent) programmes of study to provide a good foundation. Equally, it may be used alongside other resources as the early parts of GCSE courses are taught. It also has a role as extension and challenge material for younger pupils, and can be used as a bank of practice material for older students needing to gain confidence.

All questions are also available at `http://isaacphysics.org/books/step_up_phys`. Teachers may set questions to their classes and monitor progress. Equally, students completing questions on the website receive immediate feedback on their answers. A pdf version of the notes without the red text is available at `http://isaacphysics.org/books/step_up_phys` for projection in class during class discussion.

Acknowledgements

I would like to thank all of my colleagues at Isaac Physics for their support with this project, especially Dr Lisa Jardine-Wright for giving this project its impetus, Prof. Mark Warner for creating the LaTeXstyle used here, Dr Lee Phillips for his thorough review of the first draft and David Taylor for all of his administrative assistance. I am grateful to Sam Lambrick, Ashnoy Nazareth, Miguel Nocum and Jia Hao Guo, who created the online version of this book. Finally, this would not have been possible without the support and love of Helen Machacek. Soli Deo Gloria,

ACM, Cambridge, 2021

Contents

Force and Motion

1 Displacement

Displacement s measures the ________ of something.
When something ______ its displacement ________.
In our questions, the direction of a displacement is given by its sign:

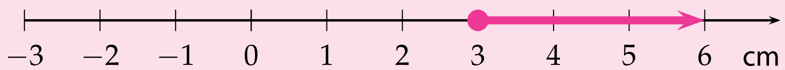
$+$ means 'on the right'
$-$ means 'on the left'

If the change of displacement is ________, the object is moving to the _____.
If the change is ________, the object is moving to the ___.

Δ (delta) means _________.
Change in displacement $(\Delta s) = s_{\text{final}} - s_{\text{starting}}$

If it ends up back at the starting point, the total displacement is ____. The total distance travelled will not be zero if it moved.

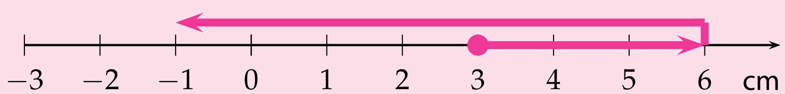
Example 1 – *Calculate the change in displacement for the motion shown below. State the distance travelled.*



Object moved from $s_{\text{starting}} = +3$ cm to $s_{\text{final}} = +6$ cm,
Change in displacement $\Delta s = 6\text{ cm} - 3\text{ cm} = +3$ cm
Distance moved $= 3$ cm

Example 2 – *An object moves directly from $s = +3$ cm to $s = -5$ cm. Calculate the change in displacement. State the distance travelled.*
Change in displacement $\Delta s = -5\text{ cm} - (3\text{ cm}) = -8$ cm
Distance moved $= 8$ cm

Example 3 – *Calculate the change in displacement for the two-stage motion shown below. State the distance travelled.*



Starting position $s_{\text{starting}} = 3$ cm, final position $s_{\text{final}} = -1$ cm

Change in displacement $\Delta s = (-1 \text{ cm}) - 3 \text{ cm} = -4 \text{ cm}$
Distance moved $= 3 \text{ cm} + 7 \text{ cm} = 10 \text{ cm}$

2 Units of Distance

Distances can be measured in different units. To convert from one unit to another, you multiply or divide by a conversion factor.

Example 1 – *There are* 1.61 *km in one mile. What is* 5 *miles in km?*

$$\begin{aligned}1.61 \text{ km} &= 1.00 \text{ miles}\\ &\quad \text{multiply by } 5 \text{ on each side}\\ 5 \times 1.61 \text{ km} &= 5.00 \text{ miles}\\ 5 \text{ miles} &= 5 \times 1.61 \text{ km} = 8.05 \text{ km}\end{aligned}$$

Example 2 – *There are* 1.61 *km in one mile. What is* 45 *km in miles?*

$$\begin{aligned}1.61 \text{ km} &= 1.00 \text{ miles}\\ &\quad \text{divide by } 1.61 \text{ on each side}\\ 1.00 \text{ km} &= \frac{1.00 \text{ miles}}{1.61}\\ &\quad \text{multiply by } 45 \text{ on each side}\\ 45 \text{ km} &= \frac{1.00 \text{ miles}}{1.61} \times 45 = 28.0 \text{ miles}\end{aligned}$$

The final line could be written

$$45.00 \text{ km} = \frac{1.00 \text{ miles}}{1.61 \cancel{\text{km}}} \times 45 \cancel{\text{km}}$$

The km units 'cancel out' on the right. If we wanted to convert miles to kilometres, we would multiply by $\frac{1.61 \text{ km}}{1.00 \text{ miles}}$.

Example 3 – *Convert* 14 *miles into nautical miles?*

$$\begin{aligned}14 \text{ miles} &= 14 \cancel{\text{miles}} \times \frac{1.61 \text{ km}}{1.00 \cancel{\text{miles}}} = 22.5 \text{ km}\\ 22.5 \text{ km} &= 22.5 \cancel{\text{km}} \times \frac{1.00 \text{ nautical miles}}{1.85 \cancel{\text{km}}} = 12.2 \text{ nautical miles}\end{aligned}$$

This could be done in one stage (NM means nautical miles):

$$14\,\cancel{\text{miles}} \times \frac{1.61\,\cancel{\text{km}}}{1.00\,\cancel{\text{miles}}} \times \frac{1.00\,\text{NM}}{1.85\,\cancel{\text{km}}} = 12.2\,\text{NM}$$

Remember: 1 mm $= 0.001$ m, 1 cm $= 0.01$ m, 1 km $= 1000$ m

3 Displacement – time graphs

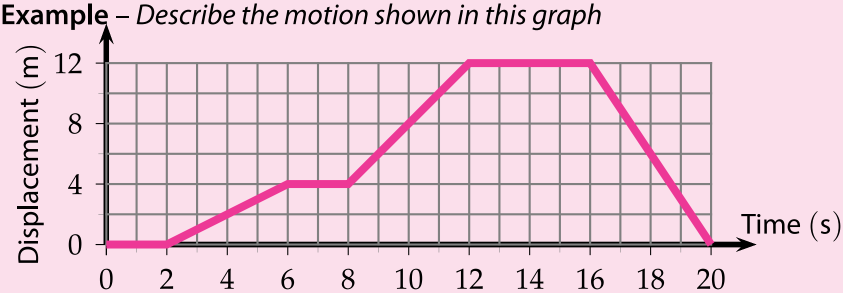
On a ________________ graph, we show where something is at different times.

The ___________ s is plotted on the y or ______ $\uparrow$ axis.

The ____ t is plotted on the x or ________ $\rightarrow$ axis.

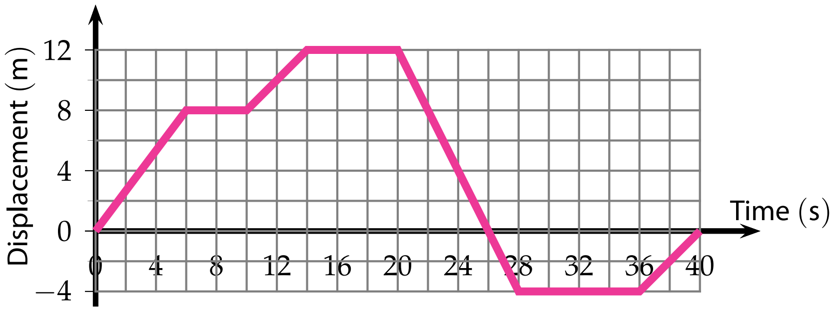
__________ represent motion at a _____ (constant) _____.
Straight, ________ lines represent times when the object is _________.
The steeper the line, the faster the object.

Example – *Describe the motion shown in this graph*



The object remains ________ at $s = 0$ m for the first two seconds
The object starts moving at $t = 2$ s at a steady speed.
It reaches $s = 4$ m when $t = 6$ s.
It remains stationary for two more seconds (until $t = 8$ s).
It then starts moving at a __________.
It reaches $s = 12$ m four seconds later, at $t = 12$ s.
It stays there for 4 s, then ______ to its starting point at $t = 20$ s.

In this next graph, the displacement s measures how far a lift (elevator) is above the ground floor of a building. The floors are 4 m apart.


Displacement (m)
12
8
4
0
−4
Time (s)
0
4
8
12
16
20
24
28
32
36
40

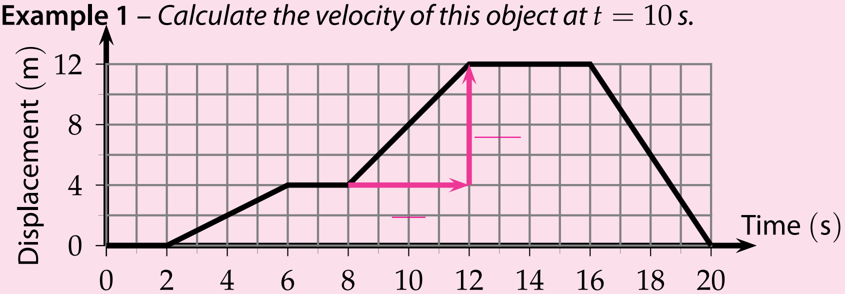
4 Velocity

The change in displacement Δs each second is called the ________ v. You can read off the Δs for one second on a straight part of a displacement – time graph.

You can also calculate the velocity by dividing the displacement change Δs by the time taken Δt. This gives the ______________________ each ________.

$$\text{Velocity (m/s)} = \frac{\text{Displacement change (m)}}{\text{Time taken (s)}}, \text{ or } v = \frac{\Delta s}{\Delta t}$$

Example 1 – *Calculate the velocity of this object at $t = 10$ s.*



10 s is part of a straight line between $t = 8$ s and $t = 12$ s.
The time taken ____________________.
The displacement change ______________________.
Velocity $v = \frac{\Delta s}{\Delta t} = \frac{+8\text{ m}}{4\text{ s}} = +2$ m/s.

The velocity is given by the _________ of the line on the displacement – time graph. Gradient is the change in the vertical ↑ co-ordinate ___________ the change in the horizontal → co-ordinate.

In our questions, the direction of a velocity is given by its sign:

- $+$ means 'moving forwards' or 'moving upwards'
- $-$ means 'moving backwards' or 'moving downwards'

The ______ is the magnitude (size) of the velocity (without its direction). If $v = -3$ m/s, it means ____
The speed is just _____ (without the $-$ sign).

$$\text{Average speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

Example 2 – *Calculate the average speed in the graph above.*
Total distance $= 12$ m $+ 12$ m (there and back) $= 24$ m
Total time $= 20$ s, so Average speed $= \dfrac{24\text{ m}}{20\text{ s}} = 1.2$ m/s.

5 Re-arranging equations

Many equations in Physics involve three quantities. On these pages, we practise re-arranging equations so that we can calculate what we need.

Let's use the equation $A = b \times c$, usually written $A = bc$

$$\text{If } b = 2 \text{ and } c = 5\text{, then } A = b \times c = 2 \times 5 = 10.$$

$$\text{We can get } c = 5 \text{ from } 5 = \frac{10}{2} \text{ so } c = \frac{A}{b}.$$

$$\text{We can get } b = 2 \text{ from } 2 = \frac{10}{5} \text{ so } b = \frac{A}{c}.$$

We can also use algebra:

$$\text{If } b = \frac{A}{c} \qquad bc = \frac{A\cancel{c}}{\cancel{c}} \quad \text{then} \quad bc = A$$

and

$$\text{If } bc = A \qquad \frac{\cancel{b}c}{\cancel{b}} = \frac{A}{b} \quad \text{then} \quad c = \frac{A}{b}.$$

Re-arrangement causes the quantities to cross the $=$ sign on a diagonal:

$$b = \frac{A}{c} \qquad bc = A \qquad\qquad bc = A \qquad c = \frac{A}{b}$$

Example 1 – *If $B = fg$, write an equation for g.*

Dividing both sides by f gives $\frac{B}{f} = \frac{\cancel{f}g}{\cancel{f}} = g$, so $g = \frac{B}{f}$

Example 2 – *If $y = kx$ and $y = 0.25$ when $x = 0.4$, calculate k.*

Rearrange $y = kx$ by dividing both sides by x: $\frac{y}{x} = k$

So $k = \frac{y}{x} = \frac{0.25}{0.4} = 0.625$

Example 3 – *If $y = kx$, and $y = 90$ when $x = 6$, calculate y when $x = 4$.*

Assume k does not change. Divide both sides by x to get $\frac{y}{x} = k$

so $k = \frac{90}{6} = 15$. Now use the new x. $y = kx = 15 \times 4 = 60$

Example 4 – *If* $\frac{a}{b} = \frac{c}{d}$ *and* $a = 2$, $b = 6$ *and* $c = 12$, *calculate* d*?*

Multiply both sides by bd giving $ad = bc$. Now divide by a, so $d = \frac{bc}{a}$

Now put in the data to give $d = \frac{6 \times 12}{2} = 36$

6 Calculating velocities

On page 7, we introduced the formula for ________. This is the ________________

$$\text{Velocity (m/s)} = \frac{\text{Displacement change (m)}}{\text{Time taken (s)}}, \text{ or } v = \frac{\Delta s}{\Delta t}$$

Since the velocity is the displacement change ____________, you can calculate the displacement change:

Displacement change (m) = Velocity (m/s) × Time taken (s), or $\Delta s = v\,\Delta t$

The time taken can also be worked out. To do this, you divide the ________________ by the ________________________________. This is the same as dividing by the ________. So

$$\text{Time taken (s)} = \frac{\text{Displacement change (m)}}{\text{Velocity (m/s)}}, \text{ or } \Delta t = \frac{\Delta s}{v}$$

Now, we put these three equations next to each other:

$$v = \frac{\Delta s}{\Delta t} \qquad \Delta s = v\,\Delta t \qquad \Delta t = \frac{\Delta s}{v}$$

This is the same equation written three ways, each with a different subject.

Example 1 – *How long does it take an object at $+4$ m/s to move $+20$ m?*
We want to know t, so take $\Delta s = v\,\Delta t$ and divide both sides by v to give

$$\Delta t = \frac{\Delta s}{v} = \frac{+20\text{ m}}{+4\text{ m/s}} = 5\text{ s}$$

Units:	1 km = 1000 m	1 cm = 0.01 m	1 mm = 0.001 m
	1 mile = 1610 m	1 nautical mile = 1850 m	1 inch = 0.025 m

Example 2 – *How far (in km) will a train travel in 45 min at 230 mph?*

$$\Delta s = v\,\Delta t = \frac{230\text{ miles}}{1\text{ hr}} \times 45\text{ min} = \frac{230 \times 1610\text{ m}}{1 \times 60\text{ min}} \times 45\text{ min}$$

$$= \frac{230 \times 1610\text{ m} \times 45\,\cancel{\text{min}}}{60\,\cancel{\text{min}}} = 280\,000\text{ m} = 280\text{ km}$$

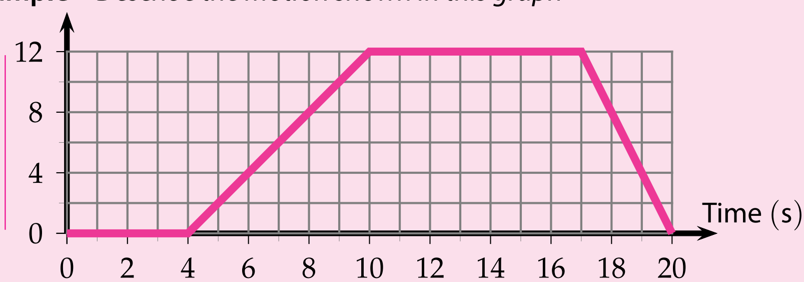
7 Velocity – time graphs

It can be helpful to show an object's velocity at different times.

The ________ v is plotted on the y or ________ $\uparrow$ axis.
The _____ t is plotted on the x or ___________ $\rightarrow$ axis.

_________________ represent motion at a __________________________.
Horizontal lines _______________ represent an object _____________.

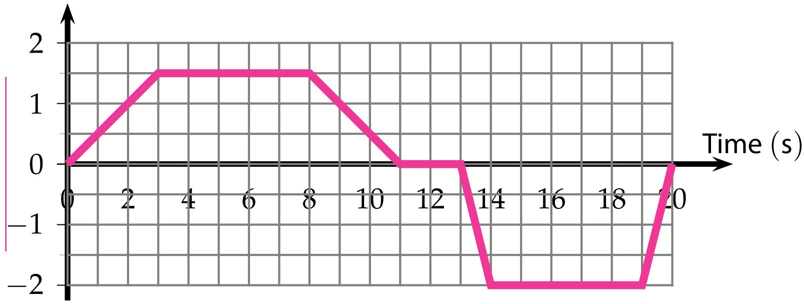
Example – *Describe the motion shown in this graph*



The object is ___________ ($v = 0$ m/s) for the first four seconds
At $t = 4$ s the object begins to speed up. It ____________.
It reaches a velocity of $v = 12$ m/s when $t = 10$ s.
It keeps going at that speed for 7 s
During this time, it travels _____________________________________.
At $t = 17$ s, it _____________. It ____________.
It comes to rest at $t = 20$ s.

The ________ the line, the ________ the acceleration or deceleration.
A straight (not horizontal) line represents a _______________________. The change in velocity is the same each second.

This graph shows the velocity of a hoist used to lift building materials on a construction site. ________ values of v are used when the hoist is ______.


2
1
0
−1
−2
0
2
4
6
8
10
12
14
16
18
20
Time (s)

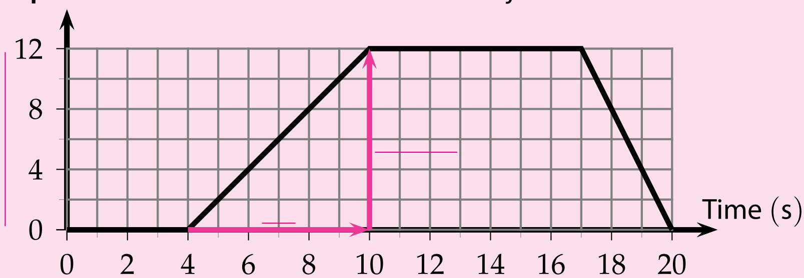
8 Acceleration

The change in velocity Δv each second is called the ____________ a. You can read off the Δv for one second on a straight part of a velocity – time graph.

You can also calculate the acceleration by dividing the velocity change Δv by the time taken Δt. This gives the ______________ each ______.

$$\text{Acceleration } (\text{m/s}^2) = \frac{\text{Velocity change } (\text{m/s})}{\text{Time taken } (\text{s})}, \text{ or } a = \frac{\Delta v}{\Delta t}$$

Example – *Calculate the acceleration of this object at $t = 6$ s.*



6 s is part of a steady acceleration between $t = 4$ s and $t = 10$ s.
The time taken for this acceleration ________________.
In this time, the velocity change ______________________.
Acceleration $a = \frac{\Delta v}{\Delta t} = \frac{+12 \text{ m/s}}{6 \text{ s}} = +2 \text{ m/s}^2$.

The acceleration is given by the ________ of the line on the velocity time graph. Gradient is the change in the vertical ↑ co-ordinate __________ the change in the horizontal → co-ordinate. In our questions, the direction of a velocity is given by its sign:

$+$ means v is getting _____
$-$ means v is getting ______

An acceleration of -3 m/s^2 could refer to an object _____________ while going ________. It could also describe an object ____________ while ________.

9 Calculating accelerations

On page 14, we introduced the formula for ____________. This is the ____________

$$\text{Acceleration }\left(\text{m/s}^2\right) = \frac{\text{Velocity change }(\text{m/s})}{\text{Time taken }(\text{s})}\text{, or } a = \frac{\Delta v}{\Delta t}$$

As the acceleration is the velocity change ____________, you can work out the velocity change:

$$\text{Velocity change }(\text{m/s}) = \text{Acceleration }\left(\text{m/s}^2\right) \times \text{Time }(\text{s})\text{, or } \Delta v = a\,\Delta t$$

The time taken can also be calculated. To do this, you divide the ______________ by the ____________________________. This is the same as dividing by the ____________.
So

$$\text{Time }(\text{s}) = \frac{\text{Velocity change }(\text{m/s})}{\text{Acceleration }\left(\text{m/s}^2\right)}\text{, or } \Delta t = \frac{\Delta v}{a}$$

Now, we put these three equations next to each other:

$$a = \frac{\Delta v}{\Delta t} \qquad \Delta v = a\,\Delta t \qquad \Delta t = \frac{\Delta v}{a}$$

This is the same equation written three ways, each with a different subject.

Example 1 – *An object's velocity is $+10$ m/s. How much time does it take to reach $+30$ m/s with an acceleration of $a = +5$ m/s^2?*
The change in velocity needed is $\Delta v = 30 - 10 = 20$ m/s
We want to know t, so take $\Delta v = a\,\Delta t$ and divide both sides by a to give

$$\Delta t = \frac{\Delta v}{a} = \frac{+20\text{ m/s}}{+5\text{ m/s}^2} = 4\text{ s}$$

Example 2 – *A motorcycle can accelerate from rest to 60 mph in 3.4 s. Calculate its acceleration in m/s^2. 1 mile $= 1610$ m.*

$$\Delta v = 60\text{ mph} = \frac{60\text{ miles}}{1\text{ h}} = \frac{60 \times 1610\text{ m}}{60 \times 60\text{ s}} = 26.8\text{ m/s}$$

$$a = \frac{\Delta v}{t} = \frac{26.8\text{ m/s}}{3.4\text{ s}} = 7.9\text{ m/s}^2$$

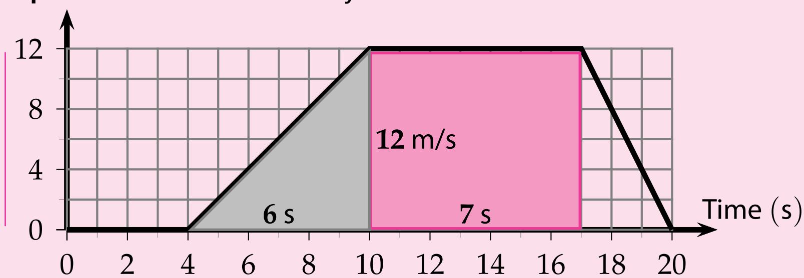
10 Displacement from a velocity – time graph

Velocity is the displacement change ________. This means that you can work out the displacement change from the velocity:

Displacement change (m) $=$ Velocity (m/s) $\times$ Time taken (s), or $\Delta s = v\,\Delta t$

This works in any part of the graph where the velocity is constant.

Example 1 – *How far does the object move between $t = 10$ s and 17 s?*



Between these times, the velocity is constant: $v = +12$ m/s.
Displacement change $\Delta s = v\,\Delta t = +12$ m/s $\times$ 7 s $= +84$ m.

This displacement change is also equal to the area of the coloured rectangle.
So the ________________ = ____ under a ________________.
Next we look at a part of the graph when the velocity is changing:

Example 2 – *How far does the object move between $t = 4$ s and 10 s?*
Method 1 – Area under the line is area of the gray triangle
Area of triangle $= \frac{1}{2} \times$ base $\times$ height $= \frac{1}{2} \times$ __ s $\times$ (____ m/s) $=$ ____ m
Method 2 – Velocity changes ________ from ______ to ________

so average velocity $= \dfrac{\_\_\_\_}{2} =$ ___ m/s
Displacement change $=$ Average velocity $\times$ Time
$=$ ___ m/s $\times$ __ s $=$ ____ m

11 Weight and resultant force

______ W is the downwards force of ______. It is measured in newtons (N).

____ m is the quantity of material. Mass is measured in kilograms (kg).

The weight of an object depends on its ____. It also depends on the strength of the local ______________.

Gravitational field strength g measures the weight of a _______ at that place.

Weight and mass are related to the field strength by this equation:

$$\text{Weight(N)} = \text{Mass(kg)} \times \text{Field strength (N/kg), or } W = mg$$

This equation can be re-written as shown on page 9 as

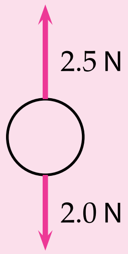
$$g = \frac{W}{m} \qquad W = m\,g \qquad m = \frac{W}{g}$$

Example 1 – *Calculate the weight of a small* $(100\ g)$ *apple on Earth, where* $g = 10$ *N/kg. Also calculate the weight on Mars, where* $g = 3.7$ *N/kg.*
There are 1000 g in 1 kg, so $m = 0.1$ kg. Masses must be given in __
On Earth, $W = mg = 0.1$ kg $\times$ 10 N/kg $= 1.0$ N
On Mars, $W = mg = 0.1$ kg $\times$ 3.7 N/kg $= 0.37$ N
Isn't it wonderful that the weight of a small apple is ≈ 1 newton!

If there is more than one force, we calculate the ____________. This is the single force which would do the same job.

The resultant force is to the ____ as 3 N $>$ 1 N.
The 1 N to the left cancels out 1 N of the 3 N pulling right.
This leaves a resultant force of $3 - 1 = 2$ N to the right.

Or we can use $+$ to mean $\rightarrow$. Then $-$ means $\leftarrow$.
The forces are -1 N and $+3$ N. These add to $+2$ N.



Example 2 – *On Earth, a large* $(200\ g)$ *apple is underwater. It has an upwards* 2.5 *N force on it. Calculate the resultant force.*

Weight $W = mg = 0.2$ kg $\times$ 10 N/kg $= 2.0$ N

Weight is -2.0 N if we use $+$ for $\uparrow$ and $-$ for $\downarrow$

Upwards force is $+2.5$ N

Resultant (total) force $= (-2.0) + (+2.5) = +0.5$ N

That is 0.5 N ________.

12 Force and acceleration

______ (balanced forces) } means that { ______ and ______ } don't change.

Example – *A bus travels North on a flat road at 30 mph. Its engine provides 2 kN forwards. How much force (backwards) resists motion?*

The bus is at a ______ and not ______. So

- the ______ is constant,
- there is ___ resultant force, and
- the resistance must balance the engine's thrust. Force $= 2$ kN.

______ (unbalanced forces) } means that { ______, or ______ will change. the object will ______.

Let's find out which box has the larger acceleration.

6 N ← 2 kg → 10 N	350 N ← $\boxed{100\text{ kg}}$ → 400 N
Resultant force $= 10 - 6 = 4$ N	Resultant force $= 400 - 350 = 50$ N
$\frac{4\text{ N}}{2\text{ kg}} = 2$ N on each kilogram	$\frac{50\text{ N}}{100\text{ kg}} = 0.5$ N on each kilogram

The 2 kg object will accelerate more rapidly.

When we measure force in newtons, the acceleration equals the resultant force on each kilogram. We have an equation:

$$\text{Acceleration}\ (\text{m/s}^2) = \frac{\text{Resultant force (N)}}{\text{Mass (kg)}}, \text{ or } a = \frac{F}{m}$$

The objects in the example have accelerations of 2 m/s^2 and 0.5 m/s^2.

The equation can be re-written as shown on page 9 as

$$a = \frac{F}{m} \qquad F = m\,a \qquad m = \frac{F}{a}$$

Resultant force is ______ in the direction of motion

If resultant force is { in the direction of motion, object ______. against the motion, object ______. to the side, object ______ (changes ______).

13 Momentum

Momentum p measures your 'amount of motion'.

- A car travelling at 30 mph has less 'motion' than at 50 mph.
- A 700 kg car has less 'motion' than a 12 400 kg bus at the same speed.

We take mass m and velocity v into account:

Momentum (kg m/s) = Mass (kg) × Velocity (m/s), or $p = mv$

In our questions, the direction of a velocity or momentum is given by its sign:

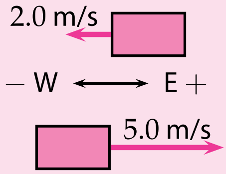
$+$ means 'moving to the East' or 'moving upwards'

$-$ means 'moving to the West' or 'moving downwards'

Example 1 – *Calculate the momentum of a 750 kg car travelling at 15 m/s to the West.*
Velocity $= -15$ m/s
Momentum = mass × velocity = 750 kg × (−15 m/s) = −11 250 kg m/s

Example 2 – *Calculate the velocity of a 90 kg pumpkin if it has a momentum of 1080 kg m/s upwards.*
Momentum = +1080 kg m/s = mass × velocity
therefore 1080 kg m/s = 90 kg × velocity
so velocity $= \dfrac{1080 \text{ kg m/s}}{90 \text{ kg}} = +12$ m/s, that is 12 m/s upwards.

Example 3 – *A 0.84 kg motion trolley's velocity changes from 2.0 m/s West to 5.0 m/s East? What is the change of momentum?*



Start: With the − sign, we write $v = -2.0$ m/s
$p = 0.84$ kg × (−2.0 m/s) = −1.68 kg m/s

End: With the + sign, we write $v = +5.0$ m/s
$p = 0.84$ kg × (+5.0 m/s) = +4.20 kg m/s

Change in momentum = 4.20 − (−1.68) = +5.88 kg m/s
Change in momentum = 5.88 kg m/s East

In the next two questions, use + to mean 'upwards', and − for 'downwards'.

14 Momentum, impulse and force

To give an object 4000 kg m/s of momentum, you could
- apply a 4000 N force for 1 second,
- apply a 2000 N force for 2 seconds, or
- apply a 1000 N force for 4 seconds.

If we measure force in newtons,

$$\text{Resultant Force} \times \text{time} = \text{Change of momentum}\text{ , or } Ft = \Delta p$$

The quantity ____________ is called the ________.

Example – *A 65 kg cyclist on a 15 kg bike is travelling at 5 m/s. She applies a 100 N resultant force for 8 s. How fast is she going now?*
Impulse $= 100$ N $\times$ 8 s $=$ 800 N s, which is the same as 800 kg m/s
Original momentum $= (65 + 15)$ kg $\times$ 5 m/s $=$ 400 kg m/s
New momentum $= 400$ kg m/s $+$ 800 N s $=$ 1200 kg m/s

$$\text{New velocity} = \frac{p}{m} = \frac{1200\text{ kg m/s}}{80\text{ kg}} = 15\text{ m/s}$$

15 Force and acceleration from momentum

________ (balanced forces) } means that ________ doesn't change.

Example 1 – *A bus travels North on a flat road at 30 mph with its engine providing 2 kN forwards. What is the (backwards) force resisting motion?*
The bus is at a ________ and not ________, so
- the ________ is constant, so there is ________, so
- resistance must balance the engine's thrust. Force $= 2$ kN.

If there is a ________, then the momentum ________.

Resultant force = Momentum change each second

Example 2 – *Calculate the acceleration of this object.*

6 N ← 2 kg → 10 N

The resultant force is $10 - 6 = 4$ N
In 1 s the momentum gain is Force × Time $= 4$ N $\times 1$ s $= 4$ kg m/s.
Velocity gain = Momentum gain ÷ Mass $= 4$ kg m/s $\div 2$ kg $= 2$ m/s.
A gain of 2 m/s each second is an ________ of 2 m/s^2.

Force = Momentum change each second
= Mass × Velocity change each second
= Mass × Acceleration, or $F = ma$

Resultant force is ________ in the direction of motion

If resultant force is:
- in the direction of motion, object ________.
- against the motion, object ________.
- to the side, object ________ (changes ________).

Force and motion summary questions are on page 58.

Electricity

16 Energy, charge and voltage

_______ Q travels around an electric circuit. It is measured in coulombs (C). Charge is given the symbol Q to represent the ________ of electrical 'material'.

The energy of each coulomb of charge is called the _______ or _________. The voltage change across a component is also called a ___________________.

Energy E is measured in joules (J), Voltage V is measured in volts (V):

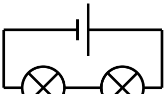
$$\text{Energy change (J)} = \text{Charge (C)} \times \text{Voltage (V), or } E = QV$$

The voltage, which measures electrically-stored energy,

- _________ when charge passes a ________________________
- ______ when charge passes a ______________________

Example – *A 230 V lamp takes 13.8 J of electrical energy. How much charge has passed?*
The voltage change is 230 V. We have lost 13.8 J of energy.
Energy change = Charge × Voltage, so 13.8 J = Charge × 230 V

$$\text{Charge} = \frac{13.8\ \text{J}}{230\ \text{V}} = 0.060\ \text{C}.$$

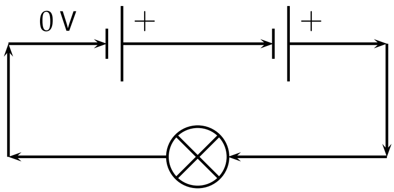


In a _____ circuit, there are no _________. Each charge passes through all of the components (one after another). It loses some of its energy to each component.
In a _______ circuit, the energy carried by each charge does not change as it passes a junction. Not all charge takes the same route.

17 Voltage in circuits

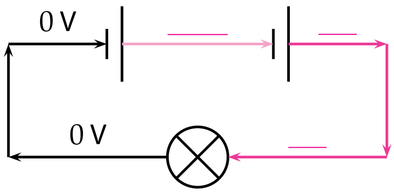
We use the idea of ________ (the ________________ of charge) to analyse circuits.

We label the negative terminal of the battery 0 V. Next, we draw arrows to show the direction of charge flow. This is round the circuit from the $+$ of the battery.



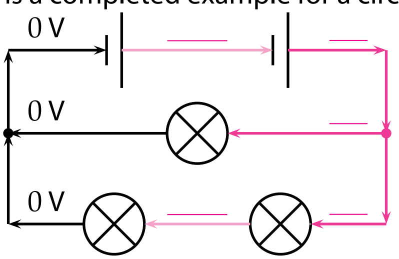
We follow the arrows, starting at the 0 V mark. Each cell _____ $+1.5$ V. We label each wire with its voltage. We use a colour code, here black means 0 V.

All points on a wire have the same voltage. This is because charge loses very little energy while flowing down a wire.



The bulb connects a 3 V wire to a 0 V wire. The drop in voltage as the charge goes through it is 3 V. For this lamp, 1.5 V means 'normal' brightness, so the lamp will be ________ than normal.

Here is a completed example for a circuit with junctions:



Top bulb:
voltage drop 3 V, bright.

Lower bulbs:
voltage drop 1.5 V, normal.

We assume that the bulbs are identical. Therefore the wire in the middle at the bottom was ________ between 0 V and 3 V.

18 Charge and current

________ Q travels around an electric circuit. It is measured in coulombs (C). Charge is given the symbol Q to represent the ________ of electrical 'material'.

On page 1 s represented the displacement or position of an object. We used Δs for the ________ of the object's position during a time period Δt. Here, in a similar way
Q is the ____________ which has flown by time t,
ΔQ (delta Q) is the charge which flows during a ____________ Δt.

________ I is the charge which flows each second. It is measured in amps (A). Current is given the symbol I to represent the ________ of the charge flow.

$$\text{Current }(\text{A}) = \frac{\text{Charge flow }(\text{C})}{\text{Time taken }(\text{s})}, \text{ or } I = \frac{\Delta Q}{\Delta t}$$

This equation can be re-arranged using the methods on page 9 to give

$$I = \frac{\Delta Q}{\Delta t} \qquad \Delta Q = I\,\Delta t \qquad \Delta t = \frac{\Delta Q}{I}$$

Example – *If 0.25 A flows for three minutes, calculate the charge.*
The time must be put in seconds: $\Delta t = 3\text{ min} = 3 \times 60\text{ s} = 180\text{ s}$
We use equation $\Delta Q = I\,\Delta t = 0.25\text{ A} \times 180\text{ s} = 45\text{ C}$.

Battery or cell 'capacity' is usually measured in amp-hours (A h) or milliamp-hours (mA h). A 1000 mA h cell can supply 1000 mA for one hour, 500 mA for two hours, and so on. Capacity (A h) = Current $(\text{A}) \times$ Time (hours).

19 Large and small numbers

Negatively charged particles called __________ move in an electric circuit. Each one has a very small charge: $-0.000\,000\,000\,000\,000\,000\,16$ C. In this section, we practise ways of working with large and small numbers. We begin with the use of prefixes like 'kilo' (k) in kilometre which tells us that 1 km = 1000 m.

$$
\begin{array}{r}
1\,000\,000\,000\ \text{C} = 1\ \text{GC} = 1\ \text{gigacoulomb} = 10^{9}\ \text{C} \\
1\,000\,000\ \text{C} = 1\ \text{MC} = 1\ \text{megacoulomb} = 10^{6}\ \text{C} \\
1000\ \text{C} = 1\ \text{kC} = 1\ \text{kilocoulomb} = 10^{3}\ \text{C} \\
0.01\ \text{C} = 1\ \text{cC} = 1\ \text{centicoulomb} = 10^{-2}\ \text{C} \\
0.001\ \text{C} = 1\ \text{mC} = 1\ \text{millicoulomb} = 10^{-3}\ \text{C} \\
0.000\,001\ \text{C} = 1\ \mu\text{C} = 1\ \text{microcoulomb} = 10^{-6}\ \text{C} \\
0.000\,000\,001\ \text{C} = 1\ \text{nC} = 1\ \text{nanocoulomb} = 10^{-9}\ \text{C}
\end{array}
$$

Example 1 – *Write 0.000 03 C with the most suitable prefix.*
0.000 001 C would be 1 μC, and our charge is 30 times larger,
so we have 30 μC (0.03 mC is equivalent but has leading zeroes).

For larger and smaller numbers, we usually use powers of ten.

Numbers larger than 1:	Numbers smaller than 1:
$10^1 = 10$	$10^{-1} = 0.1$
$10^2 = 100$	$10^{-2} = 0.01$
$10^3 = 1000$	$10^{-3} = 0.001$

When you ____ 1 to the power, the number gets ________________.
When you ________ 1 from the power, the number gets ______________.

Example 2 – *Write 33 000 000 C using a power of ten.*
$33\,000\,000 = 3.3 \times 10\,000\,000 = 3.3 \times 10^7$,
so $33\,000\,000$ C $= 3.3 \times 10^7$ C

When using ______________ we always make sure that the number multiplying the power of ten (3.3 in Example 2) is no smaller than 1, and is less than 10.

Example 3 – *How many electrons are there if the total charge is -1 nC*
Total charge $= -10^{-9}$ C

Number of electrons $= \dfrac{\text{Total charge}}{\text{Charge of one electron}} = \dfrac{-1 \times 10^{-9}\ \text{C}}{-1.6 \times 10^{-19}\ \text{C}}$

$= 6.25 \times 10^{9}$

As the electrons are negatively charged, they move around the circuit from the $-$ terminal of the cell to the $+$ terminal.

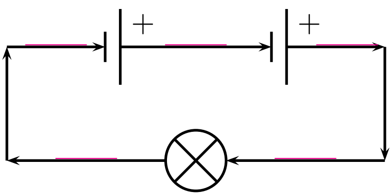
20 Current in circuits

We look at the way in which _______ behaves in electric circuits.

Current is the movement of positive or negative charges. We draw arrows to show the direction any ________ charge would move.
$+$ charge will be ________ or _____________ by the $+$ terminal of the battery.
It will be _________ or _______________ the $-$ terminal of the battery.

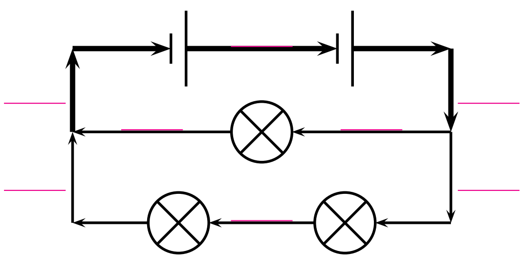
In a circuit, we draw arrows to show this direction from $+$ to $-$. Inside the battery, _________ forces pull the charge the other way from $-$ to $+$ to complete the circuit.

The first rule of charge and current is that ________________ up.



In one second, 0.3 C goes into the light bulb from the $+$ of the battery. 0.3 C also comes out the other end to go to the $-$ (at a lower voltage).
The _______ going in is _____, and the current coming out is _____.

A _______ circuit has _________. The ____ current ________ any junction is the same as the ____ current _______ it.



At junction, current flowing in $= 0.5$ A, current flowing out $= 0.3\text{ A} + 0.2\text{ A} = 0.5\text{ A}$

In this example the two branches are different. This is why the current reaching the junction does not split equally.

21 Resistance

The larger the ____________ a component, the greater the ____________ it. Components which are bad at conducting have a high ________. They need a larger voltage across them to push a set current than a good conductor would.

Resistance R is measured in _____ (Ω).

$$\text{Resistance } (\Omega) = \frac{\text{Voltage } (\text{V})}{\text{Current } (\text{A})}, \text{ or } R = \frac{V}{I}$$

This equation can be re-arranged using the methods on page 9 to give

$$R = \frac{V}{I} \qquad V = IR \qquad I = \frac{V}{R}$$

Example – *A light bulb with a resistance of* $960\ \Omega$ *is connected to a* 240 *V supply. Calculate the current.*
We re-arrange $V = IR$ by dividing both sides by R to give

$$I = \frac{V}{R} = \frac{240\ \text{V}}{960\ \Omega} = 0.25\ \text{A}.$$

The resistance of most components depends on the current passing through them. However _______ and _____ held at a steady ___________ have the same resistance at all useful currents. We say these obey _________, and call them ______ conductors. The graph shows the current through a lamp (black line) and resistor (____________) for different voltages. Use this data for questions **??** to **??**.


Current (A)
0.5
0.4
0.3
0.2
0.1
0
Voltage (V)
0
1
2
3
4
5
6

22 Electrical Power

On page 23 we saw that energy $E = VQ$ is related to the voltage V and total charge Q. For an extra charge ΔQ, which flows in time Δt the extra energy ΔE will be

$$\text{Extra energy (J)} = \text{Voltage (V)} \times \text{Extra charge (C)}, \text{ or } \Delta E = V\,\Delta Q$$

The energy used each second is called the ______ P and is measured in watts (W). For electricity, this means

$$\text{Power} = \frac{\text{Energy}}{\text{Time taken}} = \text{Voltage} \times \frac{\text{Extra charge}}{\text{Time taken}} \qquad P = \frac{\Delta E}{\Delta t} = V\,\frac{\Delta Q}{\Delta t}$$

$$\text{Power} = \text{Voltage} \times \text{Current} \qquad P = V\,I$$

where we used the fact that ______________________________ from page 26. This equation can be re-arranged using the methods on page 9 to give

$$V = \frac{P}{I} \qquad P = VI \qquad I = \frac{P}{V}$$

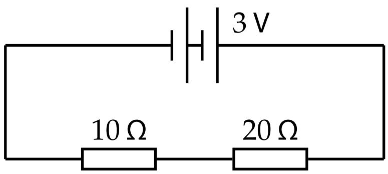
Example – *Calculate the current needed by a 2.4 V, 0.84 W light bulb.*
We re-arrange $P = VI$ by dividing both sides by V to give

$$I = \frac{P}{V} = \frac{0.84\ \text{W}}{2.4\ \text{V}} = 0.35\ \text{A}.$$

23 Sharing voltage

On page 24 we saw that when a 3 V battery was connected to two bulbs in series, the ______ was ______ between them. The bulbs were identical, so the voltage was shared ______. The voltage across each was 1.5 V.

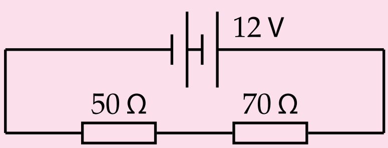
How is voltage shared between components in series if they are different?



We work it out like this:

- the total resistance is $10\,\Omega + 20\,\Omega = 30\,\Omega$
- the $10\,\Omega$ resistor has ______ of the total resistance
- so it takes ______ of the battery voltage $\frac{1}{3} \times 3\,\text{V} = 1\,\text{V}$
- the $20\,\Omega$ resistor has ______ of the total resistance
- so it takes ______ of the battery voltage $\frac{2}{3} \times 3\,\text{V} = 2\,\text{V}$

Example – *Calculate the voltage across the $50\,\Omega$ resistor.*

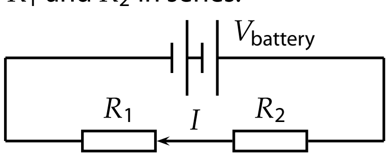


Total resistance $= 50\,\Omega + 70\,\Omega = 120\,\Omega$

The $50\,\Omega$ resistor has a fraction $\dfrac{50\,\Omega}{120\,\Omega}$ of the total resistance.

Its voltage $= \dfrac{50\,\Omega}{120\,\Omega} \times 12\,\text{V} = 5\,\text{V}$

We now explain the rule using the circuit below, where a current I flows through two resistors R_1 and R_2 in series.



The voltage dropped across R_1 is given by _________ (see page 30)
The voltage dropped across R_2 is given by _________
The battery voltage $V_{\text{battery}} =$ _______ $= IR_1 + IR_2 = I\,(R_1 + R_2)$.
So

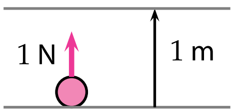
$$V_1 = I \times R_1 = \frac{V_{\text{battery}}}{R_1 + R_2} \times R_1 = \frac{R_1}{R_1 + R_2} \times V_{\text{battery}}$$

Electricity summary questions are on page 59.

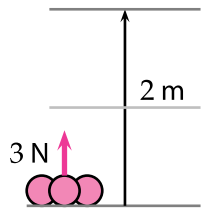
Energy and Balance

24 Work

In this section, we explore the link between energy and force. A _____ can cause stored ______ to be moved to another store. Energy E is measured in _____ (J).



A small apple weighs 1 N. We lift it 1 m.
This needs __ of energy.



Three small apples weigh 3 N.
Lifting them 1 m would need __ of energy.
Lifting them 2 m, requires __ of energy.

The _____________ an object in this way is called the _____________ :

$$\text{Work (J)} = \text{Force applied (N)} \times \text{Displacement change (m)}, \; \Delta E = F\,\Delta s$$

The equation can be re-arranged (see page 9) to give

$$F = \frac{\Delta E}{\Delta s} \qquad \Delta E = F\,\Delta s \qquad \Delta s = \frac{\Delta E}{F}$$

Example 1 – *Calculate the energy given to a cart by its engine, which pulls it 25 m East with a force of 35 N in that direction.*
If we use $+$ to mean 'East' then $F = +35$ N, and $\Delta s = +25$ m, so
$\Delta E = F\,\Delta s = 35\text{ N} \times 25\text{ m} = +875$ J so 875 J is given to the cart.

The displacement change Δs and force F have directions shown by $+$ or $-$.
If the force applied and the displacement are in opposite directions,
Δs and F will have ________ signs, so ΔE will be ________.
Energy will be _________ the object's stores. We say, work is done __ it.

Example 2 – *Calculate the work done by a cycle which stops in 8.0 m thanks to 180 N from its brakes.*
Use $+$ to mean 'forwards'. Then $\Delta s = +8.0$ m.

The force is in the other direction, so $F = -180$ N
$\Delta E = F\,\Delta s = -180$ N $\times$ 8.0 m $= -1440$ J. 1440 J of work is done by it.

Forces at ____________ to motion do ________. Example: you don't need engines and fuel to _____ a car or truck. This fact becomes important when you solve problems in two dimensions.

25 Gravitational potential energy

When you lift an object, the force you apply $(\uparrow)$ is in the direction of motion $(\uparrow)$. ____________ on it, giving it energy. This _________ its store of ____________________ (GPE).

> **Example** – *Calculate the increased store of GPE when you lift an* 8.6 *kg bucket of water* 3.5 *m up a ladder.*
> Minimum force needed to lift the bucket $=$ Weight
> Weight $=$ Mass $\times g = 8.6$ kg $\times$ 10 N/kg $= 86$ N (see page 17)
> Work $=$ Force applied $\times$ Displacement change $= 86$ N $\times$ 3.5 m $= 301$ J
> Gain in GPE $= 301$ J.

This is positive, as the displacement change is in the direction of the applied force (upwards). Usually, we write ______________ to make it clear that we measure displacements upwards when calculating GPE.
We can also write

$$\begin{aligned}\text{Change in GPE} &= \text{Weight} \times \text{Height change} & \Delta E &= W\,\Delta h\\ &= \text{Mass} \times g \times \text{Height change} & &= mg\,\Delta h\end{aligned}$$

When you lower an object, you still have to support it. The force you apply $(\uparrow)$ is opposite to the direction of motion $(\downarrow)$. The object is now __________________, giving you its energy. This ________ its store of gravitational energy.

If an object ______, you are not applying any force to it. It's own weight acts in the direction of motion, increasing its store of motion (______) energy; at a cost of reducing its gravitational potential energy.

26 Power

Power P is the ____________ (or energy transferred) ______________. Power is measured in ______ (W).

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}, \text{ or } P = \frac{\Delta E}{\Delta t}$$

Using the methods on page 9, this equation can be written

$$P = \frac{\Delta E}{\Delta t} \qquad \Delta E = P\,\Delta t \qquad \Delta t = \frac{\Delta E}{P}$$

Example – *Calculate the power needed to do* 1200 *J of work in four minutes.*
We re-arrange $\Delta E = P\,\Delta t$ by dividing both sides by Δt to give

$$P = \frac{\Delta E}{\Delta t} = \frac{1200\ \text{J}}{4 \times 60\ \text{s}} = 5.0\ \text{W}.$$

You may have noticed from the last question that

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}} = \text{Force} \times \frac{\text{Displacement}}{\text{Time taken}} \qquad P = \frac{\Delta E}{\Delta t} = F\frac{\Delta s}{\Delta t}$$

$$= \text{Force} \times \text{Velocity} \qquad P = Fv$$

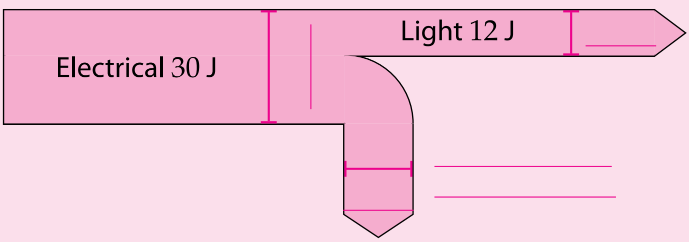
27 Energy flow and efficiency

______ stored can be given to another object or another store.
Energy can not be ________________ nor can it be _________.
This means that the ____ energy does not change.
We say _________________.

Energy stored where we don't want it (or can't use it) is ______ energy.

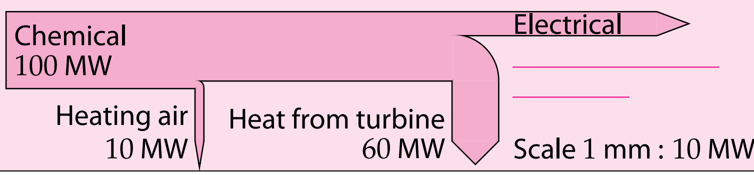
The transfer of energy can be shown in a flow diagram.

Example 1 – *A light bulb uses 30 J of chemical energy to make 12 J of light. Draw a scale diagram showing the energy flow, and calculate the energy wasted.*
The width of the line in our diagram shows the amount of energy. We draw our line 15 mm wide at the start. This represents 30 J. So 1 mm means 2 J.



We can draw diagrams using ______ rather than energy. This is the energy flow ___________.

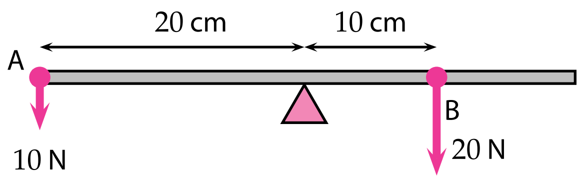
Example 2 – *Calculate the electrical power generated in the power station.*



The percentage of the energy (or power) which does the job we wanted is called the _________. The solar panel in question **??** is ____ efficient, as half of the energy from the sunlight becomes useful electricity.

Example 3 – *Calculate the efficiency of the motor in question* **??**.
The total energy is 1000 J. 300 J is wasted, so $1000 - 300 = 700$ J is used usefully. As a percentage of the total this is
$$\frac{\text{Useful energy}}{\text{Total energy}} \times 100\% = \frac{700\text{ J}}{1000\text{ J}} \times 100\% = 0.7 \times 100\% = 70\%.$$

28 Balancing and moments



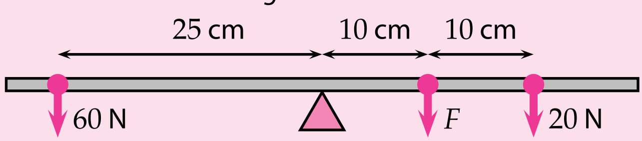
This beam balances because the force which is ______________ is ______________ from the pivot. The two forces have the same ______________ about the pivot. The strength of a turning force is called its ________:

$$\text{Moment}\,(\text{N m}) = \text{Force}\,(\text{N}) \times \text{Displacement from pivot}\,(\text{m})\text{, or } M = Fs$$

If you measure the distances in cm then the moments are measured in _____. Moments can be ______________ ↶ or __________ ↷.

If the ______________________ and the ______________________ are ______, the beam ________.

Example – *Calculate the missing force F needed to balance this beam.*



______________________ ____________ ______________________

________________ ________________

The two moments we know add to 11 N m ↶.
To balance, F must have a 11 N m ↷ moment

$$F \times 0.10\text{ m} = 11\text{ N m, so } F = \frac{11\text{ N m}}{0.10\text{ m}} = 110\text{ N downwards}$$

Next we use ideas about work (page 35) to explain balancing.

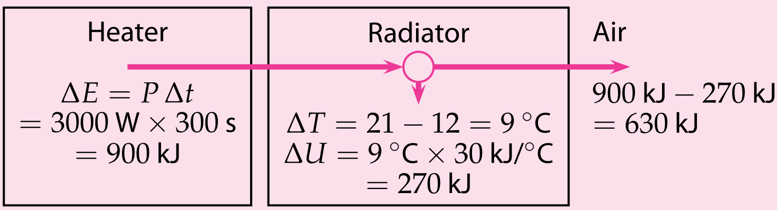
If it takes energy to change the angle of the beam, it is ______________.

29 Energy and Temperature

When an object's temperature goes up, it melts or it boils, its store of ________ energy U increases. Temperature T is measured in degrees Celsius (°C). It is a measure of the ________ internal energy of ____________ in the object.

The change in internal energy ΔU of an object when the temperature goes up by $\Delta T = 1$ °C is called the ____________ of the object, and is measured in J/°C. Your answer to question **??** (c) was the heat capacity of 2 kg of water.

Example 1 – *A 3.0 kW electric radiator has a heat capacity of 30 kJ/°C. The radiator is turned on for five minutes. Its temperature rises from 12 °C to 21 °C. Work out how much energy is passed on to the air in the room.*



The diagram shows that the heater releases 900 kJ of which 270 kJ raises the temperature of the radiator, leaving 630 kJ to escape to the air.

The heat capacity of an object depends on how much material it contains, as well as what it is made of. In question **??** (d), you calculated the heat capacity of 1 kg of water. This is called the ________ heat capacity, as it refers to 1 kg.

Example 2 – *It requires 240 kJ to warm 30 kg of bricks from 5.0 °C to 15.0 °C. Calculate the specific heat capacity of brick.*

Temperature rise $= 15 - 5 = 10.0$ °C

Heat capacity $= \dfrac{240 \text{ kJ}}{10\ °\text{C}} = 24$ kJ/°C

Specific heat capacity $= \dfrac{24 \text{ kJ/°C}}{30 \text{ kg}} = 800$ J/kg °C.

Energy summary questions are on page **??**.

Materials and Forces

30 Density

________ ρ (rho) is the ______________________________ (m^3 or cm^3) of a material. Density is measured in kg/m^3 or g/cm^3.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}, \text{ or } \rho = \frac{m}{V}$$

This equation can be re-arranged using the methods on page 9 to give

$$\rho = \frac{m}{V} \qquad m = \rho V \qquad V = \frac{m}{\rho}$$

Example 1 – *A* 3 *cm* $\times$ 5 *cm* $\times$ 10 *cm block has a mass of* 300 *g. What is the density?*
Volume $V = 3\text{ cm} \times 5\text{ cm} \times 10\text{ cm} = 150\text{ cm}^3$
We re-arrange $m = \rho V$ by dividing both sides by V to give

$$\rho = \frac{m}{V} = \frac{300\text{ g}}{150\text{ cm}^3} = 2.0\text{ g/cm}^3.$$

We need to be able to use cubic metres as well as cubic centimetres.
$1\text{ m} = 100\text{ cm}$ and so $1\text{ m}^3 = (100\text{ cm})^3 = 100^3\text{ cm}^3 = 1000\,000\text{ cm}^3$

Example 2 – *Pure water has a density of* 1.00 *g/cm*^{3}*. Calculate the mass of a cubic metre of water in kilograms.*
1 cm^3 of water has a mass of 1 g.
$1\text{ m}^3 = 1000\,000\text{ cm}^3$, so 1 m^3 of water will have a mass of $1000\,000$ g.
$1000\text{ g} = 1\text{ kg}$, so this water will have a mass of 1000 kg.

We see from the example above that

$$1\text{ g/cm}^3 = 1000\text{ kg/m}^3$$

31 Floating

We use ideas of force (page 17) and density (page 43) to look at buoyancy.

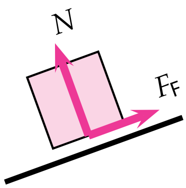
Any object in a liquid or a gas (a fluid) has an upwards force called ________. It is equal to the _______ of liquid or gas _________. This is the fluid which had to be moved out of the way to make room for the object. This idea is known as ____________________. Why is this rule true? Think about an object with mass m and volume V.

The weight of the object ______. We will write the density of the ____ as ρ.
Mass of fluid displaced ______. Weight of fluid displaced _______.

The object will float if __________ which means _______.

In other words, it will float if it is __________ than the fluid.

32 Friction



When an object sits on a surface, there are two forces on it as a result of the contact.

N the ______________ force ______________ the surface, and

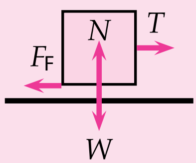
F_F the ______ force resisting motion _____ the surface.

The strength of the friction force depends on

- N (a large normal reaction means F_F can be larger),
- the texture of the surfaces (is it rough or smooth?), and
- whether the object is moving or not.

For _______ objects, the ________ (moving) friction F_F is calculated using the formula $F_F = \mu N$. μ (mu) is the ____________________________.

Example 1 – *A 2.0 kg block is being pushed along a horizontal surface at a steady speed with a force $T = 4.0$ N. Calculate μ.*



Normal reaction N must balance weight

$N = W = mg = 2.0$ kg $\times$ 10 N/kg $= 20$ N.

Motion (velocity) is not changing, so $F_F = T = 4.0$ N

$$F_F = \mu N \text{ so } \mu = \frac{F_F}{N} = \frac{4.0\text{ N}}{20\text{ N}} = 0.2$$

Example 2 – *Calculate the acceleration of a 25 kg mass being pushed along a $\mu = 0.20$ horizontal surface by a 70 N force.*

Surface is horizontal, so $N = W = mg = 25$ kg $\times$ 10 N/kg $= 250$ N

Friction $F = \mu N = 0.20 \times 250$ N $= 50$ N

Resultant force (see page 17) $= 70 - 50 = 20$ N

$$\text{Acceleration (see page 19)} = \frac{\text{Resultant force}}{\text{Mass}} = \frac{20\text{ N}}{25\text{ kg}} = 0.80\text{ m/s}^2.$$

For _________ objects, the formula $F_F = \mu N$ gives the _________ friction force the surface can provide. Here μ is the co-efficient of ____________.

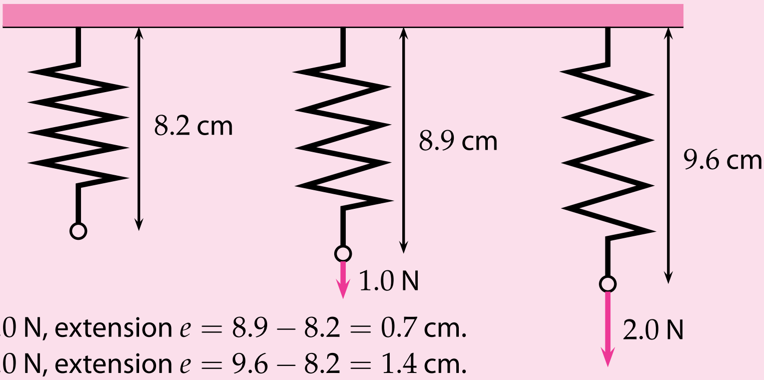
μ for static friction __ μ for dynamic friction on the same surface.

Example 3 – *We push a stationary 60 kg sack on a horizontal floor with a 90 N force. Will it start to move if static $\mu = 0.25$?*
The surface is horizontal, so $N = W = mg = 60$ kg $\times\ 10$ N/kg $= 600$ N.
The maximum static friction is $F_{\mathsf{F}} = \mu N = 0.25 \times 600$ N $= 150$ N,
Our force is smaller than this, so the sack will not start moving.

33 Springs

When you pull a spring you put it in _______. It gets longer, and the extra length is called the _________ (e). It is measured in m or cm.

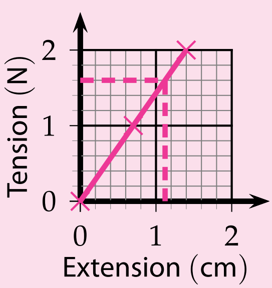
Example 1 – *When a spring is not attached to anything it is* 8.2 *cm long. When it supports a* 1.0 *N weight, its length is* 8.9 *cm. When it supports a* 2.0 *N weight, it is* 9.6 *cm long. Calculate the extension in each case.*



With 1.0 N, extension $e = 8.9 - 8.2 = 0.7$ cm.
With 2.0 N, extension $e = 9.6 - 8.2 = 1.4$ cm.

When calculating the extension, you always subtract the ___________ length (not the previous measurement).
As long as you do not pass the ___________, the spring will go back to its original length when released. The spring in the example obeys ___________: when the force was doubled, the extension also doubled.

Example 2 – *Plot a graph of tension against extension for the spring above, and work out the length of the spring when the tension is* 1.6 *N.*



Reading the graph, a force of 1.6 N matches a 1.1 cm extension.
Now add the original length (8.2 cm) to get
Length $= 1.1 + 8.2 = 9.3$ cm.

Or, we have $e = 0.7$ cm for 1 N. For 1.6 N we have $e = 1.6 \times 0.7$ cm $= 1.12$ cm ≈ 1.1 cm.
Length $= 1.1 + 8.2 = 9.3$ cm.

With some springs, they get shorter when you push them. This puts them in ___________.

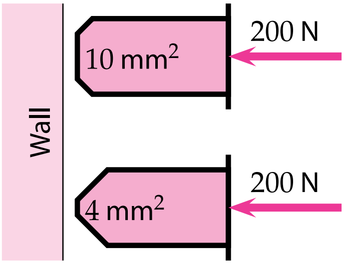
Example 3 – *A spring obeys Hooke's law. It extends by 12.3 cm with a tension of 7.5 N. Calculate the force when the extension is 3.0 cm.*

Tension for 1 cm is $\frac{7.5 \text{ N}}{12.3 \text{ cm}} = 0.610$ N/cm.

For 3.0 cm, we need 3.0 cm $\times$ 0.610 N/cm $= 1.8$ N.

The force needed to extend a spring by 1 cm (or alternatively 1 m) is called its ______________ (k). It is measured in N/cm (or N/m).

34 Pressure



The picture shows two nails and a wall.
The two nails are struck with the same _____.

The _____ nail is more likely to go into the wall, as it is _______. It touches a smaller ___________ of wall, so the force is more focused or concentrated.

The measurement of force on each unit of area is called ________ P.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}, \text{ or } P = \frac{F}{A}$$

If A is measured in m^2, P will be in N/m^2. 1 N/m^2 is also written 1 Pa.
If A is measured in cm^2, P will be in N/cm^2.
If A is measured in mm^2, P will be in N/mm^2.

Example 1 – *Calculate the force needed to apply a pressure of 50 N/cm^2 over a 4 cm $\times$ 10 cm area. Area = 4 cm $\times$ 10 cm = 40 cm^2.*
As Pressure $= \frac{\text{Force}}{\text{Area}}$, multiplying both sides by Area gives
Force = Pressure $\times$ Area = 50 N/cm^2 $\times$ 40 cm^2 = 2000 N

When driving over a muddy field, large wheels are used to make the area of contact _____. The same _____ then causes less ________. The vehicle is less likely to sink in the mud and get stuck. When we want to compare pressures

in different units, we remember:
1 m = 100 cm. This means 1 m^2 = $(100\text{ cm})^2$ = 100^2 cm^2 = 10 000 cm^2

Example 2 – *Convert a pressure of 10 N/cm^2 into Pa.*

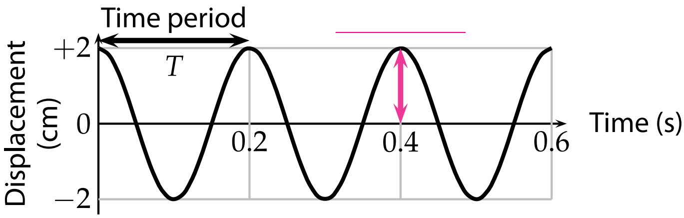
$$\frac{10\text{ N}}{1\text{ cm}^2} = \frac{10\text{ N}}{(0.01\text{ m})^2} = \frac{10\text{ N}}{0.01^2\text{m}^2} = \frac{10\text{ N}}{0.0001\text{m}^2} = 100\,000\text{ N/m}^2$$

1 Pa = 1 N/m^2, so the answer is 100 000 Pa = 100 kPa.

Force and materials summary questions are on page 61.

Waves

35 Frequency



An __________ is a __________ motion. From the ____________________ graph, we see that the repeating part lasts _____. This is called the ____________ T and is measured in seconds (s).

The largest displacement from the centre is called the __________. This oscillation has an amplitude of _____.

The number of times the motion repeats each second is called the __________ f and is measured in hertz (Hz).

> **Example** – *Calculate the frequency of the oscillation in the graph above.*
> The time period is $T = 0.2$ s.
> The number of times the motion repeats each second is $\dfrac{1.0\ \text{s}}{0.2\ \text{s}} = 5$.
> The frequency is 5 Hz.

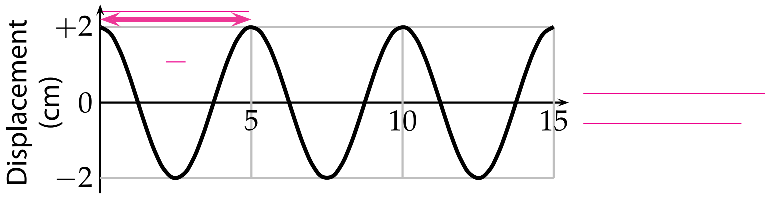
$$\text{Frequency (Hz)} = \frac{1}{\text{Time period (s)}}, \text{ or } f = \frac{1}{T}. \text{ Re-arranging gives } T = \frac{1}{f}.$$

For large frequencies, 1 kHz $=$ ________, 1 MHz $=$ ____________.
For small times, 1 ms $=$ _______, 1 μs $=$ ___________ (see page 27).

36 Wavelength and the wave equation

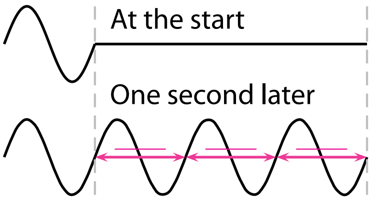
A _____ carries _______ from one place to another using oscillations. The wave can also carry ____________.

If we take a photo of a wave, the length of the repeating section is called the ____________. Its symbol is λ (lambda). The wavelength is the distance from one _____ to the next.



The wavelength of the wave above is ____.

If we know the __________ and _________ of a wave, we can work out its _____. The diagram shows the front of a wave going forward for one second.



Frequency is 3 Hz, wavelength is 2 m.
In one second, _ new waves are made.
Length of new wave is ____________.
The wave's front moves ___ each second.
The wave's speed is _____.

The formula for wave speed is

$$\text{Speed (m/s)} = \text{Frequency (Hz)} \times \text{Wavelength (m)}, \text{ or } v = f\lambda.$$

This equation can be re-arranged using the methods on page 9 to give

$$f = \frac{v}{\lambda} \qquad v = f\,\lambda \qquad \lambda = \frac{v}{f}$$

Example – *A wave's speed is 20 m/s and its wavelength is 0.40 m. What is its frequency?*
We re-arrange $v = f\,\lambda$ by dividing both sides by λ to give

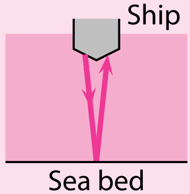
$$f = \frac{v}{\lambda} = \frac{20 \text{ m/s}}{0.4 \text{ m}} = 50 \text{ Hz}.$$

37 Echoes

You can measure the time taken for a wave to travel to a barrier, ______ off it and ______. If you know the ______ of the wave, you can work out the ________ to the barrier.

We use this idea to measure the ______ of the sea bed, to monitor where aircraft are in the sky, and to make medical images.

Example – *An ultrasound pulse travels at* 1400 *m/s in sea water. It takes* 0.61 *s to travel downwards from a ship to the sea bed, reflect and return to the ship. How deep is the sea?*



Distance travelled = Speed × Time
$= 1400\text{ m/s} \times 0.61\text{ s} = 854\text{ m}$
This is distance travelled ____________.
Depth of sea $= \dfrac{854\text{ m}}{\_} = 427\text{ m}$.

We can write this as using a formula

$$\text{Distance to barrier (m)} = \frac{\text{Wave speed (m/s)} \times \text{Time (s)}}{2}, \text{ or } s = \frac{vt}{2}$$

The _ is needed because the wave travels the distance to the barrier _____.

In these questions, use these speeds:
- speed of sound (or ultrasound) in air = 330 m/s,
- speed of sound (or ultrasound) in water or the human body = 1400 m/s,
- speed of radio, light or microwaves in air (or space) = $300\,000\,000$ m/s.

In these questions, you will need to know unit prefixes, as explained on page 27. The ones you will need here are

$$1\text{ ms} = \_\_\_\_\text{ s} = \_\_\_\_\text{ s}$$
$$1\ \mu\text{s} = \_\_\_\_\text{ s} = \_\_\_\_\_\_\_\_\text{ s}$$
$$1\text{ ns} = \_\_\_\_\text{ s} = \_\_\_\_\_\_\_\_\_\_\_\text{ s}$$

Waves summary questions are on page 62.

Calculation Practice

39 Electricity Calculation Practice

40 Energy and Balance Calculation Practice

41 Materials and Forces Calculation Practice

Extra Questions

42 Force and Motion summary questions

43 Electricity summary questions

44 Energy summary questions

45 Materials and Forces summary questions

46 Waves summary questions

47 Challenge questions

These questions can be answered using the knowledge in this book, but creative thinking will also be needed. If you are not sure how to start, try

- drawing a diagram, and label any measurements or forces
- writing down any equations or principles which may be useful
- thinking what you can work out from what you know
- thinking what might be needed before you can get the answer
- changing the problem to make it easier, and solve that first

48 Dimensional analysis - algebra with units

We can check whether an equation is sensible by doing algebra with the units. On these pages we will use the notation:

$[F]$ means 'units of F'.

Example 1 – *Two editions of a textbook have different formulae for the final speed v of an object after an acceleration a over a distance s. One says $v = 2as$, the other says $v^2 = 2as$. Which is more likely to be correct?*

$$[2as] = [as] = [a] \times [s] = \frac{\mathrm{m}}{\mathrm{s}^2} \times \mathrm{m} = \frac{\mathrm{m}^2}{\mathrm{s}^2} = \left(\frac{\mathrm{m}}{\mathrm{s}}\right)^2$$

This is the square of the unit of speed $[v^2]$, so we choose $v^2 = 2as$.

Plain numbers like 2 or π do not have units, so the 2 in the example above did not change the unit. We can also often predict the form of a formula.

Example 2 – *A geographer measures the cross sectional area A of a river and its speed v, and multiplies them. What might Av represent?*

$$[Av] = [A] \times [v] = \mathrm{m}^2 \times \frac{\mathrm{m}}{\mathrm{s}} = \frac{\mathrm{m}^3}{\mathrm{s}} = \frac{[V]}{[t]}$$

This could be the volume V of water flowing past each second.

Some units have more than one way of being written. An example is the unit of power W $=$ J/s $=$ V$\times$A. To make analysing equations simpler, we need a unique form for each unit. To do this, we work out an equivalent for each named unit which only uses kg, m, s and A.

Example 3 – What is the unit of force (the newton N) when written with only kilograms, metres and seconds?
On page 19 we see that $F = ma$,
and so N $= [F] = [m] \times [a] =$ kg $\times$ m/s^2 $=$ kg m/s^2.