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
Force	F	N
Friction force	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	t	s
Voltage	V	V
Volume	V	m^3
Speed or velocity	v	m/s
Weight	W	N

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

Δ (delta) means change in. So ΔT means change in temperature.

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.

Velocity and Displacement		Energy or Work Done	
$\Delta s = v\,\Delta t$	P 11	$\Delta E = F\,\Delta s$	P 47
Acceleration and Velocity		Gravitational Potential Energy	
$\Delta v = a\,\Delta t$	P 15	$\Delta E = W\Delta h = mg\,\Delta h$	P 49
Weight		Energy and Power	
$W = mg$	P 21	$\Delta E = P\,\Delta t$	P 51
Force and Acceleration		Energy and Temperature change	
$F = ma$	P 23	$\Delta E = mc\Delta T$	P 57
Momentum			
$p = mv$	P 25		
Momentum and Force		Moment	
$\Delta p = F\,\Delta t$	P 27	$M = Fs$	P 55

Energy and Voltage		Density	
$E = QV$	P 31	$\rho = m/V$	P 59
Charge and Current		Friction	
$\Delta Q = I\,\Delta t$	P 35	$F = \mu N$	P 63
Resistance		Springs and Force	
$V = IR$	P 41	$F = ke$	P 65
Electrical Power		Pressure	
$P = IV$	P 43	$P = F/A$	P 67

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.

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

In British schools, Year 9 (age 14) is a significant year in a student's education. This is the year, typically, when scientific studies become more detailed. Students will have met some equations before, but it is at this stage that their mathematical education enables them to delve deeper.

The material in this book builds on concepts which have already been introduced to students in a qualitative fashion, such as series and parallel circuits, speed and energy. This book and its questions place such ideas on a more mathematical footing. Practise of this form is a vital precursor to further study in Physics. This is especially true in regard of GCSE courses, which have become more mathematical in nature in the recent past.

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 for what is to follow. Equally, these questions 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 on http://isaacphysics.org. Teachers may set questions to their classes and monitor progress. Equally, students completing questions on the website receive immediate feedback on their answers.

ACM
Cambridge, 2021

Suggestions for use in lessons

Traditional approach

- Introduce the concept you wish to teach – perhaps by giving an example of a situation where this is going to be useful in the solution.
- If desired, you can project the relevant page from the teacher's pdf – with essential details, but with some key words and definitions missing, and spaces for certain explanations. Before students have opened their Isaac books, teach the main concepts, give the definitions and use class questioning and discussion to agree the answers to the 'cloze text' parts: `isaacphysics.org/books/phys_book_yr9`
- Students then turn to the relevant page, and read the 'notes' section. Students may make their own notes in their exercise books if you wish.
- While many students will be ready to begin the questions straight away, others will need your specific help in going over important points in the notes.
- By the time that the students who needed your help with the notes are ready to start the more straightforward questions, the others will have reached the more tricky questions, and will wish assistance. You may choose to make certain questions optional.
- Follow-up questions can be selected from the Isaac Physics website for homework.

Use with 'Flipped Lessons'

- Here, you would set a homework to study the notes of a particular page, and complete some of the more straightforward questions – you can check their progress using isaacphysics.org.
- Students then work on questions in class, as above. The teachers' version of the text (with spaces for the explanations and results of class discussion) could be projected onto the screen and discussed as the starter for the lesson to see how much students remember and understand from their own reading.

Contents

Force and Motion

1 Displacement

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

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

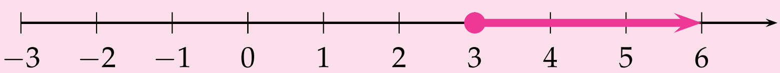
If the change of displacement is positive, the object is moving to the right.
If the change is negative, the object is moving to the left.

Δ (delta) means change in.

$$\text{Change in displacement } (\Delta s) = s_{\text{final}} - s_{\text{starting}}$$

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

Example 1 – *What is the change in displacement for the motion shown below? What is 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

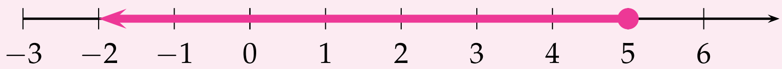
Example 2 – *An object moves directly from $s = +3$ cm to $s = -5$ cm. What is the change in displacement? What is the distance travelled?*
Change in displacement $\Delta s = -5 \text{ cm} - (3 \text{ cm}) = -8$ cm
Distance moved $= 8$ cm

1.1 What is the change in displacement when an object moves from $s = +1$ cm to $s = +7$ cm? What is the distance travelled?

1.2 What is the change in displacement when an object moves from $s = +4$ cm to $s = -3$ cm? What is the distance travelled?

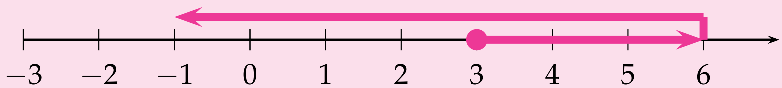
1.3 Where does something end up if $s_{\text{starting}} = -1$ cm and $\Delta s = +6$ cm?

1.4 What is the change in displacement for the motion shown below? What is the distance travelled?



1.5 An object moved 10 cm to the right, and ended up at $s = 3$ cm. Where did it start?

Example 3 – *What is the change in displacement for the two-stage motion shown below? What is the distance travelled?*



Starting position $s_{\text{starting}} = 3$ cm, final position $s_{\text{final}} = -1$ cm
Change in displacement $\Delta s = (-1\text{ cm}) - 3\text{ cm} = -4$ cm
Distance moved $= 3\text{ cm} + 7\text{ cm} = 10$ cm

1.6 What is the overall change in displacement if an object moves from $s = -2$ cm to $s = -8$ cm then to $s = +7$ cm?

1.7 What is the total distance travelled if an object moves from $s = +23$ cm to $s = +8$ cm then to $s = +18$ cm?

1.8 For motion from -2 cm to $+10$ cm, then to -1 cm, calculate the

(a) displacement change in the first stage of the motion,

(b) displacement change in the second stage of the motion,

(c) the overall displacement change.

(d) How are your last three answers related?

1.9 An ant starts at $s = +4$ cm. It has displacement changes of $\Delta s = +8$ cm, then $\Delta s = -20$ cm then $\Delta s = +12$ cm. Where does it end up?

1.10 A snail starts at $s = 0$ cm. It has displacement changes of $\Delta s = -9$ cm, then $\Delta s = +20$ cm then $\Delta s = -8$ cm. What extra displacement change would be needed to return it to its starting point?

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?*

$$\begin{aligned} 1.61\text{ km} &= 1.00\text{ miles} \\ &\quad \text{multiply by } 5 \text{ on each side} \\ 5 \times 1.61\text{ km} &= 5.00\text{ miles} \\ 5\text{ miles} &= 5 \times 1.61\text{ km} = 8.04\text{ km} \end{aligned}$$

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 $\frac{1.61\text{ km}}{1.00\text{ miles}}$.

2.1 There are 2.54 cm in one inch (1 in). Convert

(a) 141 cm into inches,

(b) 30.5 cm into inches,

(c) 12 inches into centimetres,

(d) 0.40 in into centimetres.

(e) How many inches are there in 100 cm?

2.2 Sailors and pilots use nautical miles. 1 nautical mile $= 1.85$ km

(a) What is 62 nautical miles in km?

(b) What is 94 km in nautical miles?

2.3 You buy a car and find that the speedometer is in km/hr (kilometres travelled each hour). To enable you to stay within the British speed limit of 30 mph (30 miles travelled each hour), work out how many km/hr are equivalent to 30 mph.

Example 3 – *What is 14 miles in nautical miles?*

$$14 \text{ miles} = 14 \cancel{\text{miles}} \times \frac{1.61 \text{ km}}{1.00 \cancel{\text{miles}}} = 22.5 \text{ km}$$

$$22.5 \text{ km} = 22.5 \cancel{\text{km}} \times \frac{1.00 \text{ nautical miles}}{1.85 \cancel{\text{km}}} = 12.2 \text{ nautical miles}$$

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

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

2.4 Convert 43 nautical miles into miles.

2.5 A ship travels at 12 kt (that means 12 nautical miles each hour). How many miles does it travel each hour?

2.6 On a day when £1.00 is equivalent to €1.16, what is the price of a €15.50 calculator in British pounds?

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

2.7 What is 287 cm in m?

2.8 What is 87 mm in m?

2.9 What is 32 nautical miles in m?

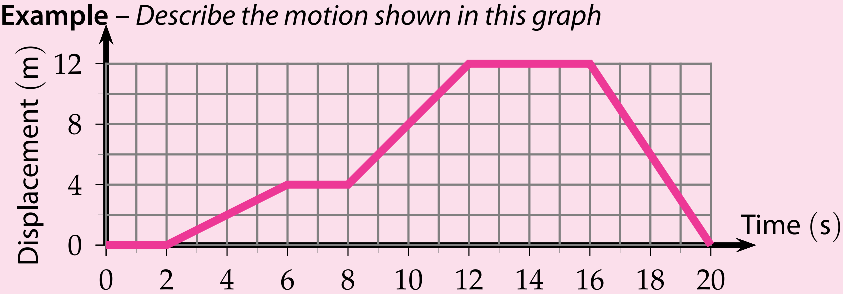
2.10 What is 0.001 miles in cm?

3 Displacement – time graphs

On a displacement – time graph, we show where something is at different times.

The displacement s is plotted on the y or vertical $\uparrow$ axis.
The time t is plotted on the x or horizontal $\rightarrow$ axis.
Straight lines represent motion at a steady (constant) speed.
Straight, horizontal lines represent times when the object is not moving.
The steeper the line, the faster the object.

Example – *Describe the motion shown in this graph*



The object remains stationary 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 steady speed.
It reaches $s = 12$ m four seconds later, at $t = 12$ s.
It stays there for 4 s, then reverses to its starting point at $t = 20$ s.

3.1 Answer these questions using the graph in the example.

(a) At what times was the object at $s = 6$ m?

(b) Where was the object at $t = 10$ s?

(c) For how many seconds was the object moving forwards?

(d) What was the total distance travelled?

(e) What was the displacement change between $t = 8$ s and 10 s?

(f) Was it moving faster at $t = 4$ s or at $t = 11$ s?

3.2 Make a graph with displacement from 0 to 4 km, and time from 0 to 20 min. Then draw the line for a person who sets out at $t = 0$ min. They walk 0.8 km before they reach a bus stop 8 min later. They wait until $t = 15$ min, then catch the bus. This takes them to town ($s = 4$ km) five minutes later.

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.

3.3 Where is the lift when s is negative?

3.4 During which times is the lift moving upwards?

3.5 Where is the lift when $t = 6$ s? Give your answer as a value of s and also a floor number.

3.6 During which part of the motion is the lift fastest? How can you tell?

3.7 For how many seconds is the lift stationary?

3.8 When the lift is moving up only one floor (storey), how much time does it take?

3.9 When the lift is moving up only one floor (storey), how many metres does it move each second?

3.10 What is the change in displacement each second when the lift is moving downwards?

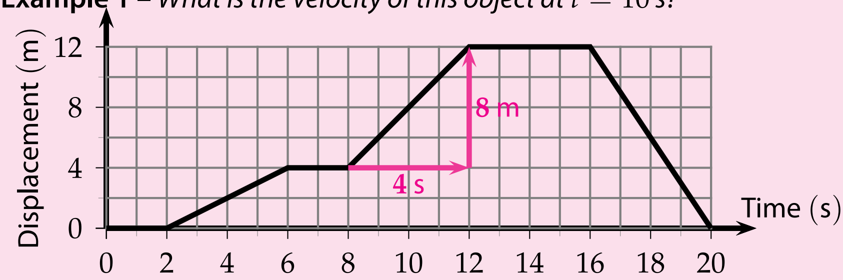
4 Velocity

The change in displacement Δs each second is called the velocity 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 displacement change each second.

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

Example 1 – *What is 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 $\Delta t = 12 - 8 = 4$ s.
The displacement change $\Delta s = 12 - 4 = +8$ m.
Velocity $v = \frac{\Delta s}{\Delta t} = \frac{+8\text{ m}}{4\text{ s}} = +2$ m/s.

The velocity is given by the gradient of the line on the displacement – time graph. Gradient is the change in the vertical $\uparrow$ co-ordinate divided by the change in the horizontal $\rightarrow$ co-ordinate.

4.1 In the graph above, what is the velocity at

(a) $t = 4$ s?

(b) $t = 7$ s?

(c) $t = 18$ s?

(d) $t = 9$ s?

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

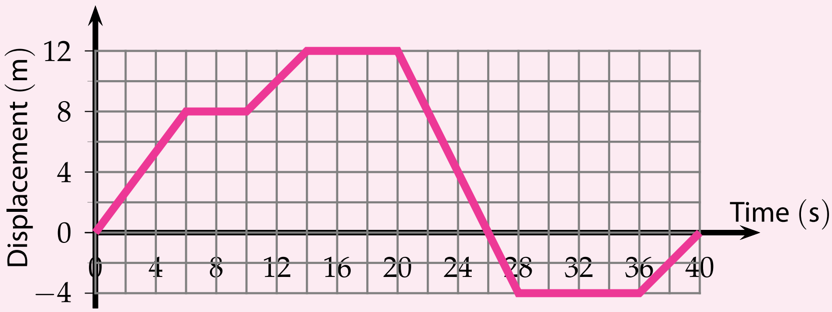
$+$ means 'moving forwards' or 'moving upwards'

$-$ means 'moving backwards' or 'moving downwards'

The speed is the magnitude (size) of the velocity (without its direction). If $v = -3$ m/s, it means moving backwards, travelling 3 metres every second. The speed is just 3 m/s (without the $-$ sign).

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

Example 2 – *What is 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.



4.2 What is the velocity at
- (a) $t = 4$ s?
- (b) $t = 8$ s?
- (c) $t = 12$ s?
- (d) $t = 16$ s?
- (e) $t = 22$ s?
- (f) $t = 27$ s?
- (g) $t = 30$ s?
- (h) $t = 37$ s?

4.3 What is the speed at $t = 24$ s?

4.4 What is the total distance moved in the first 14 s of the motion?

4.5 What is the average speed in the first 14 s of the motion?

4.6 What is the average speed in the first 26 s of the motion?

4.7 What is the total distance moved in the motion shown?

4.8 What is the average speed over the whole graph?

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 $A = bc$

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

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

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

We can also use algebra:

If $b = \frac{A}{c}$ $\xrightarrow{\times c \text{ on both sides}}$ $bc = \frac{A\cancel{c}}{\cancel{c}}$ then $bc = A$

and

If $bc = A$ $\xrightarrow{\div b \text{ on both sides}}$ $\frac{\cancel{b}c}{\cancel{b}} = \frac{A}{b}$ then $c = \frac{A}{b}$.

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

moving c in $b = \frac{A}{c}$ gives $bc = A$ moving b in $bc = A$ gives $c = \frac{A}{b}$

Example 1 – *If $B = fg$, what is g?*

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

5.1 In the following equations, what is a?

(a) $b = ac$
(b) $q = ra$
(c) $d = av$
(d) $h = 2a$
(e) $v = au$
(f) $w = ra$
(g) $g = ac$
(h) $1 = na$

5.2 In the following equations, what is v?

(a) $b = \frac{v}{c}$
(b) $w = \frac{v}{p}$

(c) $f = \frac{g}{v}$

(d) $t = \frac{v}{1}$

(e) $x = \frac{q}{v}$

(f) $z = \frac{1}{v}$

Example 2 – *If $y = kx$ and $y = 0.25$ when $x = 0.4$, what is k?*
Rearrange $y = kx$ by dividing both sides by x: $\frac{y}{x} = k$
So $k = \frac{y}{x} = \frac{0.25}{0.4} = 0.625$

5.3 If $y = kx$ and $y = 6$ when $x = 2$, what is k?

5.4 If $s = ut$ and $s = 32$ when $t = 8$, what is u?

5.5 If $q = It$ and $q = 0.25$ when $t = 250$, what is I?

5.6 If $a = \frac{v}{t}$ and $a = 10$ when $v = 5$, what is t?

Example 3 – *If $y = kx$, and $y = 90$ when $x = 6$, what is 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. $y = kx = 15 \times 4 = 60$

5.7 If $s = ut$, and $s = 30$ when $t = 0.50$, what will t be when $s = 15$?

5.8 If $T = An$, and $A = 120$ when $n = 3$, what will A be when $n = 24$?

Example 4 – *If $\frac{a}{b} = \frac{c}{d}$ and $a = 2$, $b = 6$ and $c = 12$, what is 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 $d = \frac{6 \times 12}{2} = 36$

5.9 If $\frac{r}{s} = \frac{u}{v}$, $r = 2.5$ and $v = 12$,

(a) work out u if $s = 6$.

(b) work out s if $u = 10$.

6 Calculating velocities

On page 7, we introduced the formula for velocity. This is the displacement change each second:

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

Since the velocity is the displacement change each second, you can calculate the displacement change:

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

The time taken can also be worked out. To do this, you divide the total displacement change by the displacement change each second. This is the same as dividing by the velocity. 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:

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

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

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

6.1 How much time does it take a coach at $+26$ m/s to travel $+1000$ m?

6.2 How far will an object at $+12$ m/s travel in 9.5 s?

6.3 The world record for running 400 m is 40.3 s. What is the velocity?

6.4 How far will a car travel during the 0.60 s reaction time of its driver

(a) when the velocity is 13 m/s (this is 30 mph)?

(b) when the velocity is 31 m/s (this is 70 mph)?

6.5 Complete the table below, filling in the missing values

Displacement change (m)	**Velocity (m/s)**	**Time taken (s)**
$+400$	$+8.4$	(a)
-0.15	-0.025	(b)
$+1500$	(c)	25
92 000	(d)	1460
(e)	-31	250
(f)	$+250$	7200

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?*

$$\Delta s = v\,\Delta t = \frac{230\text{ miles}}{1\text{ hr}} \times 45\text{ min} = \frac{230 \times 1610\text{ m}}{1 \times 60\text{ min}} \times 45\text{ min}$$
$$= \frac{230 \times 1610\text{ m} \times 45\,\cancel{\text{min}}}{60\,\cancel{\text{min}}} = 280\,000\text{ m} = 280\text{ km}$$

6.6 Complete the table:

Displacement change	**Velocity**	**Time taken**
90 miles	18 m/s	(a)
42.2 km	(b)	2.00 hr
(c)	13 mph	25 min

6.7 A ship travels at 21 kt, which means 21 nautical miles each hour.

(a) How far will it travel each hour in metres?

(b) What is its speed in m/s?

(c) How much time will it take to cover a distance of 230 km?

6.8 A garden snail can move half an inch every second. How much time will it take to cross an 80 cm pavement?

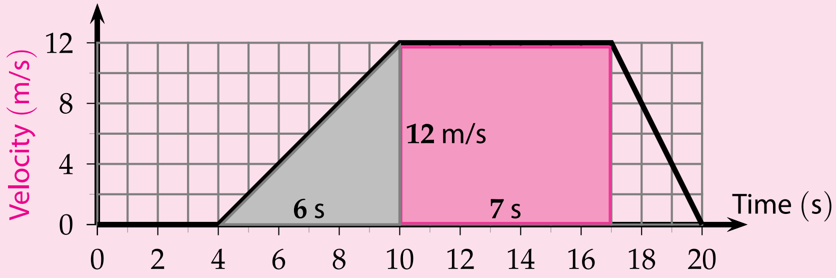
10 Displacement from a velocity – time graph

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

Displacement change (m) = Velocity (m/s) × 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.

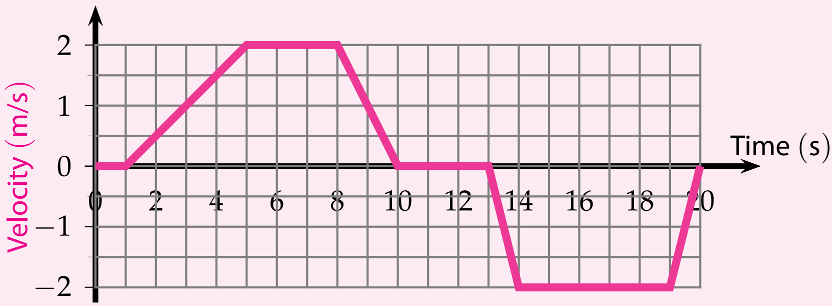
This displacement change is also equal to the area of the coloured rectangle.
So the displacement change = area under a velocity–time graph.
Next we look at a part of the graph when the velocity is changing:

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 $= \frac{1}{2} \times 6$ s $\times$ $(+12$ m/s$) = +36$ m
Method 2 – Velocity changes steadily from 0 m/s to +12 m/s
so average velocity $= \dfrac{0+12}{2} = +6$ m/s
Displacement change = Average velocity × Time
$= +6$ m/s $\times$ 6 s $= +36$ m

10.1 How far does the object move between $t = 17$ s and 20 s?

10.2 What is the total displacement change over the whole graph?

The next questions are based on this graph. It shows the velocity of a hoist on a building site. Positive values of v are used when the hoist is rising.



10.3 What is the displacement change between the times shown below? Don't forget that negative velocities will lead to negative displacement changes.

(a) t=0 s and $t = 1$ s
(b) t=5 s and $t = 8$ s
(c) t=14 s and $t = 19$ s
(d) t=1 s and $t = 5$ s
(e) t=1 s and $t = 3$ s
(f) t=8 s and $t = 10$ s
(g) t=13 s and $t = 14$ s
(h) t=19 s and $t = 20$ s

10.4 What is the total displacement change while the hoist is moving upwards?

10.5 What is the total displacement change while the hoist is moving downwards?

10.6 What is the total displacement change over the whole motion?

10.7 What is the total distance moved over the whole graph?

10.8 Using your answers in question 3 parts (d) and (e), complete this sentence: In a constant acceleration from rest, when you double the time, the displacement...

10.9 A car's braking distance from 30 mph is 14 m. Use your answer to question 8 to work out the distance taken for a car to stop from 60 mph.

10.10 What is the displacement change of the hoist between $t = 8$ s and $t = 9$ s? Can you find more than one way of working it out?

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:

$$\text{Momentum (kg m/s)} = \text{Mass (kg)} \times \text{Velocity (m/s)}, \text{ or } p = mv$$

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 $= 750\text{ kg} \times (-15\text{ m/s}) = -11\,250\text{ kg m/s}$

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.

13.1 Complete the table below, filling in the missing values

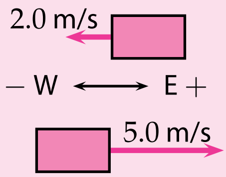
Mass (kg)	Velocity (m/s)	Momentum (kg m/s)
2.5	+9.2	(a)
5.0	−8.4	(b)
14	(c)	+120
11 000	6.5 West	(d)
(e)	80 East	10 000 000 East

13.2 Calculate the momentum of a 0.82 kg motion trolley moving at +0.65 m/s.

13.3 Calculate the momentum of a 0.12 kg apple moving to the West at 3.5 m/s.

13.4 Calculate the mass of a supermarket trolley if it has a momentum of 37.2 kg m/s when travelling at 1.24 m/s.

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
$p = 0.84 \text{ kg} \times (-2.0 \text{ m/s}) = -1.68 \text{ kg m/s}$

End: With the $+$ sign, we write $v = +5.0$ m/s
$p = 0.84 \text{ kg} \times (+5.0 \text{ m/s}) = +4.20 \text{ kg m/s}$

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

13.5 A 1200 kg van was travelling East at 13 m/s. It accelerates to 25 m/s. Calculate the change in momentum.

13.6 A 1200 kg van was travelling West at 25 m/s. It slows down to 13 m/s. Calculate the change in momentum.

13.7 A 1200 kg van was travelling East at 13 m/s. It does a U-turn and then travels West at the same speed. Calculate the change in momentum.

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

13.8 A 2.4 kg ball is thrown upwards at 15 m/s. It loses 55 kg m/s of momentum. What will its new velocity be?

13.9 A 30 g ball falls to the ground at 6.5 m/s. It bounces up at 60 % of that speed. What is the momentum change ?

13.10 How fast would a $350\,000$ kg supertanker have to travel to have as much momentum as a train made of five $16\,000$ kg carriages and a $20\,000$ kg locomotive travelling at 44 m/s (this is 100 mph)?

Electricity

16 Energy, charge and voltage

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

The energy of each coulomb of charge is called the voltage or potential. The voltage change across a component is also called a potential difference.

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,
- increases when charge passes a battery, cell or generator
- drops when charge passes a bulb, motor or resistor

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

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

16.1 Complete the table below, filling in the missing values

Energy change (J)	Voltage (V)	Charge (C)
(a)	6.0	0.50
(b)	12.0	2.5
250	(c)	5.0
250	(d)	20.0
18	0.6	(e)

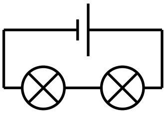
16.2 A 5.0 V USB supply gives 0.45 J of energy to a mobile phone on charge. How much charge is needed?

16.3 A car headlamp which takes 1200 J of electrical energy from 100 C of charge. What is the voltage across it?

16.4 The mains in a home has a voltage of 230 V. How much energy is delivered to an oven when 9720 C of charge passes through it?

16.5 The National Grid enables 0.025 C of charge to carry $10\,000$ J of electrical energy. What voltage is needed?

In a series circuit, there are no junctions. Each charge passes through all of the components (one after another). It loses some of its energy to each component.



16.6 A 9.0 V battery is connected to a series circuit containing two identical light bulbs. 1.5 C of charge flows around the circuit.

(a) What is the energy change of the charge in the battery?

(b) How much energy will this charge give to each light bulb?

(c) What is the voltage across each light bulb

16.7 Two different lamps are connected in series to a 12 V battery. The voltage drops by 7.5 V as 10 C of charge goes through the first lamp.

(a) How much energy was given to this charge by the battery?

(b) How much energy was released in the first bulb?

(c) How much energy will be released in the second bulb?

(d) What is the voltage across the second bulb?

In a parallel circuit, the energy carried by each charge does not change as it passes a junction. Not all charge takes the same route.

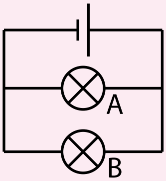
16.8 Two different bulbs are connected in parallel to a 9.0 V battery. Of 12 C leaving the battery, 5.0 C passes through lamp A before returning to the battery. How much

(a) energy is given to this 5.0 C by the battery?

(b) energy is taken from the 5.0 C by lamp A?

(c) What is the voltage across lamp A?

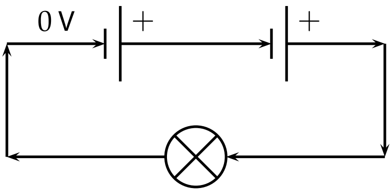
(d) How much charge passes lamp B?



17 Voltage in circuits

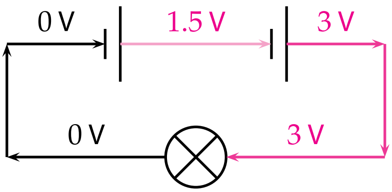
We use the idea of voltage (the energy content of charge) to analyse circuits.

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.



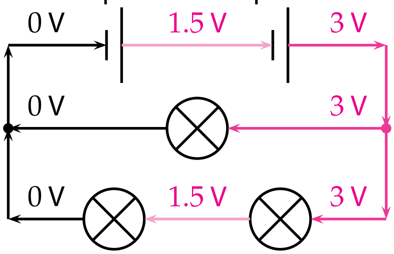
We follow the arrows, starting at the 0 V mark. Each cell adds $+1.5$ V. We label each wire with its voltage. We use a colour code, here black means 0 V.

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 brighter than normal.

Here is a completed example for a circuit with junctions:

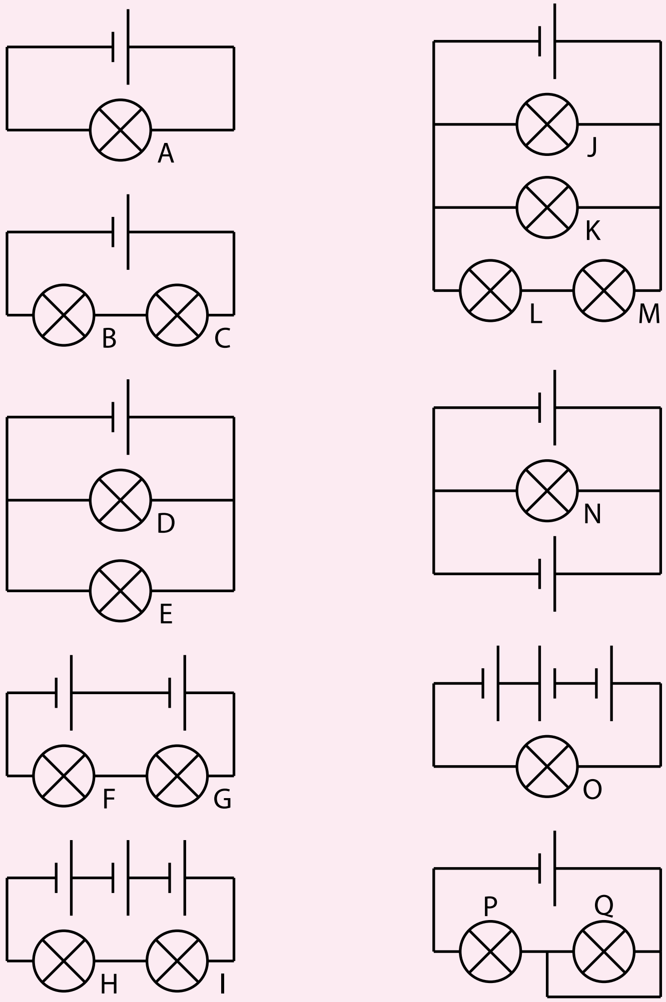


Top bulb:
voltage drop 3 V, bright.

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 half way between 0 V and 3 V.

Label the circuits below with the voltage of each wire. Then write down the voltage drop for each lamp.
Hint: if the charge goes through a cell the wrong way, then the voltage will drop by 1.5 V.



19 Large and small numbers

Negatively charged particles called electrons 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.

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

Example 1 – *Write $0.000\,03$ C without 'leading zeroes' (zeroes in front of the '3').*
$0.000\,001$ 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).

19.1 Write the following measurements without leading zeroes.

(a) 0.005 A
(b) $6\,00\,000$ C
(c) 0.0056 A
(d) $8\,250\,000\,000$ C

19.2 Write the following measurements without a prefix.

(a) 23 kN
(b) 2 mC
(c) 0.3 mA
(d) 240 kN

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 add 1 to the power, the number gets multiplied by 10.
When you subtract 1 from the power, the number gets divided by 10.

19.3 Write these numbers in full.

(a) 10^5 (b) 10^{-6}

19.4 Write these numbers using powers of ten.

(a) $10\,000\,000$ (c) 0.001

(b) $0.000\,01$ (d) $100\,000$

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 standard form 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.

19.5 Write the charge on one electron in standard form.

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

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

$= 6.25 \times 10^9$

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

19.6 How many electrons are there in -3.4×10^{-13} C?

19.7 An LED carries a current of 50 mA in electrons.

(a) How much charge flows in 1 s?

(b) How many electrons flow each second?

19.8 1.25×10^{22} electrons flow out of a cell in 2000 s.

(a) What is the total charge?

(b) What is the current?

21 Resistance

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

Resistance R is measured in ohms (Ω).

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

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 Ω is connected to a 240 V supply. Calculate the current.*
We re-arrange $V = IR$ by dividing both sides by R to give

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

21.1 Complete the table below, filling in the missing values.

Resistance (Ω)	**Current (A)**	**Voltage (V)**
25	3.0	(a)
400	(b)	5.0
5.0	(c)	1.5
(d)	0.25	12
(e)	11.5	230

21.2 The resistance of the 230 V mains cable to a home is 1.8 Ω. If the ends of the wires touch each other, there won't be any other resistance in the circuit. How much current would flow?

21.3 A 50 kΩ resistor is connected to 20 V. What is the current?

21.4 A $20\ k\Omega$ sensor is connected to a 12 V battery. Calculate the current in milliamps (mA).

The resistance of most components depends on the current passing through them. However resistors and wires held at a steady temperature have the same resistance at all useful currents. We say these obey Ohm's law, and call them ohmic conductors.

21.5 A resistor passes a current of 0.25 A when connected to 5.0 V.

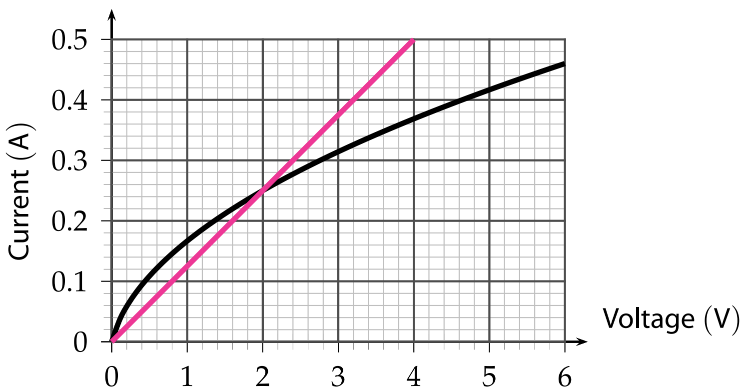
(a) What is its resistance in Ω?

(b) What will the current be when connected to 15 V?

(c) What voltage would be needed for a current of 0.33 A?

21.6 A wire has a resistance of $24\ \Omega$. What will be the voltage across it when it carries a current of 25 mA?

The graph shows the current through a lamp (black line) and resistor (coloured line) for different voltages. Use this data for questions 7 to 9.



21.7 Calculate the resistance of the lamp when the

(a) voltage is 6.0 V

(b) current is 0.4 A

(c) voltage is 2.0 V

(d) current is 0.1 A.

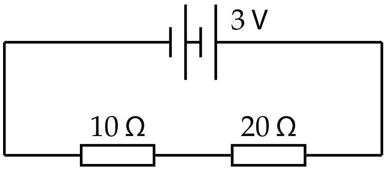
21.8 What happens to the resistance of the lamp as the current through it increases?

21.9 What is the resistance of the resistor?

23 Sharing voltage

On page 33 we saw that when a 3 V battery was connected to two bulbs in series, the voltage was shared between them. The bulbs were identical, so the voltage was shared equally. The voltage across each was 1.5 V.

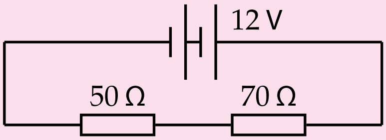
How is voltage shared between components in series if they are different?



We work it out like this:

- the total resistance is $10\ \Omega + 20\ \Omega = 30\ \Omega$
- the $10\ \Omega$ resistor has one third of the total resistance
- so it takes one third of the battery voltage $\frac{1}{3} \times 3\ \text{V} = 1\ \text{V}$
- the $20\ \Omega$ resistor has two thirds of the total resistance
- so it takes two thirds 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 $= \dfrac{50\ \Omega}{120\ \Omega} \times 12\ \text{V} = 5\ \text{V}$

23.1 A $25\ \Omega$ and a $75\ \Omega$ resistor are connected in series to a 6.0 V battery.

(a) What is the voltage across the $25\ \Omega$ resistor?

(b) What is the voltage across the $75\ \Omega$ resistor?

23.2 A $10\ \Omega$, a $20\ \Omega$ and a $30\ \Omega$ resistor are all connected in series to a 24 V battery.

(a) What is the voltage across the $10\,\Omega$ resistor?

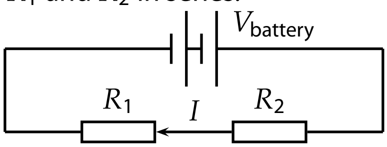
(b) What is the voltage across the $20\,\Omega$ resistor?

(c) What is the voltage across the $30\,\Omega$ resistor?

23.3 I need to connect a $300\,\Omega$ component to a 15 V power supply. There must only be 5.0 V across the component. I connect it to the supply in series with a resistor. What is the resistance of the resistor?

23.4 I replace the $50\,\Omega$ resistor in the circuit above with a thermistor. At room temperature, its resistance is $50\,\Omega$. When I cool it down, its resistance rises to $80\,\Omega$. What will the voltage across the thermistor become?

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 $V_1 = I\,R_1$ (see page 41)
The voltage dropped across R_2 is given by $V_2 = I\,R_2$
The battery voltage $V_{\text{battery}} = V_1 + V_2 = IR_1 + IR_2 = I\,(R_1 + R_2)$.
So

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

23.5 A light meter has a light dependent resistor (LDR) and a resistor connected in series to a battery. The darker the LDR, the greater its resistance. If we want the reading on a voltmeter to go up when the room gets brighter, which component do we connect it across?

23.6 Forty decorative light bulbs are connected in series to a 230 V supply. The current is 120 mA. A bulb breaks. What resistance of resistor can I replace it with for the other lamps to light normally?

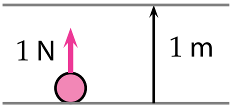
23.7 What would your answers to question 1 be if the resistors were in parallel? Hint: will the voltage be shared? See page 33.

Electricity summary questions are on page 71.

Energy and Balance

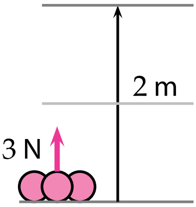
24 Work

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



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

Three small apples weigh 3 N.
Lifting them 1 m would need 3 J of energy.
Lifting them 2 m, requires 6 J of energy.



The energy given to an object in this way is called the work done on it :

Work (J) $=$ Force applied (N) $\times$ 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.

24.1 Calculate the work done on a sack which is dragged 13 m across the floor with a 45 N force.

24.2 Calculate the distance it will take for a 20 N force to do 600 J of work

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 opposite signs, so ΔE will be negative.
Energy will be taken from the object's stores. We say, work is done by 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.

24.3 Complete the table below, filling in the missing values

Force (N)	**Displacement change** (m)	**Energy change** (J)
$+25$	$+4.0$	(a)
-30	$+23$	(b)
90 down	3.5 down	(c)
90 down	0.62 up	(d)
120 down	(e)	$+7200$
300 East	(f)	-1500
(g)	15 up	$+450$

24.4 A crane lifts 150 bricks (each weighing 28 N) to a height of 3.5 m. How much work does it do?

24.5 A 28 N brick falls 5.2 m into a trench. How much work is done on it?

24.6 A weightlifter lifts a 200 N weight to a height of 55 cm fifteen times. How much work does she do?

24.7 Calculate the distance taken for a 7 kN braking force to stop a van, if 280 kJ of motion energy needs to be taken from it.

24.8 A car moves 2 km at a steady speed. The engine's force is 4 kN.

(a) Calculate the work done on the car by the engine.

(b) How strong are the forces resisting motion? Hint: page **??**

(c) Calculate the work done by the car against the resistance.

Forces at right angles to motion do no work. Example: you don't need engines and fuel to steer 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 $(\uparrow)$. You do work on it, giving it energy. This increases its store of gravitational potential energy (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 21)
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 height change to make it clear that we measure displacements upwards when calculating GPE.
We can also write

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

25.1 A 875 kg car is lifted 1.2 m by the jacks at a service station. Calculate the GPE given to it.

25.2 Complete the table below, filling in the missing values

Mass (kg)	**Height gain** (m)	**GPE gain** (J)
12	1.5	(a)
8.2	4.5	(b)
72	0.75	(c)
0.35	(d)	1.0
120	(e)	25
(f)	2.5	1200

25.3 A chocolate bar gives a 72 kg mountaineer 2.2 MJ of energy. If he were able to put this entirely into a store of his GPE, how tall a mountain could he climb?

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 doing work on you, giving you its energy. This reduces its store of gravitational energy.

25.4 Complete the table below, filling in the missing values. Use negative numbers to represent a loss of height or GPE.

Mass (kg)	**Height change (m)**	**GPE change (J)**
3.1	0.24	(a)
0.62	−0.62	(b)
42	(c)	15
120	(d)	−825

25.5 A lift (elevator) is winched up a shaft which also has a 300 kg counterweight which moves the other way. One day there are three people (each 76 kg) in the 230 kg lift car. The floors in the building are 3.0 m apart.

(a) What is the gain in GPE of the people and the 'car' when the lift goes up three floors?

(b) What is the change in GPE of the counterweight when the lift goes up three floors?

(c) How much energy will have to be provided to the machinery of the lift in order to lift the three people up three floors?

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

25.6 A 350 kg pumpkin is grown, and then dropped at a festival.

(a) Calculate the GPE gain when the pumpkin is lifted 11 m.

(b) Write down the kinetic energy gained by the pumpkin as it falls to the ground. Assume that nothing resists its motion.

(c) How much kinetic energy would be gained if the air were warmed by 3500 J as the pumpkin fell?

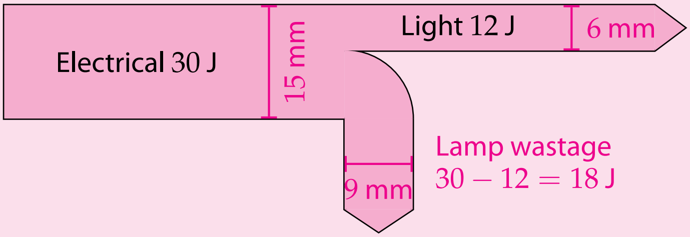
27 Energy flow and efficiency

Energy stored can be given to another object or another store.
Energy can not be made from nothing nor can it be destroyed.
This means that the total energy does not change.
We say energy is conserved.

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

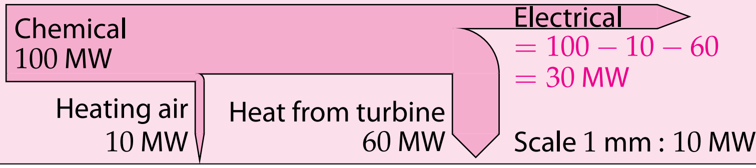


27.1 A traditional light bulb gives out heat and light. It makes 5 J of light for every 60 J of electricity it uses. How much heat does it make?

27.2 A battery in an electric scooter provides 1000 J of electrical energy to the motor as it accelerates up a hill. 300 J warms up the motor's coil, and the scooter gains 600 J gravitational potential energy. The increased store of kinetic (motion) energy makes up the rest. Draw a flow diagram. How much kinetic energy does the scooter gain?

We can draw diagrams using power rather than energy. This is the energy flow each second.

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



27.3 When 800 W of sunlight falls on a solar panel, it generates 400 W of electricity and warms up. Draw a flow diagram. What is the heating power of the sunlight on this solar cell?

27.4 From 100 MW of fuel in a power station, 60 MW warms air in the cooling tower and 40 MW reaches the turbine. 1 MW of this warms up the generator and 4 MW warms up the wires of the National Grid. The rest of the energy is sold to customers as electricity. Draw a power flow diagram and calculate the electrical power delivered.

The percentage of the energy (or power) which does the job we wanted is called the efficiency. The solar panel in question 3 is 50% efficient, as half of the energy from the sunlight becomes useful electricity.

Example 3 – *Calculate the efficiency of the motor in question 2.*
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

$$\frac{\text{Useful energy}}{\text{Total energy}} \times 100\% = \frac{700\text{ J}}{1000\text{ J}} \times 100\% = 0.7 \times 100\% = 70\%.$$

27.5 Calculate the efficiency of the light bulb in Example 1.

27.6 Calculate the efficiency of the light bulb in question 1.

27.7 Calculate the efficiency of the system in question 4.

27.8 An engine is 40% efficient. Calculate

(a) the useful power when the total power is 15 kW,

(b) the wasted power when the total power is 30 kW,

(c) the total power when the useful power is 2.0 kW.

Materials and Forces

30 Density

Density ρ is the mass of each unit of volume (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 × 5 cm × 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

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

30.1 Complete the table below, filling in the missing values.

Mass (g)	**Volume** (cm^3)	**Density** (g/cm^3)
60	50	(a)
713	1000	(b)
16.2	(c)	0.84
3.0	(d)	0.60
(e)	400	5.2
(f)	13.5	12

30.2 500 cm^3 of olive oil has a mass of 450 g. What is its density?

30.3 Steel has a density of 7.8 g/cm^3. What is be the mass of a cubic block with a side length 5.0 cm?

We need to be able to use cubic metres as well as cubic centimetres.
1 m $= 100$ cm and so 1 m^3 $= (100 \text{ cm})^3 = 100^3$ cm^3 $= 1000\,000$ 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 m^3 $= 1000\,000$ cm^3, so 1 m^3 of water will have a mass of $1000\,000$ g.
1000 g $= 1$ kg, so this water will have a mass of 1000 kg.

We see from the example above that

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

30.4 The density of sea water is 1.03 g/cm^3. What is this in kg/m^3?

30.5 A swimming pool measures 10 m by 25 m and has an average depth of 1.2 m. Calculate the mass of the pure water in it.

30.6 A 750 cm^3 bottle contains a mixture of pure water and ethanol. 10% of the volume is ethanol. Ethanol has a density of 0.79 g/cm^3.

(a) What is the volume of the ethanol?

(b) Calculate the mass of the ethanol.

(c) What is the volume of the water?

(d) Calculate the mass of the water.

(e) Calculate the density of the mixture.

30.7 Bricks have a density of 1500 kg/m^3. If you can put 1600 kg of bricks on a pallet for loading onto a truck, what is the volume of bricks?

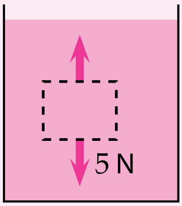
30.8 An airliner has a mass (when empty) of $43\,000$ kg. It is about to carry 150 people with an average mass of 80 kg each. It is not safe to take off if the total mass is more than $75\,000$ kg. Jet fuel has a density of 850 kg/m^3.

(a) Calculate the maximum mass of fuel allowed.

(b) What is the maximum volume of fuel which can be carried?

31 Floating

We use ideas of force (page 21) and density (page 59) to look at buoyancy.



31.1 The diagram shows liquid in a beaker. The liquid has been still for a few minutes. A part of the liquid is marked by a dotted line. This part weighs 5 N. There is also an upwards force on it.

(a) Are the forces balanced?

(b) How strong is the upwards force?

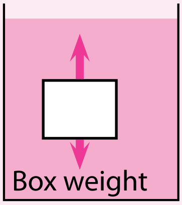
31.2 The liquid marked in the diagram has now been removed with a pump. The dotted region is now in a box to keep this region clear of fluid.

(a) Has the rest of the liquid changed?

(b) How strong is the upwards force now?

(c) If the box weighed 1 N, would it rise or fall?

(d) If the box weighed 6 N, would it rise or fall?



Any object in a liquid or a gas (a fluid) has an upwards force called upthrust. It is equal to the weight of liquid or gas displaced. This is the fluid which had to be moved out of the way to make room for the object. This idea is known as Archimedes' Principle.

31.3 Water has a density of $1.00\ \mathrm{g/cm^3}$. A 100 g apple with a volume of $110\ \mathrm{cm^3}$ is held under the surface in a bucket of water.

(a) What is the volume of water displaced?

(b) What is the mass of water displaced? Hint: page 59

(c) What is the weight of water displaced? Hint: page **??**

(d) What is the weight of the apple?

(e) Will the apple float or sink when it is released?

31.4 Repeat question 3 for a 100 g steel weight with a volume of $12.5\ \mathrm{cm^3}$.

31.5 We now look for a quicker way of working out whether an object will float.

(a) Calculate the density of the apple in question 3.

(b) Calculate the density of the steel mass in question 4.

(c) Compare the densities of water, the apple and the steel mass. Complete the sentence: "An object will float if its density is..."

Why is this rule true? Think about an object with mass m and volume V. The weight of the object $= mg$. We will write the density of the fluid as ρ. Mass of fluid displaced $= \rho V$. Weight of fluid displaced $= \rho V g$.
The object will float if $mg < \rho V g$ which means $\frac{m}{V} < \rho$.
In other words, it will float if it is less dense than the fluid.

31.6 The density of air is approximately 1.2 kg/m^3. The densities of other gases are given below. For each one, state whether it will rise in air.

(a) Neon, $\rho = 0.84$ kg/m^3

(b) Hydrogen, $\rho = 0.084$ kg/m^3

(c) Argon, $\rho = 1.66$ kg/m^3

(d) Krypton, $\rho = 3.49$ kg/m^3

31.7 Use the data in question 6 to state which gases would rise in an atmosphere of helium. Helium has a density of 0.17 kg/m^3.

31.8 An airship has a 4000 m^3 gas balloon filled with helium.

(a) Calculate the weight of the helium. ($\rho = 0.17$ kg/m^3)

(b) Calculate the weight of air displaced. ($\rho = 1.20$ kg/m^3)

(c) What is the maximum mass of the structure and payload if the airship is to be able to float on air.

(d) How much more payload (in kg) could it carry if it were filled with hydrogen ($\rho = 0.084$ kg/m^3) instead?

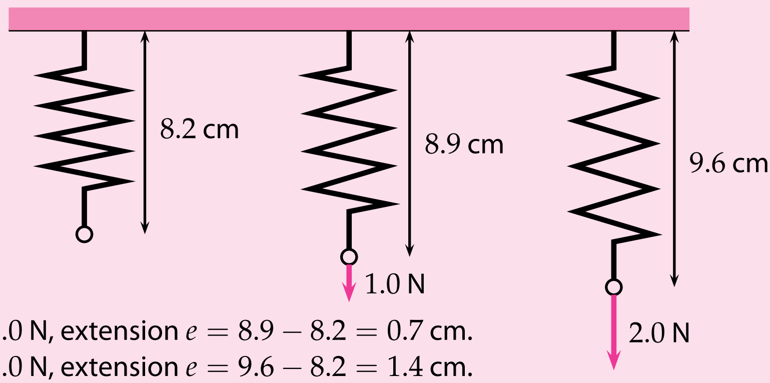
31.9 What is the minimum volume of air needed in a float, if it is to support a 120 kg person in sea water ($\rho = 1030$ kg/m^3)?

31.10 A boat has a horizontal cross sectional area of 3.3 m^3. Two 70 kg people get in. How far will the sea water's surface rise up the boat's side? ($\rho = 1030$ kg/m^3)

33 Springs

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

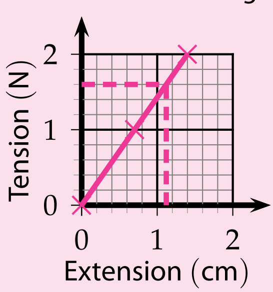
Example 1 – *When a spring is not attached to anything it is* 8.2 *cm long. When it supports a* 1.0 *N weight, its length is* 8.9 *cm. When it supports a* 2.0 *N weight, it is* 9.6 *cm long. Calculate the extension in each case.*



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 unstretched length (not the previous measurement).
As long as you do not pass the elastic limit, the spring will go back to its original length when released. The spring in the example obeys Hooke's Law: 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 compression.

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 $\dfrac{7.5 \text{ N}}{12.3 \text{ cm}} = 0.610$ N/cm.

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

33.1 A spring obeys Hooke's Law and extends by 25 cm under a tension of 10 N. Work out the tension needed for extensions of

(a) 5.0 cm (b) 15.0 cm (c) 10.0 cm (d) 12.5 cm (e) 7.0 cm (f) 19.0 cm

33.2 A spring obeys Hooke's Law and extends by 25 cm under a tension of 10 N. Work out the extension when the tension is 7.0 N. Hint: first work out the extension for 1.0 N.

33.3 A spring obeys Hooke's Law below 9.0 N, and has an unstretched length of 7.4 cm. It extends by 14.3 cm under a tension of 8.5 N. Work out its length for tensions of

(a) 1.0 N (b) 5.0 N (c) 2.7 N (d) 7.5 N (e) 5.4 N (f) 19.0 N

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

33.4 What is the spring constant (in N/cm) for the spring in question 3?

33.5 Calculate the tension for a $k = 2500$ N/m spring obeying Hooke's Law with an extension of 0.32 m.

33.6 Write an equation for the force F needed to stretch a spring with constant k to an extension e.

33.7 A spring extends by 8.0 cm when a 40 kg suitcase is hung from it. Calculate the spring constant.

33.8 The spring in a minibus suspension needs to compress by less than 2.0 cm with a force of 20 kN.

(a) Calculate the minimum spring constant needed.

(b) How much would a 200 kg mass compress this spring?

Extra Questions

35 Force and Motion summary questions

35.1 For motion from $s = -2$ cm to -10 cm, then to $+8$ cm, calculate

(a) the total displacement change, (b) the distance travelled.

35.2 If something starts at $s = +4$ cm and then has displacement changes of $\Delta s = -10$ cm, then $\Delta s = +32$ cm then $\Delta s = -14$ cm, where does it end up?

35.3 A high speed train is attempting a record speed of 150 m/s. There are 1.61 km in one mile.

(a) How many seconds are there in one hour?

(b) How far (in km) would the train go in one hour at 150 m/s?

(c) What is this distance in miles?

35.4 One day, £1.00 buys 31.2 Czech crowns (CZK). A ticket costs 73 CZK. How much is this in British pounds?

35.5 Use the graph below to answer the questions.

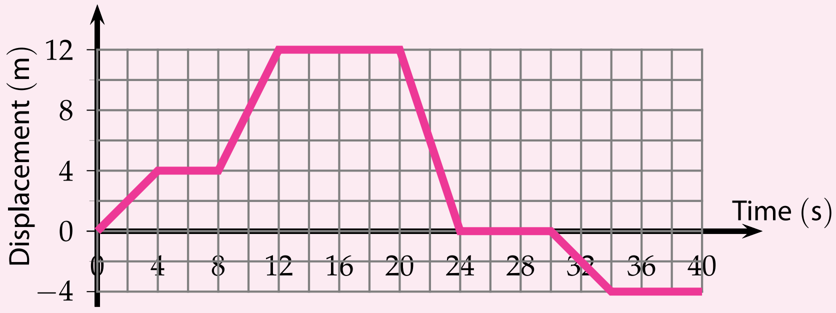
(a) Describe the motion at $t = 14$ s.

(b) Describe the motion between $t = 20$ s and $t = 24$ s.

(c) What is the total distance travelled?

(d) What is the velocity at $t = 10$ s?

(e) What is the average speed for the motion?



35.6 Re-arrange the following equations to make a the subject.

(a) $v = ap$

(b) $q = \frac{a}{r}$

(c) $f = ga$

(d) $\frac{y}{t} = \frac{z}{a}$

35.7 How far will a bus travel in 180 s? Its speed is 12 m/s.

35.8 A train travels 240 km in one hour. Calculate the speed in m/s.

35.9 Use the graph below to answer the questions

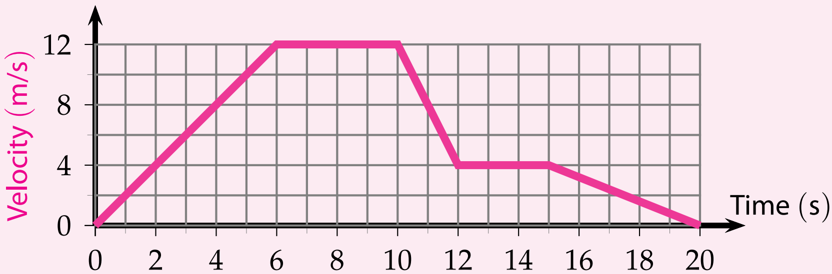
(a) Describe the motion at $t = 9$ s.

(b) What is the velocity when $t = 4$ s?

(c) Calculate the acceleration at $t = 3$ s.

(d) Calculate the displacement change in the first 4 s.

(e) Calculate the displacement change between $t = 10$ s and 12 s?



35.10 On Earth, what is the mass of a 15 N weight?

35.11 A 50 kg cycle has a 300 N force pulling it forward, and two 100 N forces pulling backwards.

(a) What is the resultant force?

(b) What is the acceleration?

35.12 A 8.1 kg cannon ball is falling, and has a 4.5 m/s^2 acceleration. Calculate the air resistance.

35.13 A 72 kg driver in a 840 kg car is travelling at 12 m/s.

(a) Calculate the momentum of the car and driver.

(b) The car has brakes on each of the 4 wheels. How much force do we expect from each brake if the car is to stop in 3.5 s?

36 Electricity summary questions

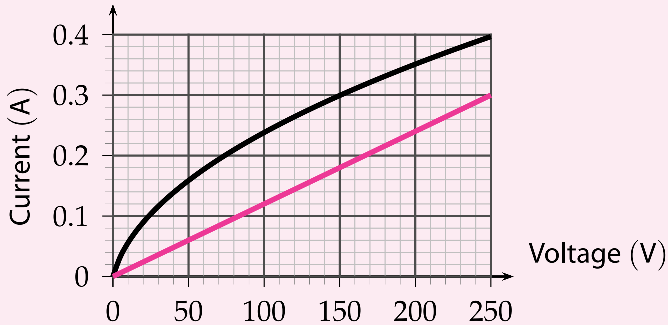
36.1 How much energy is gained by 45 C on passing a 12 V battery?

36.2 How much time does it take 2.3 kC to flow if the current is 50 mA?

36.3 A 450 Ω resistor connected to a 9.0 V battery. What is the current?

36.4 A 2.2 kW hair dryer is connected to a 230 V supply. What is the current?

The graph below shows the current through a lamp (black line) and resistor (coloured line) when connected to different voltages.



36.5 Calculate the power of the

(a) lamp at 100 V
(b) lamp at 0.30 A
(c) resistor at 250 V
(d) resistor at 0.15 A.

36.6 Calculate the resistance of the

(a) lamp at 50 V
(b) lamp at 0.30 A
(c) resistor at 150 V
(d) resistor at 0.30 A.

36.7 Does the resistance of the light bulb rise, fall or stay the same as the current increases?

36.8 For each statement, state whether it describes voltage or current.

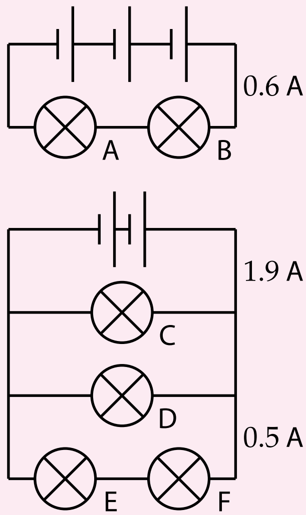
(a) It is the same for components in series.
(b) It measures the energy 'content' of each charge.
(c) The value is the same either side of a component.
(d) If two components are in parallel, they will have the same value.

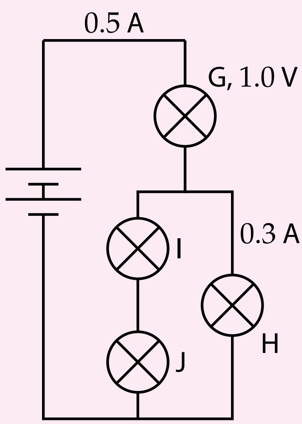
(e) It is shared between components which are connected in series.

(f) It can 'split' at junctions.

(g) It is related to the charge passing a point every second.

36.9 In the circuits below, the cells each have a voltage of 1.5 V, and all bulbs are identical. State the voltage across, and current through, each labelled component. The voltage across bulb G is given.

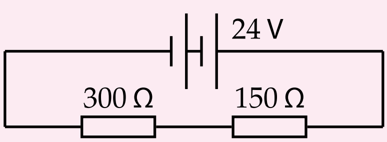




36.10 What is the voltage of battery needed and the battery current if

(a) two 3.5 V, 0.35 A bulbs are wired to it in series?

(b) three 3.5 V, 0.35 A bulbs are wired to it in parallel?



36.11 In the circuit above, calculate the voltage across the 150 Ω resistor

(a) in the circuit as drawn

(b) if the 300 Ω resistor were replaced with a 650 Ω resistor.